

GROWNOTES™

TRITICALE

PLANNING/PADDOCK PREPARATION

PRE-PLANTING

PLANTING

PLANT GROWTH AND PHYSIOLOGY

NUTRITION AND FERTILISER

WEED CONTROL

INSECT CONTROL

NEMATODE MANAGEMENT

DISEASES

PLANT GROWTH REGULATORS AND
CANOPY MANAGEMENT

CROP DESICCATION AND SPRAY OUT

HARVEST

STORAGE

ENVIRONMENTAL ISSUES

MARKETING

CURRENT AND PAST RESEARCH

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Contents

Introduction

A.1	Crop overview	xxi
A.1.1	Triticale for human consumption.....	xxii
A.1.2	Triticale for animal consumption.....	xxiii
A.1.3	Triticale for biofuel.....	xxv
A.2	Growing regions	xxv
A.3	History of triticale growing	xxvii
A.3.1	Triticale in Australia.....	xxvii

1 Planning/Paddock preparation

	<i>Key messages</i>	1
1.1	Paddock selection	1
1.1.1	Topography.....	1
	<i>Frost risk</i>	2
1.1.2	Soil.....	2
	<i>Soil pH</i>	3
	<i>Acidic soils</i>	4
	<i>Managing acidic soils</i>	4
	<i>Alkalinity</i>	6
	<i>Salinity</i>	6
	<i>Sodic or dispersive soils</i>	10
	<i>Soil compaction</i>	14
	<i>The impact of soil moisture and soil compaction on the growth of triticale roots</i>	15
	<i>Solodic soils</i>	17
	<i>Subsoil constraints</i>	17
	<i>Soil testing</i>	18
1.1.3	Paddock selection for forage cereals.....	20
1.1.4	Weed burden and herbicide history.....	21
1.1.5	Fallow moisture and management.....	21
1.2	Paddock rotation and history	21
1.2.1	Triticale as a rotation crop.....	21
	<i>Benefits of cereals as a rotation crop</i>	23
	<i>Disadvantages of cereals as a rotation crop</i>	23
1.2.2	Long-fallow disorder.....	23
1.3	Fallow weed control	24
1.3.1	The green bridge.....	25
1.3.2	Management strategies.....	26
1.3.3	Stubble retention.....	26
	<i>Reducing erosion risk</i>	27
	<i>Increasing soil water content</i>	28
	<i>Increasing soil carbon</i>	28

Other benefits of stubble retention 29

Management practices affecting stubble cover 29

1.4 Fallow chemical plant-back effects..... 29

 1.4.1 Conditions required for breakdown 31

Plant-back periods for fallowing herbicides..... 31

 1.4.2 Herbicide residues in soil: an Australia-wide study 32

Conclusions..... 34

1.5 Seedbed requirements..... 35

 1.5.1 Tillage..... 35

1.6 Soil moisture..... 36

 1.6.1 Dryland..... 36

Technologies to support decision-making..... 36

 1.6.2 Irrigation..... 37

Dry matter accumulation and changes in forage quality during primary growth and regrowth of irrigated winter cereals..... 39

The future of irrigation 40

1.7 Yield and targets 40

Yield and yield structure of triticales compared with wheat in northern New South Wales..... 41

Estimating crop yields..... 42

Yield Prophet..... 42

 1.7.1 Seasonal outlook 43

Queensland..... 43

New South Wales..... 43

CropMate..... 44

CliMate..... 44

Climate Analogues 44

 1.7.2 Fallow moisture 45

HowWet N?..... 45

 1.7.3 Water Use Efficiency 46

Ways to increase yield 46

The French–Schultz approach..... 47

 1.7.4 Nitrogen-use efficiency 48

Optimising nitrogen-use efficiency..... 48

 1.7.5 Double-crop options 48

1.8 Disease status of paddock 49

 1.8.1 Testing soil for disease 49

PreDicta B..... 50

 1.8.2 Effects of cropping history 50

1.9 Nematode status of paddock..... 52

 1.9.1 Testing soil for nematodes 53

PreDicta B..... 53

 1.9.2 Effects of cropping history 53

1.10 Insect status of paddock..... 53

1.10.1	Testing soil for insects	54
	<i>Soil sampling by spade.....</i>	55
	<i>Germinating-seed bait technique.....</i>	55
	<i>Identifying insects.....</i>	55
1.10.2	Effects of cropping history.....	56
2	Pre-planting	
	<i>Key messages.....</i>	1
2.1	Triticale as a dual-purpose crop	2
2.1.1	Benefits of growing dual-purpose or winter-forage crops.....	2
	<i>Minimises risks</i>	2
	<i>Capitalises on early rainfall</i>	3
	<i>Flexibility in enterprise mix.....</i>	3
	<i>Improved cash-flow.....</i>	3
	<i>Dual purpose cereal crops - NSW trials.....</i>	4
2.1.2	Choice of variety is critical.....	6
2.1.3	When to graze.....	7
2.1.4	Breeding dual-purpose triticale.....	9
2.1.5	Triticale grain for livestock.....	9
2.1.6	Triticale as a cover crop	10
	<i>Under-sowing lucerne</i>	11
2.2	Varietal performance and ratings yield	11
	<i>Astute(Ⓛ)</i>	11
	<i>Berkshire(Ⓛ)</i>	12
	<i>Bison(Ⓛ)</i>	12
	<i>Bogong(Ⓛ)</i>	12
	<i>Canobolas(Ⓛ)</i>	12
	<i>Chopper(Ⓛ)</i>	13
	<i>Fusion(Ⓛ)</i>	13
	<i>Goanna</i>	13
	<i>KM10</i>	13
	<i>Tahara</i>	14
	<i>Yowie</i>	14
	<i>Hawkeye(Ⓛ)</i>	14
	<i>Jaywick(Ⓛ)</i>	14
2.2.1	Dual-purpose triticales.....	15
	<i>Cartwheel(Ⓛ)</i>	15
	<i>Endeavour(Ⓛ)</i>	15
	<i>Rufus.....</i>	15
	<i>Tobruk(Ⓛ)</i>	15
	<i>Tuckerbox</i>	16
	<i>Yukuri.....</i>	16
	<i>Crackerjack(Ⓛ)</i>	16
2.2.2	Forage varieties.....	16
	<i>SF Bolt.....</i>	16

2.2.3	Triticale trials.....	16
2.3	Planting-seed quality	19
2.3.1	Seed size.....	19
2.3.2	Seed germination and vigour	21
2.3.3	Seed storage.....	22
2.3.4	Safe rates of fertiliser to sow with seed.....	23
	<i>Factors to consider when selecting fertilisers and rates</i>	<i>23</i>
3	Planting	
	<i>Key messages:.....</i>	<i>1</i>
3.1	Seed treatments	1
3.1.1	Emergence problems.....	1
3.1.2	Fertiliser at seeding.....	3
3.2	Time of sowing	3
3.3	Targeted plant population	4
3.4	Calculating seed requirements.....	6
3.5	Sowing depth	7
3.6	Sowing equipment.....	8
3.6.1	Air seeders	10
3.6.2	Disc seeder.....	11
3.6.3	Disc seeders versus tyne seeders	12
	<i>Making the change from tyne to disc.....</i>	<i>13</i>
3.6.4	Setting up and calibrating the seeder	14
	<i>Seeder levelling</i>	<i>14</i>
	<i>Coulter alignment</i>	<i>14</i>
	<i>Tyne tension</i>	<i>14</i>
	<i>Tilth and speed</i>	<i>14</i>
	<i>Soil types and moisture</i>	<i>14</i>
	<i>Calibration</i>	<i>15</i>
	<i>Point maintenance</i>	<i>15</i>
3.6.5	Sowing into stubble.....	15
	<i>Seeder blockages.....</i>	<i>15</i>
	<i>Seeder set-up and modifications.....</i>	<i>16</i>
	<i>Selecting a seeder when sowing into stubble</i>	<i>16</i>
3.6.6	Sandy soil systems	17
3.6.7	Managing herbicide toxicity	17
4	Plant growth and physiology	
	<i>Key messages.....</i>	<i>1</i>
4.1	Characteristics of triticale	1
4.2	Germination and emergence	3
	<i>Phase 1: Water absorption.....</i>	<i>3</i>
	<i>Phase 2: Activation.....</i>	<i>3</i>
	<i>Phase 3: Visible germination.....</i>	<i>3</i>

4.2.1 Conditions of germination 3

4.2.2 Soil moisture..... 7

4.3 Effects of temperature, photoperiod, climate and environment.....7

4.3.1 Temperature 7

4.3.2 Photoperiod..... 8

4.3.3 Salinity..... 8

The effect of salt stress on photosynthesis and growth of triticale..... 9

4.3.4 Drought..... 9

Water stress 9

4.4 Plant growth stages10

4.4.1 Zadoks scale of cereal growth stages 10

Reading the Zadoks growth key..... 12

4.4.2 Germination and early seedling growth..... 12

4.4.3 Tillering and vegetative growth13

4.4.4 Stem elongation and heading14

4.4.5 Flowering and grainfilling..... 15

4.4.6 Growth of triticale compared to other cereals 16

Variation in temperate cereals in rain-fed environments 18

5 Nutrition and fertiliser

Key messages1

5.1.1 Declining soil fertility 2

Balancing sources of nutrition3

5.1.2 Fertilisers..... 3

5.1.3 Fungi and soil health..... 5

Management to optimise mycorrhizae6

5.2 Crop removal rates 7

5.3 Soil testing 7

5.3.1 Why test soil? 8

5.3.2 Basic requirements 8

5.3.3 Types of test..... 9

5.4 Plant-tissue testing for nutrition levels..... 9

5.4.1 What plant-tissue analysis shows 9

5.5 Nitrogen10

Responses of triticale, wheat, rye and barley to nitrogen fertiliser 11

Nitrogen timing for boot-stage triticale forage yield and phosphorus uptake..... 12

Lodging risk..... 12

5.5.1 Symptoms of Nitrogen deficiency 12

What to look for in the paddock..... 13

What to look for in the plant 13

What else it could be 14

5.5.2 Managing nitrogen14

N Budgeting 15

	<i>Timing of application</i>	17
	<i>Optimising nitrogen-use efficiency</i>	18
5.6	Phosphorus	20
	<i>Cereal types, soil types and phosphorus use</i>	21
5.6.1	Symptoms of Phosphorus deficiency	22
	<i>What to look for in the paddock</i>	22
	<i>What to look for in the plant</i>	22
	<i>What else it could be</i>	24
	<i>Soil testing</i>	24
5.6.2	Managing phosphorus.....	24
5.7	Sulfur	25
	<i>Triticale and sulfur</i>	26
5.7.1	Symptoms of Sulfur deficiency	26
	<i>What to look for in the paddock</i>	26
	<i>What to look for in the plant</i>	26
	<i>What else it could be</i>	28
5.7.2	Managing sulfur.....	28
	<i>Supplies of sulfur (elemental or sulphate)</i>	28
	<i>Local tools help S fertiliser decision making</i>	29
5.8	Potassium	29
	<i>Potassium deficiency in northern soils</i>	30
5.8.1	Symptoms of Potassium deficiency	30
	<i>What to look for in the paddock</i>	30
	<i>What to look for in the plant</i>	30
	<i>What else it could be</i>	32
5.8.2	Managing potassium.....	33
	<i>Fertiliser types</i>	33
	<i>Fertiliser placement and timing</i>	33
5.9	Micronutrients	34
5.9.1	Manganese	34
	<i>Symptoms of Manganese deficiency</i>	35
	<i>Managing manganese deficiency</i>	36
5.9.2	Copper	37
	<i>Tolerance of triticale, wheat and rye to copper deficiency in low and high soil pH</i> 37	
	<i>Symptoms of Copper deficiency</i>	38
	<i>Managing copper deficiency</i>	41
5.9.3	Zinc	41
	<i>Symptoms of Zinc deficiency</i>	42
	<i>Managing zinc deficiency</i>	44
5.9.4	Iron.....	45
	<i>Symptoms of Iron deficiency</i>	45
	<i>Managing iron deficiency</i>	48
5.10	Paddock nutrition	48
5.10.1	Aluminium toxicity.....	49

CONTENTS TRITICALE

TABLE OF CONTENTS

FEEDBACK

6 Weed control 1

Key messages 1

6.1 Weed competitiveness of triticale 1

 6.1.1 Best management practices for weed control in triticale 3

6.2 Integrated weed management 3

 6.2.1 IWM for triticale 3

The effect of cultivation and row spacing on the competitiveness of triticale 4

 6.2.2 IWM principles and tactics 5

Review past actions 5

Assess the current weed status 6

Identify weed management opportunities 6

Fine-tune the list of options 6

Combine and test ideas 6

 6.2.3 IWM in the Northern Region 6

Row direction 7

Competitive choices 8

6.3 Weeds in northern cropping systems 8

 6.3.1 Awnless barnyard grass 8

Resistance levels 9

Residual herbicides in fallow and in the crop 9

Double-knock control 9

 6.3.2 Flaxleaf fleabane 10

Resistance levels 11

Residual herbicides in fallow and in the crop 11

Knockdown herbicides in fallow and in the crop 11

Double-knock control 11

 6.3.3 Feathertop Rhodes grass 12

Residual herbicides in fallow and in the crop 12

Double-knock control 12

 6.3.4 Windmill grass 13

Resistance levels 14

Residual herbicides in fallow and in the crop 14

Double-knock control 14

 6.3.5 Non-herbicide weed control in the Northern Region 14

Strategic tillage 15

Strategic burning 16

Crop competition 16

Cover crops 17

6.4 Key weeds of Australia’s cropping systems 18

RIM (Ryegrass Integrated Management) 18

6.5 Herbicides 19

 6.5.1 Herbicides explained 19

Residual and non-residual herbicides 19

Pre-emergent and post-emergent herbicides 20

<i>Herbicide groups</i>	20
6.6 Pre-emergent herbicides	20
6.6.1 Benefits and concerns	21
6.6.2 Understanding pre-emergent herbicides	21
<i>Behaviour of pre-emergent herbicides in the soil</i>	21
6.6.3 Top tips for using pre-emergent herbicides.....	23
6.6.4 Incorporation by sowing.....	23
6.7 Post-sowing pre-emergent herbicides	25
6.8 In-crop herbicides: knockdowns and residuals	25
6.8.1 Applying in-crop herbicides	25
<i>How to get the most out of post-emergent herbicides</i>	27
6.9 Conditions for spraying	27
6.9.1 Minimising spray drift	28
6.9.2 Types of drift.....	29
6.9.3 Factors influencing the risk of spray drift	30
<i>Volatility</i>	30
6.9.4 Minimising drift.....	31
6.9.5 Spray release height	32
6.9.6 Size of area treated	32
6.9.7 Capture surface	32
6.9.8 Weather conditions to avoid	33
6.10 Testing for herbicide tolerance	33
6.11 Potential herbicide damage of triticale	34
6.11.1 Avoiding crop damage from residual herbicides	34
<i>What are the issues?</i>	34
<i>Which herbicides are residual?</i>	34
<i>How can I avoid damage from residual herbicides?</i>	35
6.11.2 Plant-back intervals	36
<i>Conditions required for breakdown</i>	38
6.12 Herbicide resistance	38
6.12.1 How does resistance start?	42
6.12.2 General principles to avoid resistance	42
Glyphosate-resistant weeds in Australia	44
6.12.3 Ten-point plan to weed out herbicide resistance	45
1. Act now to stop weed seedset	45
2. Capture weed seeds at harvest.....	45
3. Rotate crops and herbicide modes of action.....	46
4. Test for resistance to establish a clear picture of paddock-by-paddock status ..	46
5. Never cut the rate	46
6. Don't automatically reach for glyphosate.....	47
7. Carefully manage spray events.....	47
8. Plant clean seed into clean paddocks with clean borders.....	47
9. Use the double-knock technique.....	48

10. Employ crop competitiveness to combat weeds	48
6.12.4 If you think you have resistant weeds	48
<i>Testing services</i>	49
6.12.5 Monitoring weeds	49
<i>Tips for monitoring</i>	50
7 Insect control	1
<i>Key messages</i>	1
7.1 Potential insect pests	1
7.2 Integrated pest management	4
7.2.1 Key IPM strategies for winter cereals	4
<i>Insecticide choices</i>	4
<i>Insecticide resistance</i>	4
<i>Bees</i>	4
<i>Insecticides and beneficial insects</i>	4
7.2.2 Emerging insect threats in northern crops	5
7.2.3 Insect sampling methods	6
<i>Factors that contribute to quality monitoring</i>	6
<i>Keeping good records</i>	6
<i>Sampling methods</i>	7
<i>Identifying insects</i>	9
7.3 Russian wheat aphid	10
7.3.1 Damage caused by RWA	11
7.3.2 Where to look and what to look for	12
<i>Measures to increase the likelihood of detecting RWA</i>	13
7.3.3 Thresholds for control	15
7.3.4 Management of RWA	15
<i>Control options</i>	15
<i>General instructions</i>	16
7.4 Other aphids	16
7.4.1 Oat or wheat aphid	16
7.4.2 Corn aphid	17
7.4.3 Rose-grain aphid	18
7.4.4 Rice root aphid	18
7.4.5 Damage caused by aphids	19
7.4.6 Conditions favouring aphid development	20
7.4.7 Thresholds for control	21
7.4.8 Managing aphids	21
<i>Chemical control</i>	21
<i>Aphids in cereals—Northern region</i>	22
<i>Biological control</i>	23
<i>Cultural control</i>	23
7.4.9 Monitoring	24
7.5 Cutworms	24

CONTENTS TRITICALE

TABLE OF CONTENTS

FEEDBACK

- 7.5.1 Damage caused by cutworms 26
- 7.5.2 Conditions favouring development..... 27
- 7.5.3 Thresholds for control..... 27
- 7.5.4 Management of cutworms 27
 - Biological control*..... 27
 - Cultural control*..... 28
 - Chemical control*..... 28
- 7.6 Armyworm 28**
 - 7.6.1 Damage caused by armyworms 30
 - 7.6.2 Thresholds for control..... 31
 - 7.6.3 Managing armyworms 32
 - Sampling and detection*..... 32
 - Biological control*..... 33
 - Cultural control*..... 33
 - Chemical control*..... 34
- 7.7 Mites 34**
 - 7.7.1 Brown wheat mite 34
 - 7.7.2 Blue oat mite 35
 - Damage caused by BOM*..... 36
 - Managing BOM*..... 37
- 7.8 Helicoverpa species 39**
 - 7.8.1 Varietal resistance or tolerance 42
 - 7.8.2 Damage caused by *Helicoverpa* species..... 42
 - 7.8.3 Thresholds for control..... 42
 - 7.8.4 Management of *Helicoverpa* species..... 43
 - Chemical control*..... 43
 - Cultural control*..... 44
 - Biological control*..... 45
 - Take a whole-farm or regional approach* 46
 - 7.8.5 *Helicoverpa* and insecticide resistance 47
 - Insecticide resistance management strategy* 47
 - Helicoverpa control in an area*..... 48
 - Control considerations* 48
 - 7.8.6 Monitoring..... 49
- 7.9 Lucerne flea..... 49**
 - 7.9.1 Damage caused by lucerne fleas 51
 - 7.9.2 Managing lucerne fleas 51
 - Biological control*..... 52
 - Cultural control*..... 52
 - Chemical control*..... 53
- 7.10 Slugs and snails..... 53**
 - 7.10.1 Economic thresholds for control 56
 - 7.10.2 Managing slugs and snails 56

<i>Biological control</i>	56
<i>Cultural control</i>	57
<i>Chemical control</i>	57
<i>Monitoring snails</i>	57
<i>Monitoring slugs</i>	58
7.11 Wireworms and false wireworms	59
7.11.1 False wireworms	59
<i>Biology</i>	61
<i>Damage caused by false wireworms</i>	62
7.11.2 True wireworm	62
<i>Biology</i>	63
<i>Damage</i>	64
7.11.3 Sampling and detection of wireworms.....	64
<i>Sampling</i>	64
<i>Detection</i>	64
7.11.4 Control	64
8 Nematode management	
<i>Key messages</i>	1
8.1 Root-lesion nematodes	2
8.1.1 Symptoms	5
<i>What to look for in the paddock</i>	5
<i>What to look for in the plant</i>	6
8.1.2 Varietal resistance or tolerance	7
8.1.3 What does resistance and tolerance mean?	7
8.1.4 Damage caused by RLN.....	11
8.1.5 Conditions favouring development.....	12
<i>How long does it take to reduce Pt in soils?</i>	12
8.1.6 Thresholds for control.....	13
8.1.7 Management of RLN	14
Fallow	17
<i>Weed control</i>	17
Nutrition	17
Nematicides (<i>control in a drum</i>).....	17
<i>Natural enemies</i>	17
<i>Biological suppression of RLN in northern soils</i>	18
8.1.8 Soil testing	19
<i>Leslie Research Centre tests</i>	19
<i>PreDicta B tests</i>	20
8.2 Cereal cyst nematode	20
8.2.1 Symptoms and detection	22
8.2.2 Varietal resistance or tolerance	24
8.2.3 Damage caused by CCN.....	25
8.2.4 Management	25

CONTENTS TRITICALE

TABLE OF CONTENTS

FEEDBACK

Disease breaks for CCN.....26

8.3 Nematodes and crown rot.....26

 8.3.1 Management27

Soil testing27

Varietal choice28

9 Diseases

Key messages.....1

 9.1.1 GrowNotes Alert™.....2

9.2 General disease-management strategies..... 3

 9.2.1 Integrated disease management tactics in triticale 3

 9.2.2 Tools for diagnosing cereal diseases 4

Foliar diseases—the Ute guide4

Crop Disease Au app4

9.3 Rusts 4

 9.3.1 Varietal resistance or tolerance5

 9.3.2 Symptoms7

 9.3.3 Stripe rust.....7

Managing stripe rust8

 9.3.4 Stem rust9

 9.3.5 Leaf rust10

 9.3.6 Managing cereal rusts10

Breeding cereals for rust resistance in Australia12

9.4 Yellow leaf spot (tan spot).....12

 9.4.1 Varietal resistance or tolerance13

 9.4.2 Damage caused by disease.....14

 9.4.3 Symptoms14

 9.4.4 Conditions favouring development.....15

 9.4.5 Management of disease.....16

In-crop fungicides and timing.....16

9.5 Take-all17

 9.5.1 Symptoms17

What to look for in the paddock.....18

What to look for in the plant18

 9.5.2 Conditions favouring development.....19

Hosts.....20

 9.5.3 Managing take-all.....20

Soil testing21

Take-all decline.....21

9.6 Crown rot21

Update on the latest research.....22

 9.6.1 Damage caused by crown rot.....23

 9.6.2 Symptoms of crown rot24

CONTENTS TRITICALE

TABLE OF CONTENTS

FEEDBACK

9.6.3 Conditions favouring development..... 26
Interaction with root-lesion nematodes..... 26

9.6.4 Management 26
Crop rotation..... 27
Variety selection..... 28
Crop management..... 28
Cultivation..... 29
Stubble burning..... 29
Reducing water loss..... 29
Grass-weed management..... 29
Sowing time..... 29
The incidence of crown rot on cultivars sown on two dates in northern NSW..... 30
Row placement..... 30
Soil type..... 30
Interaction with root-lesion nematodes..... 31
Soil testing..... 31

9.7 Common root rot..... 31

9.7.1 Damage caused by disease..... 31

9.7.2 Symptoms 32
What to look for in the paddock..... 32
What to look for in the plant..... 32

9.7.3 Conditions favouring development..... 32

9.7.4 Management 33

9.8 Smut and bunt..... 33

9.8.1 Bunt or stinking smut 33
Managing bunt..... 34

9.8.2 Loose smut 34
Managing smut..... 35

9.9 Rhizoctonia root rot 35

Key factors influencing Rhizoctonia occurrence and severity..... 36

9.9.1 Symptoms 37
What to look for in the paddock..... 38
What to look for in the plant..... 38

9.9.2 Conditions favouring development..... 40
Soil nutrition..... 40
Soil disturbance..... 40
Soil moisture..... 40
Weeds..... 40
Herbicides..... 40

9.9.3 Managing Rhizoctonia root rot 40
Summer weed control..... 41
Crop choice rotations..... 41
Fungicide treatments..... 42
Nitrogen..... 42
Disease suppression..... 42

	<i>Cultivation practices</i>	42
9.10	Scald	43
9.10.1	Symptoms	44
9.10.2	Conditions favouring development.....	45
9.10.3	Management of Scald.....	45
	<i>Cultural Practices</i>	46
	<i>Resistant Varieties</i>	46
	<i>Fungicides</i>	46
9.11	Ergot	46
9.11.1	Damage caused by disease.....	46
	<i>Gangrenous ergotism of humans and cattle</i>	46
	<i>Convulsive ergotism</i>	47
9.11.2	Symptoms	47
	<i>What to look for in the plant</i>	47
	<i>What to look for in stock</i>	47
9.11.3	Conditions favouring development.....	48
9.11.4	Management of disease.....	49
9.12	<i>Septoria tritici</i> blotch	50
9.12.1	Symptoms	51
9.12.2	Varietal resistance or tolerance	52
9.12.3	Conditions favouring development.....	52
9.12.4	Management	52
	<i>Variety selection</i>	52
	<i>Cultural practices</i>	53
	<i>Crop rotations</i>	53
	<i>Fungicides</i>	53
	<i>Septoria fungicide update–2017</i>	54
9.13	Cereal fungicides	55
9.13.1	Fungicide stewardship	56
9.14	Barley yellow dwarf virus	56
9.14.1	Symptoms	57
9.14.2	Conditions favouring development.....	59
9.14.3	Management	59
	<i>Seed dressings</i>	60
	<i>Insecticides</i>	60
	<i>Delayed sowing</i>	60
	<i>Control during the green bridge</i>	61
9.15	Disease following extreme weather	61
9.15.1	Cereal disease after drought.....	61
9.15.2	Cereal disease after flood	61
10	Plant growth regulators and canopy management	
	<i>Key messages</i>	1

10.1 Plant Growth Regulators 1

10.2 Canopy management 1

 10.2.1 What is canopy management?1

Canopy management in the Liverpool Plains4

 10.2.2 Canopy management in a nutshell..... 7

 10.2.3 Setting up the canopy..... 7

 10.2.4 Status of soil moisture 7

 10.2.5 Soil nitrogen 8

 10.2.6 Seeding rate and date 9

 10.2.7 Row spacing 9

Yield.....10

Plant spacing10

Dry matter.....10

Grain quality..... 11

Nitrogen management..... 11

 10.2.8 In-crop nitrogen 11

Limitations of tactical nitrogen application..... 12

11 Crop desiccation/spray out

12 Harvest

Key messages.....1

12.1 Harvesting issues 1

 12.1.1 Windrowing.....2

Timing.....2

Cutting.....2

Harvesting the windrow3

12.2 Harvest timing..... 3

 12.2.1 Lodging..... 4

12.3 Harvesting triticale for silage 5

12.4 Considerations for harvest equipment..... 6

 12.4.1 Setting header height 7

 12.4.2 Forage harvesters..... 8

12.5 Fire prevention..... 9

 12.5.1 Harvester fire-reduction checklist 9

 12.5.2 Harvesting in low-risk conditions..... 10

12.6 Receival standards11

12.7 Harvest weed-seed management.....13

 12.7.1 Which northern weeds suit HWSC?13

 12.7.2 Harvest weed-seed controls.....13

Early harvest..... 14

Narrow windrow burning 14

Chaff carts 14

13 Storage 1

Key messages 1

13.1 GRDC’s Stored Grain Information Hub 2

13.2 How to store grain on-farm 2

 13.2.1 Silos 4

Pressure testing 5

Why test the pressure? 6

The importance of a gas-tight silo 6

 13.2.2 Grain bags 7

 13.2.3 Hygiene 8

 13.2.4 Monitoring stored grain 8

 13.2.5 Grain storage: get the economics right 9

Comparing on-farm storages 9

13.3 Stored grain pests 12

 13.3.1 Insecticide treatment 12

Prevention is better than cure 12

 13.3.2 Common species 12

Why identify insect pests of stored grain pests? 13

 13.3.3 Monitoring grain for pests 13

 13.3.4 Hygiene 14

Where to clean 14

When to clean 15

How to clean 15

 13.3.5 Aeration cooling for pest control 17

 13.3.6 Structural treatments 17

 13.3.7 Application 17

Silo application 18

 13.3.8 Fumigation 18

Phosphine application 20

Non-chemical treatment options 21

 13.3.9 Maximum residue limits (MRLs) 21

13.4 Aeration during storage 22

 13.4.1 Dealing with moist grain 22

 13.4.2 Aeration cooling 23

Blending 23

 13.4.3 Aeration drying 24

High airflow for drying 24

Ducting for drying 24

Venting for drying 25

Weather conditions for drying 25

Phase one of drying 25

Phase two of drying 26

Supplementary heating 26

Cooling after drying..... 26

13.4.4 Aeration controllers 26

13.5 Grain protectants for storage..... 27

K-Obiol® EC Combi 27

Conserve™ On-farm 28

14 Environmental issues

Key messages..... 1

14.1 Frost issues for triticale 1

14.1.1 Frost risk in Queensland: a grower’s experience..... 3

14.1.2 Triticale and frost..... 4

Frost tolerance in triticale and other winter cereals at flowering 4

14.1.3 Conditions that lead to frost..... 6

14.1.4 Diagnosing stem and head frost damage in cereals..... 7

What to look for in the paddock..... 9

What to look for in the plant 10

14.1.5 Managing frost risk 11

Farm management planning tactics..... 12

Frost zone management tactics..... 12

Stubble reduces frost severity 14

14.1.6 New insight into frost events and management..... 16

14.1.7 Guidelines to reduce frost risk and assess frost damage 19

Matching variety to planting opportunity 19

Measuring crop temperature 19

14.1.8 What to do with a frosted crop 20

Option 1: Take through to harvest..... 21

Option 2: Cut and bale..... 21

Option 3: Grazing, manuring and crop-topping..... 22

Useful tools..... 23

14.1.9 National Frost Initiative 23

14.2 Drought and heat stress 23

14.2.1 Managing heat and drought stress 26

14.3 Waterlogging and flooding issues for triticale 26

14.3.1 Where waterlogging occurs 28

Identifying problem areas 28

14.3.2 Symptoms and causes..... 29

What to look for in the paddock..... 29

What to look for in the plant 30

How waterlogging can be monitored 31

Other impacts of waterlogging and flood events 31

14.3.3 Managing waterlogging 32

Draining 32

Choice of crop species 33

Seeding rates 33

<i>Nitrogen fertiliser</i>	33
<i>Weeds</i>	33
15 Marketing	
15.1 Price determinants for feed grains in northern markets.	1
15.2 Executing tonnes into cash	2
15.2.1 How to sell for cash	2
<i>Price</i>	2
<i>Quantity and Quality</i>	2
<i>Delivery terms</i>	2
<i>Payment terms</i>	2
15.2.2 Counterparty risk	4
15.2.3 Read market signals	4
15.2.4 Know the specifications of your grain	4
15.3 Ensuring access to markets for Northern Australian feed grains	5
15.3.1 Storage and Logistics	5
15.3.2 Separate the delivery decision from the pricing decision	6
15.3.3 Cost of carrying grain	6
<i>Principles revised</i>	7
16 Current and past research	
17 References	

Introduction

A.1 Crop overview

Triticale is an established (but minor) cereal crop that combines the productivity of wheat with the hardiness of rye. Triticale (genus *X Triticosecale*) was developed by humans crossing wheat (genus *Triticum*) and rye (genus *Secale*). Its kernels are longer than wheat seeds and are plumper than rye. Its colour can range from the tan of wheat to the grey-brown of rye (Photo 1). Triticale has several advantages in Australian conditions: it is a relatively low-input cereal crop with good disease resistance, particularly to some rusts; it is as high quality a feed grain as wheat; and it is a hardy plant.

It has been developed to incorporate the high yield potential and quality of wheat and the adaptability of rye, and is adapted to a wide range of soil types and environments. Triticale has an aggressive root system that binds light soils better than wheat, barley or oats. Under ideal conditions, researchers have found that triticale can out-yield wheat and barley, and sometimes oats. It can out-yield wheat in several situations: on acid soils, in cool high-rainfall areas, and on low-nutrient soils such as those with low levels of manganese and copper. Triticale is well established as an ingredient in livestock rations.

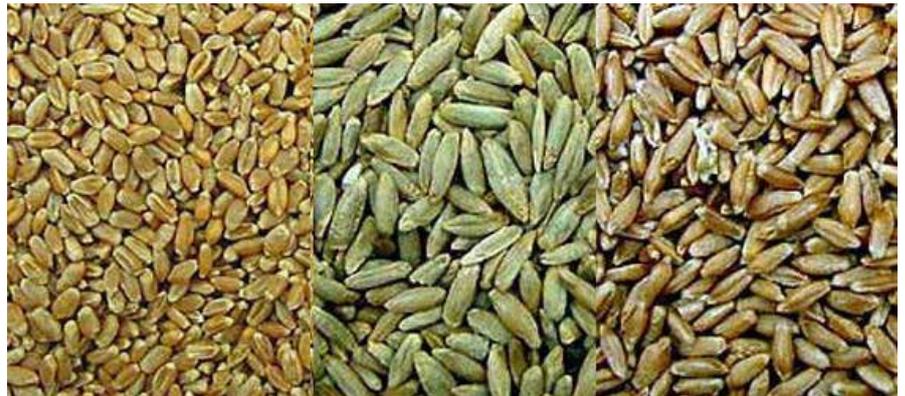


Photo 1: Grains of wheat (left), rye (middle) and triticale (right). Note that triticale grain is significantly larger than wheat grain.

Source: USDA

It is a tall crop bred for strong straw strength which can be useful in rocky paddocks or circumstances where crops have been known to lodge. Its dual-purpose use as grain or forage makes it a useful crop for mixed-enterprise farms.

Triticale in Australia has a spring growth habit, which means it behaves similarly to most cereal crops, maturing in late spring to early summer. Breeding and selection programs have ensured that varieties possess a range of disease and pest characteristics which can compliment disease management for other cereals. It can also carry diseases which may affect other cereal species, e.g. crown rot.

Triticale can be less susceptible to the common fungal diseases of cereals. Some varieties have good resistance to stem, leaf and stripe rusts, mildew and *Septoria tritici* blotch, as well as both resistance and tolerance to cereal cyst nematode.

For more information on triticale variety disease ratings, see [Section 9: Diseases, Table 1](#).

INTRODUCTION TRITICALE

TABLE OF CONTENTS

FEEDBACK

MORE INFORMATION

[A review of triticale uses and the effect of growth environment on grain quality](#)

[Triticale agronomy](#)

Triticale has poor tillering capacity, but good tolerance to shattering. This makes triticale a useful cereal as a cover crop to establish under-sown lucerne or medic, although seeding rates may need to be reduced.¹

When added to a cropping sequence, triticale may increase yields of other crops in the rotation and help to reduce costs. Triticale production may also provide environmental benefits, such as erosion control.²

Triticale yields more than its ancestors in two types of marginal conditions: in soils where acidity, phosphorus deficiency and foliar diseases are dominant, and in arid and semi-arid zones where drought affects crop production.³

Observed traits suggesting higher yields in triticale than wheat include greater early vigour, a longer spike-formation phase with same duration to flowering, reduced tillering, increased remobilisation of carbohydrates to the grain, early vigorous root growth, and more effective transpiration.⁴

Triticale is a mainstream crop in Australia, mostly as spring types grown for grain production, and also as longer-season, dual-purpose types grown for fodder use as hay, silage or grazing followed by grain production.

The grain is primarily used as stock feed, with a low level of triticale use in food products. Most of the grain is used domestically although small amounts are exported.

Triticale usually commands a lower price per tonne than wheat at the farm gate, but holds a similar price to other feed grains. An exception to this can be where there is strong local demand for feed grain, in which case a better cash return with low transport costs could be expected.⁵

The market for triticale is small compared to other cereals as it must compete with barley and sorghum as a preferred feed grain. To combat this, breeders have released better-adapted varieties that have good yield and grain-quality characteristics, with many of the factors identified as the causes of inferior performance having been eliminated.⁶

A.1.1 Triticale for human consumption

Small amounts of triticale are marketed as niche products for human food consumption (Photo 2). Uses include as a flour supplement to wheaten flour for bread, biscuits and cakes, as rolled whole grains for breakfast cereals, as triticale noodles, and in brewing and distilling. Triticale has a distinctive nutty, aromatic and naturally sweet flavour.⁷ Triticale as a main cereal for bread making is constrained by variations in bread-making quality, low and inferior gluten content, and lower flour yield. Further, wheat and rye have already been established as the traditional bread cereals and hence consumers' preference for triticale would take some time to change.

- 1 Agriculture Victoria (2012) Growing triticale. Note AG0497. Updated. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>
- 2 LR Gibson, C Nance, DL Karlen (2005) Nitrogen management of winter triticale. Iowa State University, <http://farms.ag.iastate.edu/sites/default/files/NitrogenManagement.pdf>
- 3 M Mergoum, H Gómez-Macpherson (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>
- 4 S Bassu, S Asseng, R Richards (2011) Yield benefits of triticale traits for wheat under current and future climates. Field Crops Research, 124 (1), 14–24.
- 5 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety guide 2016. NSW DPI, <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>
- 6 Birchip Cropping Group (2004) Triticale agronomy 2005. Online Farm Trials, <http://www.farmtrials.com.au/trial/13801>
- 7 Agriculture Victoria (2012) Growing triticale. Note AG0497. Updated. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>



Photo 2: Wholegrain triticale flour (left) and kibbled triticale (right) milled for human consumption.

Source: Blue Lake Milling

As consumers in general become more health conscious, they are becoming aware of the health benefits of including a broader range of cereal grains in their diets. The greater consumption of grains, together with the current increasing trend in trying novel products, is leading to an increase in consumer interest in baked products, such as breads made using cereal grains other than wheat.

The main culinary uses of triticale are:

- As flour—can be used to make biscuits, rye-type crispbreads, cakes and muffins. The flavour and texture of breads made from triticale are similar to that of light rye bread.
- As flakes—when whole-grain triticale is pressed and rolled, it may be used like rolled oats to make a breakfast cereal or substituted for rolled oats in recipes (e.g. in biscuits and muffins).

The nutritional credentials of whole-grain triticale are:

- It is similar to wheat, with 13% protein, but lower in lysine and niacin.
- It is lower in the protein complex which forms gluten.
- It is a good source of phosphorus and magnesium, and a very good source of manganese.
- It contains B-group vitamins, most notably thiamin and folate.⁸

One study suggested that triticale grain and flour could replace other more commonly used grain to help reduce obesity and diabetes.⁹

Taking these and the agronomic advantages of triticale into account, triticale may have the necessary attributes to become an important food cereal for humans in future.¹⁰

A.1.2 Triticale for animal consumption

In livestock diets, triticale has a similar role to other cereals. Triticale is higher in energy than barley and has many desirable nutritional characteristics that suit all classes of livestock. It is primarily an energy source, having moderate protein content with high starch and other carbohydrates.

⁸ Grains and Legumes Nutrition Council (2016) Triticale. Grains and Legumes Nutrition Council, <http://www.glnc.org.au/grains/types-of-grains/triticale/>

⁹ K. Cooper (1985). Triticale food use—Australia. In *Genetics and breeding of triticale: proceedings, 3rd EUCARPIA Meeting, Cereal Section on Triticale, INRA, Station d'Amelioration des Plantes, Clermont-Ferrand, France, 2–5 juillet 1984* [Editors, M. Bernard, S. Bernard]. Paris: Institut National de la Recherche Agronomique, c1985..

¹⁰ CM McGovern, F Snyders, N Muller, W Botes, G Fox, M Manley (2011) A review of triticale uses and the effect of growth environment on grain quality. *Journal of the Science of Food and Agriculture*, 91 (7), 1155–1165.

MORE INFORMATION

[Food uses of triticale](#)

INTRODUCTION TRITICALE

TABLE OF CONTENTS

FEEDBACK

The major uses for triticale grain are as a feed supplement in the dairy industry (Photo 3),¹¹ as a component ingredient in feed used in beef feedlots, and as a constituent of compound rations for intensive livestock (pigs and poultry) rations, where it is a direct substitute for barley or wheat in animal feed rations.

In pig and poultry diets, triticale is equal to or better than wheat or maize in terms of energy value, and superior in terms of protein content and quality. In dairy rations, triticale has an advantage over barley due to its high metabolisable energy, palatability and ease of milling.¹²



Photo 3: *Triticale is often chosen by farmers for stock feed due its high nutritional qualities.*

Source: The Australian Dairyfarmer

A key physical feature of triticale is that it is a soft grain, with a hardness index almost half that observed for wheat and barley. This is an advantage as less mechanical energy is required to mill triticale compared to wheat and barley prior to including it in livestock diets. On the farm, triticale can be fed to livestock in the same way wheat, oats or barley would be fed to stock (Table 1).¹³

Many triticale growing regions correspond with intensive livestock production in Australia making it readily accessible by most feed mills. The reduced transport costs and the slightly higher price for triticale compared to other feed grains makes triticale an attractive proposition, and there is a high demand for it in livestock-rearing regions, especially in the dairy and pig industries.¹⁴

¹¹ E Downey (2015) Dairies find value in triticale. 18 March. The Australian Dairyfarmer, <http://adf.farmonline.com.au/news/magazine/feed/cropping/dairies-find-value-in-triticale/2726590.aspx>

¹² Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, <http://www.farmtrials.com.au/trial/13801>

¹³ Agriculture Victoria (2012) Growing triticale. Note AG0497. Updated. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>

¹⁴ Plant Breeding Institute (2012) Triticale. University of Sydney, http://sydney.edu.au/agriculture/plant_breeding_institute/key_work_results/triticale.shtml

INTRODUCTION TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 1: Dry matter, energy, protein and fibre content (dry matter basis) of cereals and pulses commonly fed to sheep. The average across the range of values tested in WA is shown in brackets.

Cereals and pulses	Dry matter (%)	Metabolisable energy (MJ/kg)	Crude protein (%)	Acid detergent fibre (%)
Wheat	91	12.4–13.3 (12.9)	7.5–15.0 (11.5)	2.5–4.5 (3.0)
Barley	91	11.6–12.2 (11.9)	7.0–13.0 (11.0)	7.0–9.5 (8.0)
Triticale	90	12.0–13.0 (12.5)	7.5–14.0 (11.0)	3.5–5.0 (4.0)
Oats	92	10.4–11.3 (10.7)	5.5–13.5 (9.0)	16.0–21.5 (18.5)
Narrow leaf lupins	92	13.1–14.1 (13.7)	27.0–42.0 (34.0)	17.5–23.0 (20.0)
Albus lupins	92	13.4–15.0 (14.0)	34.0–44.0 (38.0)	17.0–21.0 (19.0)
Peas	91	12.5–13.5 (13.0)	21.5–30.0 (25.5)	6.0–10.5 (9.0)
Vetch	91	12.4–13.2 (12.8)	26.0–34.5 (29.0)	7.5–9.5 (8.5)
Chick peas	91	12.0–13.0 (12.4)	18.0–24.0 (21.0)	12.0–16.0 (14.0)
Faba beans	90	12.4–13.2 (12.9)	22.0–30.0 (26.0)	7.5–9.5 (8.5)
Canola (>35% oil)	95	15.0–17.0 (16.0)	20.0–25.0 (22.0)	22.5–26.5 (24.0)

Source: [DAFWA](#)

MORE INFORMATION

[Triticale: stock feed guide](#)

[A guide to the use of triticale in livestock feeds](#)

[Triticale offer benefits over wheat for biofuel](#)

A.1.3 Triticale for biofuel

Triticale also has a use in alternative fuels, which are increasingly sought after owing to the impending shortage of fossil fuels, and increasing global concern about the health of the environment. Biofuels are produced from organic matter and are a possible alternative fuel. Modern cultivars of triticale make a competitive feedstock for ethanol production. This is because it possesses an auto-amyolytic enzyme system that aids in converting large quantities of starch into fermentable sugars. It is better suited to the production of biofuel than wheat. The use of triticale for biofuels has been explored in Europe, and may have potential elsewhere in the world.

A.2 Growing regions

The Northern region includes all of Queensland and stretches as far south as the NSW-Victoria border.

This region consists of varying weather patterns, from summer dominant in the north to a more temperate, winter based rainfall system in the southern parts of NSW.

With the wide climatic variations in the Northern region, sowing and harvesting times can vary greatly from north to south. Sowing time depends on what crop is being grown, location and use pattern for this crop. For example, forage crops such as

INTRODUCTION TRITICALE

TABLE OF CONTENTS

FEEDBACK

triticale and oats will be sown from early March in the south of the region but the bulk of the bread wheats would not be sown till May. Whilst in central Queensland the main season for bread wheats would be sown as early as March. Consequently, the harvest of the northern region's winter crops can stretch from September through to December.

Similarly, in the Northern region, summer crops are planted from September to February, with harvest spanning the period February to May.

The main grain crops grown in the northern region are:

- Winter—wheat, barley, oats, chickpeas, triticale, faba beans, lupins, field peas, canola, vetch, safflower and linseed (Figure 1).
- Summer—sorghum, sunflowers, maize, mungbeans, soybeans, cotton and peanuts.¹⁵



Figure 1: Agro-ecological zones and corresponding crops grown in the northern region.

Source: AEGIC

¹⁵ Australian Export Grains Innovation Centre (2016) Australian grain production: a snapshot. AEGIC, <http://aegic.org.au/australian-grain-production-a-snapshot/>

A.3 History of triticale growing

The first wheat–rye cross-breeding occurred in Scotland in 1875, but the grain was sterile; in 1888, German botanists discovered how to produce a fertile hybrid of the two grains. The name triticale first seems to have been used in Germany about 1935.¹⁶

In the 1950s, plant geneticists hoped that a cross-fertilisation of wheat and rye would produce a cereal with superior yield. They developed a grain with the hardiness and disease resistance of rye that combined with the milling and baking qualities of wheat.

In 1970, the first commercial variety of triticale went on sale and triticale bread, flour and breakfast cereal became available. During this time, triticale was touted as a miracle crop, but initial interest faded when crops proved to give inconsistent yields, and after that acceptance was slow. Even now, triticale breeders have not achieved their objective to see triticale dominate as a grain for food production, although it is found in a range of grain foods in Australia.¹⁷

A.3.1 Triticale in Australia

Triticale varieties were introduced into Australia in the early 1970s as experimental lines for evaluation. Breeding and selection programs were initiated by several universities and state departments of agriculture, and a number of varieties were released, mostly spring-grain lines introduced from the International Maize and Wheat Improvement Center (CIMMYT). Triticale was quickly taken up as a useful crop for grain and fodder production on acid and waterlogged soils, and for producing an economical and soil-conserving crop on lower-rainfall, nutrient-impooverished soils. Initially, triticale was mostly used on the farm or traded locally as stockfeed. On the one hand, it was often sought as a more easily traded feed grain than wheat, which had to be marketed through the Australian Wheat Board. On the other hand, since it was not well-known, and as the quantity available was limited, in some areas triticale could prove difficult to sell for a good price, and this tended to limit its adoption.

The first Australian cultivar was Growquick, a later-maturing line of poor grain type most suitable for grazing. By the mid-1980s, 11 grain cultivars had been released.

In the early 1980s, wheat stem rust races evolved in Queensland that were virulent on these cultivars. In order to reduce the likelihood of rust epidemics and further evolution of virulent races, agronomist and seed sellers stopped recommending rust-susceptible cultivars, and breeders sought to produce cultivars with full rust resistance. Once this was achieved, an increasing amount of triticale was produced, and after many years of good results, users gained confidence in the grain, driving an increasing demand for triticale and improved prices.

By the early 2000s, triticale had gained popularity in Australia, mainly in southern regions, to the point where it was treated as an economic crop. More recently, the area of production has declined.¹⁸

Figure 2 shows the decreasing volume and low area planted to triticale over the last 20 years. This decline is likely due to the crop being disadvantaged in relative yield against wheat and barley.

¹⁶ Whole Grains Council. Rye + triticale August grains of the month, Whole Grains Council, <http://wholegrainscouncil.org/whole-grains-101/easy-ways-enjoy-whole-grains/grain-month-calendar/rye-triticale-august-grains-month>

¹⁷ Grains and Legumes Nutrition Council (2016) Triticale. Grains and Legumes Nutrition Council, <http://www.glnc.org.au/grains/types-of-grains/triticale/>

¹⁸ KV Cooper, RS Jessop, NL Darvey. In M Mergoum, H Gómez-Macpherson (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

INTRODUCTION TRITICALE

TABLE OF CONTENTS

FEEDBACK

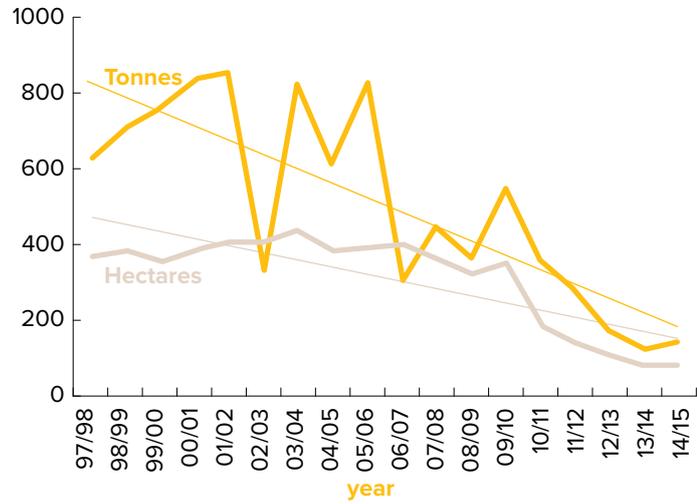


Figure 2: *Triticale Production 1997/98–2016/17 ('000 tonnes and hectares).*

Source: ABS Agricultural Commodities and ABARES Crop Reports.

Planning/Paddock preparation

Key messages

- Triticale is suited to all soil types but has a significant yield advantage over wheat and barley when grown in a number of problem-soil situations .
- Of all the cereals available to farmers, triticale has the best adaptation to waterlogged soils and those with high pH (alkaline).
- Triticale is also tolerant of low pH (acid) soils, grows well on sodic soils, and tolerates soils high in boron.
- Triticale can out-produce other winter cereals on lighter soils with lower fertility. It has a more vigorous root system than wheat, barley or oats, binding light soils and extracting more nutrients from the soil.
- Incorporate crop rotation in farming systems: triticale can provide valuable benefits to a sequence.
- Ensure that paddocks are weed free before planting seed.
- Before planting, test soils for diseases and nematodes, and sample paddock soil for insects.
- Triticale is grown in areas with an annual average rainfall of about 300 mm to at least 900 mm. Very little triticale is irrigated.

1.1 Paddock selection

The choice of paddock to sow cereals is based on a range of issues. Economics, production risk from disease or weed pressure, herbicide residues, nutritional status, seasonal forecasts, stored soil water, and achieving a balance of risk across the farm with other crop types. ¹

1.1.1 Topography

Topographical characteristics can determine crop and pasture options. Crops and varieties prone to lodging should be avoided in uneven paddocks. Waterlogged conditions also reduce root growth and can predispose plants to root rots. Triticale is less prone to waterlogging than other cereals, and can be a good option for areas where water may sit.

There are potential environmental and economic benefits of site-specific topography-driven management of crops. Decisions regarding where to plant crops can vary depending on the management goals and complexity of the terrain. For example, crops like triticale, with its large biomass, seem to be particularly advantageous on eroded, unfertile slopes where legumes bring the needed N inputs, while all cover crops contribute to erosion control and carbon (C) sequestration there. ²

Triticale can suit uneven paddocks and/or those with many gilgais as its tall growth habit makes harvesting more manageable in such paddocks.

Agronomist's view

¹ Agriculture Victoria (2012) Growing wheat. Note AG0458. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat>

² M Ladoni, AN Kravchenko, GP Robertson (2015) Topography mediates the influence of cover crops on soil nitrate levels in row crop agricultural systems. PLOS ONE, 10 (11), DOI doi:10.1371/journal.pone.0143358.

Frost risk

Frost damage is most frequent, and most severe, in 'frost pockets', which can vary greatly in size, depending on topography and related factors. Low lying paddocks or areas within a paddock are at higher risk of damaging frost events.

Winter cereals are most susceptible to low temperatures during the reproductive stage as reproductive parts are not protected by the leaf sheaths and ice can nucleate directly on them. As a result, complete or serious yield losses are felt when frost occurs between the booting and grain ripening stages.

Triticale has been rated as susceptible to frost damage. One study has ranked frost resistance in the order of most resistance as; rye, bread wheat, triticale, barley, oats, and durum wheat, and another study reported that triticale is the most susceptible crop, followed by wheat, barley, rye and oats.³

Physically mapping or marking areas identified as frost-prone will enable growers to target frost management strategies to these high-risk areas. As triticale is vulnerable to frost damage, it is important to either avoid sowing it in frost prone paddocks, or adopt other frost management strategies (e.g. time of sowing, canopy management etc.).

For more information on Frost, see [Section 14: Environmental issues, Section 14.1 Frost](#).

1.1.2 Soil

Surface and subsurface soil characteristics such as soil pH, sodicity, salinity, acidity, texture, drainage characteristics and compaction will affect variety selection and crop choice.

Triticale is a high-yielding grain suited to all soil types (see Photo 1), but has yield advantages over wheat and barley in some problematic soils. It does better than them on light, acid soils high in exchangeable aluminium (greater than 10% of the total cations, such as in southern NSW, north-eastern Victoria and WA). In these soils, triticale significantly out-yields wheat, barley and sometimes oats in all seasonal conditions, wet or dry. It has more vigorous root system than wheat, barley or oats, and this allows it to bind light soils and extract more nutrients from the soil.⁴

In low soil fertility, triticale responds well to high inputs of seed and fertiliser. Adequate fertiliser needs to be applied to achieve optimum yields.

On good soils, and in better seasons, triticale yields are equal to or exceed those of wheat. However, in dry springs triticale yields may be 10–15% below wheat, due to its longer grainfilling period.

Of all the cereals available to farmers, triticale has the best adaptation to waterlogged soils (such as those on the northern NSW coast) and those of high pH, common to the northern parts of the northern region.⁵ Triticale is also tolerant of low pH (acid soils), grows well on sodic soils and tolerates soils high in boron. Triticale has the capacity to survive utilising trace elements in soils which would be considered nutrient-deficient for any other type of crop.⁶ On alkaline soils where other cereals are affected by manganese, zinc or copper deficiency, triticale is less affected.

3 J Roake, R Trethowan, R Jessop, M Fittler (2009) Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

4 Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, <http://www.farmtrials.com.au/trial/13801>

5 Waratah Seed Co. (2010) Triticale: planting guide. Waratah Seed Co., http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

6 Agriculture Victoria (2012) Growing triticale. Note AG0497. Updated. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 1: Paddock of triticale.

Source: Seed Force

Soil pH

Key points:

- Triticale can grow on acidic soils and alkaline soils.
- Soil pH is a measure of the concentration of hydrogen ions in the soil solution.
- Low pH values (under 5.5) indicate acidic soils and high pH values (over 8.0) alkaline soils.
- Soil pH between 5.5 and 8 is not usually a constraint to crop or pasture production.
- Outside of the optimal soil pH range, microelement toxicity damages crops.

The concentration of hydrogen ions in the soil, called pH, is influenced by chemical reactions between soil components and water. Soil pH is affected by the varied combinations of positively charged ions (sodium, potassium, magnesium, calcium, aluminium, manganese and iron) and negatively charged ions (sulfate, chloride, bicarbonate and carbonate) (Figure 1). The pH directly affects the concentration of major nutrients and the forms of microelements available for plant uptake, and can result in deficiencies or toxicities.

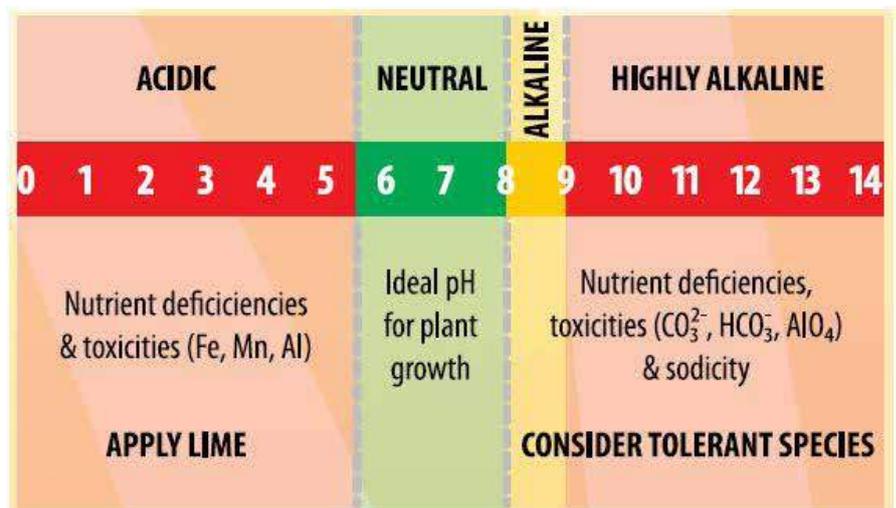


Figure 1: Classification of soils on the basis of pH, showing the implications for plant growth and some management options.

Source: Soilquality.org

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Acidic soils

Queensland has more than 500,000 hectares of agricultural and pastoral land that has become acidic or is at risk of acidification, and more than half of the intensively used agricultural land in NSW is affected by soil acidity. Soils most at risk are the lighter-textured sands and loams with low levels of organic matter, and the naturally acidic red clay loams commonly found in areas such as the South Burnett and Atherton Tableland. The soils least likely to become acidic are the neutral to alkaline clay soils (e.g. brigalow soils and the grey–black Vertisols).

Acidic soils cause significant losses in production, and where the choice of crops is restricted to acid-tolerant species and varieties, profitable market opportunities may be reduced. In pastures grown on acidic soils, production will be reduced and some legume species may fail to persist.

There are many negative effects on plant growth and soil biology, fertility and structure when soils become too acidic. One major effect is when pH falls to 4.8. At this point aluminium starts to become more soluble where it is toxic to plants and restricts their root growth and function. At harvest this results in a yield penalty and smaller grain size, usually most noticeable in seasons with a dry finish as plants have restricted access to stored subsoil water for grain filling.

Plant species have different tolerances to soluble aluminium. There are four broad categories of plant tolerance (Highly sensitive, Sensitive, Tolerant and Highly tolerant). Plants highly sensitive to aluminium have their yields effected at low levels of aluminium (approximately Al % CEC > 2%). When pH falls below 4.5, the amount of aluminium increases markedly and even plants tolerant of aluminium will suffer yield reductions or fail to persist.⁷

Triticale can grow on acidic soils (pH less than 4.5 CaCl₂) (Table 1).

Table 1: Crop sensitivity to acidity.

Highly sensitive	Durum wheat, most barley cultivars, faba beans, lentils, chickpeas, lucerne, medics, strawberry clover
Sensitive	Some wheats, canola, phalaris, red clover, Balansa clover
Tolerant	Wheats, annual and perennial ryegrass, tall fescue, Haifa white and subterranean clovers
Highly tolerant	Lupins, oats, triticale, cereal rye, cocksfoot, kikuyu

Source: GRDC, modified from Brett Upjohn, 2005 NSW.

Managing acidic soils

Soil acidification is not as obvious as other soil issues such as salinity, erosion or structural decline. Symptoms are less visible, production declines are gradual and these changes are often attributed to other factors such as weather.

Soil testing

Ideally, soil samples should be taken when soils are dry and have minimal biological activity. Soil samples should be taken from a number of locations across the paddock, as pH may vary in even a small area. Samples should be taken at the surface (0–10 cm) and from the subsurface (50–60 cm) of the soil so as to detect subsurface acidity, which may underlie topsoil with an optimal pH. The location of samples need to be pinpointed accurately (e.g. by using GPS) to allow monitoring. Sampling should be repeated every 3–4 years to enable the grower to detect changes and adjust management practices.

To maintain a good soil pH profile, producers should aim for a pH_{Ca} above 5.0 in the 0–10 cm of topsoil or 5.5 if subsoil acidity issues are present. The target in the 10–30 cm zone is greater than pH_{Ca} 4.8.

⁷ J Small (2016) GRDC Update Papers: Crop yield impacts and management of soil acidity in Central Western NSW. <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Crop-yield-impacts-and-management-of-soil-acidity-in-Central-Western-NSW>

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Farming practices to reduce acidification

It is most important that soil acidity be treated early. If acidity spreads to the subsoil, serious yield reduction may occur. Subsoil acidity is difficult and costly to ameliorate. Farming practices recommended to minimise acidification include:

- Match nitrogen fertiliser inputs to crop demand. Soil testing should be carried out to ensure that fertiliser rates match plant requirements.
- Use forms of nitrogen fertiliser that cause less acidification. Table 2⁸ summarises the acidifying effect of different N fertilisers. Nitrate-based fertilisers such as calcium nitrate and potassium nitrate are the least acidifying, but their higher cost limits their use to high-value horticultural crops.
- Apply nitrogen in split applications, if practicable. Application of a crop’s entire fertiliser needs at planting time may contribute to soil acidification by allowing the leaching of nitrate nitrogen before the crop roots have developed sufficiently to take all of it up.
- Sow early after fallow to ensure more rapid utilisation of available N.
- Grow deep-rooting perennial species to take up nitrogen from greater depths.
- Regularly apply lime to counter the acidification inherent in the agricultural system.
- Grow crop varieties that are more tolerant of acid soils.
- Irrigate efficiently to minimise leaching.

Table 2: Acidification potential of nitrogen fertilisers, assuming that some leaching loss of applied nitrogen occurs.

Fertiliser	Acidification Potential
Calcium nitrate, potassium nitrate	Low
Nitram, urea, animal manure	Medium
Ammonium sulphate, MAP, DAP	High

MAP = mono-ammonium phosphate; DAP = diammonium phosphate
Source: Soilquality.org

Applying lime or dolomite

When soils are too acidic for a crop, lime or dolomite can be used to increase soil pH to the desired level. The amount required to correct an acidic pH will depend on the soil and the crop.

Above pH 4.8 aluminium becomes non-toxic in the soil, enabling the plants to develop effective root systems. Research shows that as well as improving crop yields and widening rotation options, liming has a long-term positive impact on the ecosystem by potentially boosting soil microbial activity, improving availability of major plant nutrients and helping to reduce weed seed banks.⁹

Soils with a high amount organic matter and clay will be more resistant to changes in pH and will require more lime or dolomite. To obtain an estimate of the amount of lime required to correct an existing soil-acidity problem, conduct a test of the lime-requirement or buffer pH type.

Testing is used to give a lime recommendation to raise the soil pH of the surface 10 cm of one hectare of soil to a target pH that will not limit crop yield. In general, a target pH of 5.5 is suggested.

Once the target soil pH is reached, additional lime or dolomite may still be required, depending on the crop. The acidifying effect of cropping systems is related to the amount of material removed at harvest, the amount and type of fertilisers normally used, and the amount of leaching that occurs.¹⁰ There are opportunities to

8 Soilquality.org (2017) Soil acidity, Queensland. Soilquality.org, <http://www.soilquality.org.au/factsheets/soil-acidity-qld>
9 GRDC (2016) Soil Acidity in WA. <https://grdc.com.au/archive/key-issues/soil-acidity-in-wa/details>
10 Soilquality.org (2017) Soil acidity, Queensland. Soilquality.org, <http://www.soilquality.org.au/factsheets/soil-acidity-qld>

SECTION 1 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

VIDEOS

[GCTV8: Liming Acids Soils](#)


MORE INFORMATION

[Impact of soil acidity on crop yield and management in Central Western NSW](#)
[Chemistry and crop agronomy in alkaline soils](#)
[Making better liming decisions](#)

decrease lime rates by adjusting nitrogen fertiliser rates or by changing the form of nitrogen used.¹¹

If the topsoil pH is below 5.5, recovery liming is recommended to prevent the development of subsurface acidity, even if the subsurface pH is at 4.8 (Table 3).

Table 3: *The amount of lime that may be required on sandy soils over five years to achieve a pH above 5.5 in the topsoil and 4.8 in the subsurface after 10 years. Increases in pH will depend on soil type, rainfall, lime quality and quantity applied and other farming practices, as well as the soil pH profile. Expert advice should be sought for individual recommendations as ongoing acidification resulting from agricultural production will require additional lime.*

Soil depth (cm)	pH _{Ca}	Lime amount over five years (t/ha)
0–10	<5.0	2
0–10	<5.5	1
Add to		
10–20	<4.5	2
10–20	<4.8	1
Add to		
20–30	<4.5	1
20–30	<4.8	Measure pH in 3 years

Source: GRDC

Alkalinity

Alkaline soils occupy about 23.8% of total land area in Australia. More than 30% reduction in grain productivity occurs when the pH is above 9.0. When pH is more than 9, the soils are considered highly alkaline and often have toxic amounts of bicarbonate, carbonate, aluminium and iron. Nutrient deficiency is also likely to be a major problem and the high amount of exchangeable sodium in these soils reduces soil physical fertility. On alkaline soils where other cereals are affected by manganese, zinc or copper deficiency, triticale is less affected, and can grow well compared to other crops.

In high pH soils, using alkalinity tolerant species/varieties of crops (like triticale) and pasture can reduce the impact of high pH.

Management

Treating alkaline soils by the addition of acidifying agents is not generally a feasible option due to the large buffering capacity of soils and uneconomic amounts of acidifying agent (e.g. sulfuric acid, elemental sulfur or pyrites) required.

Acidification to reduce pH below 9.0 can be reasonably achieved by growing legumes and the simultaneous application of gypsum. Gypsum will reduce sodicity and this can reduce alkaline pH to some extent. Growing legumes in crop rotation may help in sustaining any pH reduction. Reducing the soil pH below 9.0 enhances crop productivity in alkaline soils by avoiding the toxicity of aluminium and carbonates, nutrient deficiency and other possible microelement toxicity.

Reducing soil alkalinity by applying these treatments can increase yield by 10–30%, providing economic benefits to farmers.¹²

Salinity

Key points:

- Soil salinity varies across the landscape and within paddocks.

¹¹ Soilquality.org (2017) Soil acidity, Queensland. Soilquality.org, <http://www.soilquality.org.au/factsheets/soil-acidity-qld>

¹² P Rengasamy (2010) GRDC Final Reports: UA00092–Chemistry and crop agronomy in alkaline soils, <http://finalreports.grdc.com.au/UA00092>

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- The severity varies over time, in response to both climate and land management.
- Soil salinity can be managed by farming actions.
- One study found that though saline soil increased the quality of protein in triticale, it decreased the quality of grain overall.¹³

What is soil salinity?

A saline soil is one that contains sufficient soluble salts (most commonly sodium chloride) that the growth of most plants is retarded, with damage occurring sooner in plants more sensitive to salt and much later in salt-tolerant plants such as saltbush. Salinity reduces a plant's ability to extract water from the soil, and specific ions in the salts can cause toxicity. A salinity outbreak is where symptoms of salinity are present.

Soils become saline via interaction with groundwater. If groundwater rises to within two metres of the soil surface, capillary action can bring water to the surface. When this happens, salts dissolved in the water are brought into the root zone, and when the water evaporates at the soil surface, concentrated salts are left behind.

Triticale and wheat are rated as highly tolerant to saline soils (Table 4), however, salinity has been found to reduce yields when values of electrical conductivity are above 6 decisiemens per metre (dS/m) throughout the root zone.

Table 4: Tolerance of some common crops to salinity.

High tolerance	Moderate tolerance	Low tolerance
Wheat	Lucerne	Maize
Barley	Peas	Sugar cane
Canola	Sweetcorn	Red clover
Cotton		Sub. clover
Ryegrass		
Sorghum		
Soybeans		

Source: Australian Soil Fertility manual, JS Glendinning 1999

Salinity affects crop yield and growth in dryland regions mainly by reducing Water Use Efficiency of crops through osmotic effect. Toxic effects of individual ions such as sodium can also cause yield reduction. When the osmotic pressure of the soil solution is less than (<) 700 kilopascals (kPa), there is a low rate of reduction in yield irrespective of the type of ions (salt). At these lower osmotic pressures the specific ion effect, particularly of sodium, is significant. For osmotic pressure greater than (>) 700 kPa the rate of crop yield reduction is severe. When the osmotic pressure is above 1,000 kPa, the crop yield is reduced by >50% and 80–95% of available soil water is not taken up by plants.¹⁴

For more information on the effects of soil salinity on triticale growth, see [Section 4: Plant growth and physiology](#).

Signs of salinity in the paddock

Any of these signs should trigger investigations for potential salinity:

- Crop symptoms including reduced yield, and burnt leaf tips and/or margins (Photo 3).¹⁵
- Salt-tolerant species thriving while others grow poorly.
- Dieback of trees.

¹³ M Salehi, A Arzani (2013). Grain Quality traits in Triticale influenced by field salinity stress. Australian Journal of Crop Science. 7(5):580–587. In F Eudes (2015) Triticale. Springer International Publishing, Switzerland.

¹⁴ P Rengasamy (2006) GRDC Final Reports: UA00023—Improving farming systems for the management of transient salinity and risk assessment in relation to seasonal changes in southern Australia. <http://finalreports.grdc.com.au/UA00023>

¹⁵ DAFWA (2016) Changing land use on unproductive soils in the north-eastern agricultural region. DAFWA, <https://www.agric.wa.gov.au/soil-constraints/changing-land-use-unproductive-soils-north-eastern-agricultural-region>

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- Waterlogged soil (separate from rain or flood events).
- Bare patches of soil.
- Wet, dark greasy patches.
- Salt crusts on the soil surface when it is dry.
- Stock congregating and licking surface salt.
- Very clear water in dams and waterways.



Photo 2: *Cereal crop suffering in a saline paddock.*

Source: DAFWA

Measuring salinity

Soil salinity varies across paddocks and farms, and vertically within the soil profile. Soil may be saline at depth but not in the topsoil. This situation indicates that there may be a future problem in the topsoil.

Samples can be taken to assess salinity by measuring the electrical conductivity (EC) of soil and water. EC is usually measured in dS/m). Distilled water has an EC of 0 dS/m, sea water has an EC of 35–55 dS/m, and the desirable limit for human consumption is 0.8 dS/m. Measurements may be taken instead of the electrical conductivity of a soil extract (ECe), of a water sample (ECw) and of irrigation water (ECiw) or drainage water (ECdw).

Dryland salinity

Dryland salinity occurs when naturally occurring salts in rocks and soil are mobilised and redistributed by water, e.g. by surface run-off after rain, the recharge of groundwater, subsurface lateral flows of groundwater, or groundwater discharge. It occurs throughout NSW (Photo 4).¹⁶ Saline outbreaks in upland areas of the NSW Murray–Darling Basin cover around 62,000 hectares, but individual areas are usually less than 10 hectares. Most salt scalds occur in the 600–700 mm rainfall zone.

16 S Alt (2017) Salinity, New South Wales. Soilquality.org, <http://soilquality.org.au/factsheets/salinity-nsw>



Photo 3: Scalding by salt.

Photo: Graham Johnson, NSW Government.

Irrigation salinity

Irrigation salinity in NSW occurs mainly in southern NSW in the Murray and Murrumbidgee irrigation areas.

Areas of land affected by irrigation salinity have dropped sharply in the last 10 years (from 2015), from 14,000 hectares to less than 500 hectares in the Murray Valley. The mechanisms for this change are not completely understood, but are possibly due to a combination of reduced winter rainfall and better farm management and infrastructure.

Managing groundwater levels

Salinity management aims to maintain groundwater levels at least two metres below the soil surface, mainly by maximising the water plants use to reduce groundwater recharge. Useful techniques include:

- Monitoring groundwater levels.
- In low lying, non-production areas, growing species tolerant of salt and waterlogging.
- Growing perennial pastures, as they can use twice as much water as annual pastures.
- Avoiding long fallows when the profile is greater than 75% of field capacity.
- Appropriate crop selection and crop rotations.
- Efficient irrigation management.

Troubleshooting

Recognising and acting on salinity problems early is the best solution, as salinity can be a more difficult and expensive issue to correct once it is well advanced. Dryland salinity outbreaks can be managed by excluding grazing on saline areas and sowing saline tolerant species. Irrigation salinity can be managed by improving irrigation management, specifically application efficiency. Specific management of salt-affected areas could include having hill and bed shapes that minimise salt accumulation around seedlings, and pumping and recycling groundwater (although this requires advice from a hydrology consultant).¹⁷

i MORE INFORMATION

[Improving farming systems for the management of transient salinity and risk assessment in relation to seasonal changes in southern Australia](#)

¹⁷ S Alt (2017) Salinity, New South Wales. Soilquality.org, <http://soilquality.org.au/factsheets/salinity-nsw>

Sodic or dispersive soils

Sodicity is a term given to the amount of sodium held in a soil. Dispersive soils are generally a surface problem, sodicity can be at the surface but also at depth; i.e. plant roots hit this layer and become restricted in growth and cannot extract as much water out of the profile. High sodicity causes clay to swell excessively when wet. The clay particles move so far apart that they separate (disperse). This weakens the aggregates in the soil, causing structural collapse and closing-off of soil pores and hence infiltration points. For this reason, water and air movement through sodic soils is severely restricted. In crop paddocks, sodic layers or horizons in the soil may prevent adequate water penetration during irrigation, making the water storage low. Additionally, waterlogging is common in sodic soil, since swelling and dispersion closes off pores, reducing the internal drainage of the soil. Sodicity of the surface soil is likely to cause dispersion of surface aggregates, resulting in surface crusts, which can also prevent seedling emergence.

Soils with an exchangeable sodium percentage (ESP) ≥ 6 are classified as sodic. Poor drainage, surface crusting, hardsetting (Photo 5) and poor trafficability or workability are common when the soil has a large proportion of sodium ions (Na⁺), leading to reduced crop yield.

A surface crust is typically less than 10 mm thick and when dry can normally be lifted off the loose soil below. Crusting forces the seedling to exert more energy to break through to the surface, thus weakening it. A surface crust can also form a barrier reducing water infiltration.

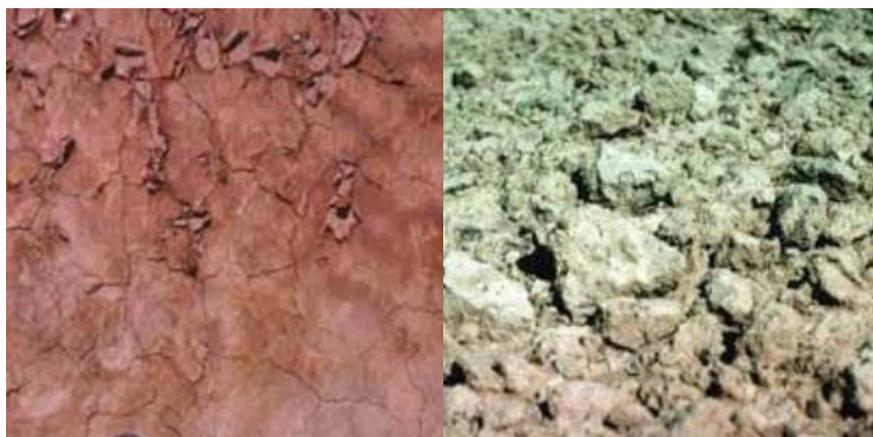


Photo 4: Soil crusting (left) and cloddy seedbed (right) associated with high concentrations of exchangeable sodium; i.e. sodic soil.

Source: Soilquality.org

Field research in Victoria/South Australia indicates that soil salinity and sodicity can substantially reduce crop yields. The impact of sodicity was most apparent for yields in the range 3.0–3.5 t/ha, where the probability of wheat yielding in this range was 60% for sites where ESP 19% compared with 12% when ESP >19%.¹⁸ This response is likely to be similar in triticale crops.

Crop growth is affected by salinity and sodicity in two ways: firstly, the osmotic potential effect and secondly specific ion toxicity. Salts lowers the osmotic potential (i.e. makes it more negative) or increases osmotic pressure leading to yield losses as plants cannot extract water from soils when soil solution has lower osmotic potential than the plant cell. The impact on grain productivity of rising electrical conductivity (EC) and ESP values at different depths is shown in Figure 2, which demonstrates that identifying the complete picture is essential to applying the management option.

¹⁸ Agriculture Victoria (2009) Chapter 4: Salinity and Sodicy, Subsoils Manual. [http://vro.agriculture.vic.gov.au/dpi/vro/site.nsf/pages/soil_mgmt_subsoil_pdf/\\$FILE/BCG_subsoils_09_ch04.pdf](http://vro.agriculture.vic.gov.au/dpi/vro/site.nsf/pages/soil_mgmt_subsoil_pdf/$FILE/BCG_subsoils_09_ch04.pdf)

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

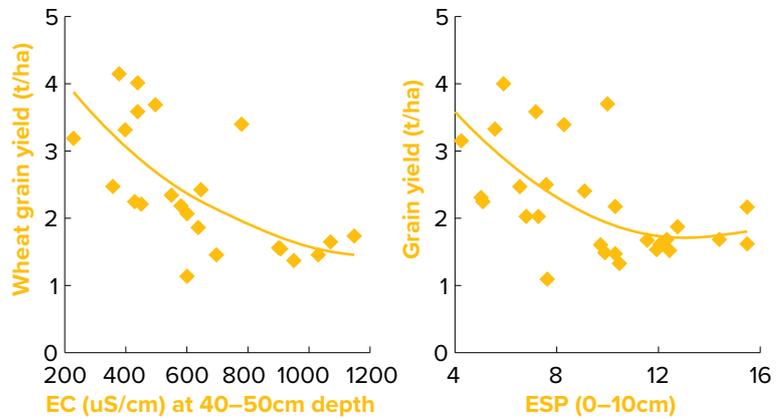


Figure 2: Impacts of salinity and sodicity on productivity. High sodium levels in subsoil limits yields and water use in marginal cropping areas. (Grains Research & Development Corporation project no. DNR 6, final report)

Source: Dalal R.C, Blasi M, So H.B (2002)

Sodic soils are prone to poor soil structure, particularly if the natural equilibrium between salinity and sodicity are out of balance. High salinity helps to counteract the effects of sodicity, but as described above, can cause yield issues. Both acidic–sodic and alkaline–sodic soils occur within the Northern grains zone, often within the one soil profile. Sodic soils often disperse more after mechanical disturbance (e.g. tillage) and erosion. Gypsum application to these soils improves the soil structure facilitating leaching of salts, even under dry land conditions. Correcting cation imbalances requires providing a source of the ‘good’ cations, Ca²⁺ and/or Mg²⁺, which might come from gypsum, lime or dolomite applications. The choice will depend on considerations such as cost, the existing cation balance in the soil and the speed at which a change is required. The application of gypsum will generally give a quicker result as it has a relatively high solubility, whereas agricultural lime has a very low solubility and therefore takes longer to observe results. It is also dependant on the pH of the soil.

The use of decision process models such as [Gypsy©](#) can be used as a guide when deciding on the cost of gypsum applications.¹⁹

Plant available water capacity

A key determinant of potential yield in dryland agriculture is the amount of water available to the crop, either from rainfall or stored soil water. In the Northern region, the contribution of stored soil water to crop productivity for both winter and summer cropping has long been recognized. The amount of stored soil water influences decisions to crop or wait (for the next opportunity or long fallow), to sow earlier or later (and associated variety choice) and the input level of resources such as nitrogen fertiliser.

The amount of stored soil water available to a crop - Plant Available Water (PAW)—is affected by pre-season and in-season rainfall, infiltration, evaporation and transpiration. It also strongly depends on a soil’s Plant Available Water Capacity (PAWC), which is the total amount of water a soil can store and release to different crops. The PAWC, or ‘bucket size’, depends on the soil’s physical and chemical characteristics as well as the crop being grown.

Information regarding the PAW at a point in time, particularly at planting, can be useful in a range of crop management decisions. Estimating PAW, whether through use of a

¹⁹ M Crawford (2015) GRDC Update Papers: Profit suckers—understanding salinity, sodicity and deep drainage. <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/Profit-suckers-understanding-salinity-sodicity-and-deep-drainage>

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

soil water monitoring device or a push probe, requires knowledge of the PAWC and/or the Crop Lower Limit (CLL).

A wide variety of soils in the Northern region have been characterised for PAWC and the characterisations are publicly available in the APSoil database, which can be viewed in Google Earth and in the 'SoilMapp' application for iPad.

The field-based method for characterising PAWC has been tried and tested across Australia, but users need to be mindful of common pitfalls that can cause characterisation errors. Knowledge of physical and chemical soil properties like texture or particle size distribution and (sub) soil constraints helps interpret the size and shape of the PAWC profiles of different soils. It can also assist in choosing a similar soil from the APSoil database.

Extrapolating from the point-based dataset to predict PAWC at other locations of interest is a challenge that needs further research. Preliminary analyses drawing on soil landscape mapping (NSW) and land resource area (LRA) mapping (Queensland) suggest that an understanding of position in the landscape and the story of its development may assist with extrapolation. This is because in many landscapes the soil properties determining PAWC are tightly linked to a soil's development and position in the landscape and these same aspects underpin soil and land resource surveys.

While the concept of using soil-landscape information to inform land management is not new, the availability of these maps on-line makes them more accessible and assists with visualising a location's position in the landscape. Combining these maps with the geo-referenced APSoil PAWC characterisations will increase the value that both resources can provide to farmers and advisors

Uncertainty of PAWC estimates translates into uncertainty in PAW. The extent to which this affects potential decision making depends on the question asked, but also needs to be viewed in terms of the spatial variability in PAW and the accuracy of the method to convert this water into a yield forecast.

Factors that influence PAWC

An important determinant of the PAWC is the soil's texture. The particle size distribution of sand, silt and clay determines how much water and how tightly it is held. Clay particles are small (< 2 microns in size), but collectively have a larger surface area than sand particles occupying the same volume. This is important because water is held on the surface of soil particles which results in clay soils having the ability to hold more water than a sand. Because the spaces between the soil particles tend to be smaller in clays than in sands, plant roots have more difficulty accessing the space and the more tightly held water. This affects the amount of water a soil can hold against drainage (DUL) as well as how much of the water can be extracted by the crop (CLL).

The effect of texture on PAWC can be seen by comparing some of the APSoil characterisations from the Northern region. The soil's structure and its chemistry and mineralogy affect PAWC as well. For example, subsoil sodicity may impede internal drainage and subsoil constraints such as salinity, sodicity, toxicity from aluminium or boron and extremely high density subsoil may limit root exploration, sometimes reducing the PAWC bucket significantly.

The CLL may differ for different crops due to differences in root density, root depth, crop demand and duration of crop growth. Some APSoil characterisations only determined the CLL for a single crop. The CLL for wheat (and triticale), barley and oats are often considered the same and that of canola can be found to be similar as well, but care needs to be taken with such extrapolations as different tolerances for subsoil constraints can cause variation between crops.²⁰

MORE INFORMATION

Methods and tools to characterise soils for plant available water capacity (Coonabarabran)

²⁰ K Verburg, B Cocks, T Webster, J Whish (2016) GRDC Update Papers: Methods and tools to characterise soils for plant available water capacity (Coonabarabran). <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Methods-and-tools-to-characterise-soils-for-plant-available-water-capacity-Coonabarabran>

Testing for sodicity

The first step in determining whether a soil needs treatment for sodicity is to determine how sodic it is using a dispersion test. If this test gives a dispersion score of 6 to 16, then the soil may be gypsum responsive. In this situation do a soil test to calculate the ESP.

Ensure to sample both surface and subsurface soil layers. There is increasing evidence of the value of assessing soil-based physicochemical constraints to production, including sodicity, salinity and acidity/aluminium, from both the surface and subsoil layers. Soil sampling to greater depth (0 to 60 cm) is considered important for testing sodicity.

Applying gypsum

Gypsum contains calcium sulfate. Calcium sulfate is a salt, but unlike sodium chloride (the main component of salt in saline water tables) it is not toxic to plants. Gypsum will help to reduce swelling and dispersion of the soil through two mechanisms. These are:

1. Gypsum slightly increases the salinity of the soil solution, and hence reduces swelling. The same effect can be seen when using saline bore water, but this often contains high levels of sodium and chlorine that are toxic to plants. Gypsum will slightly increase salinity without any detrimental effect on plants.
2. Calcium from the gypsum will swap with the sodium that is held on the clay surfaces, which is then leached down the profile away from the plant roots. This reduces the sodicity of the soil and is called cation exchange.

Gypsum can provide better soil tilth, and can reduce crusting in sodic surface soils, hence improving establishment. If using gypsum where the surface soil is sodic, time the application so that rain or irrigation does not leach the gypsum from the surface soil by sowing time.

In soils with moderate surface sodicity, applying gypsum at 2.5–5.0 t/ha has been found to significantly improve wheat grain yield in Queensland (Photo 5).²¹



Photo 5: Gypsum application (right) can help treat surface sodicity and improve grain yield under Queensland conditions.

Source: Soilquality.org

Cultivation practices on sodic soils should be aimed at preserving soil organic matter in the surface soil. This is usually achieved by less aggressive, reduced tillage. Non-inversion tillage is useful for leaving the more sodic subsoil at depth. In many soils of the Murray and Murrumbidgee Valleys (especially red brown earths), the topsoil is non-sodic and of reasonable depth (10 to 40 cm). However, these soils will often have sodic subsoils. Gypsum applications to these soils will have little effect on the topsoil but will increase the structure, aeration and permeability of the subsoils. This is likely to increase water storage and reduce waterlogging.

²¹ Soilquality.org (2017) Seedbed soil structure decline, Queensland. Soilquality.org, <http://www.soilquality.org.au/factsheets/seedbed-soil-structure-decline-queensland>

The depth of the non-sodic topsoil is an important consideration in the likely response of a sodic subsoil to gypsum improvement. Since a non-sodic topsoil is a better environment for plant growth anyway than a sodic topsoil, responses to gypsum will be low or unlikely when there is good depth of topsoil—the existing soil structure will allow optimum plant growth.

As a rough guide, if the non-sodic topsoil is greater than 15 to 20 cm deep, then a gypsum response may be unlikely. Remember, it may take a few months before gypsum leaches into the subsoil and begins to take effect.

Deep ripping

This can be used to break up compacted and poorly structured soils and to help generate structure and porosity. However, the benefits can be very short-lived. Sometimes deep ripping makes the soil worse because worked (tilled) soil disperses more readily. Ripping can bring up large clods of dispersive soil and bring toxic elements such as boron and salt to the surface. Consequently, only undertake deep ripping after careful consideration. If in doubt, first carry out deep ripping on a small test strip. After ripping apply gypsum or lime (in acid soils), preferably with additional organic matter, to help stabilise the deep ripped soil. A tramline (controlled traffic) farming system will help prevent re-compaction of the loosened soil.²²

Lime application to sodic soils

Lime (calcium carbonate), like gypsum, is a compound containing calcium. Therefore, it can contribute to reducing the effects of sodicity. However, lime is relatively insoluble at a soil pH (CaCl₂) above 5. In most soils of the Murray and Murrumbidgee Valleys the pH (CaCl₂) is above 5, so lime is of little benefit. If the pH is below 5, lime will help to reduce both acidity and sodicity problems. A mixture of lime and gypsum may be a good option on sodic soils with a pH (CaCl₂) in the 5 to 6.5 range, to provide a more long-lasting effect than gypsum only. Again, soil tests and test strips are strongly recommended.

Cultivating sodic soils

dispersive and sodic soils are more prone to structural degradation than non-sodic soils. For this reason, they must be cultivated minimally and carefully. Excessive cultivation of these soils will cause major soil structure problems. In this may be evident as crusting, hardsetting and poor water penetration.²³

Soil compaction

Soil compaction has been found to limit triticale and other cereal crops growth. Severe compaction reduces leaf numbers, leaf area and dry matter of shoots and roots, and increases shoot-to-root dry-matter ratio. In addition, high levels of soil compaction decrease the length of seminal and seminal adventitious roots, and the number and length of lateral roots developed on the seminal root. Severely compacted soil also negatively impacts photosynthesis, gas exchange, transpiration rate and stomatal conductance.²⁴

Subsoil compaction can reduce rooting depth of plants by slowing the rate of root penetration (Photo 6). This means roots are unable to access subsoil moisture and leachable nutrients such as nitrogen (N). This can result in poor nitrogen-use efficiencies.²⁵

i MORE INFORMATION

[Sodic soil management](#)

[Sodic soils a management labyrinth](#)

22 T Overheu (2017) Management of dispersive (sodic) soils experiencing waterlogging. DAFWA. <https://www.agric.wa.gov.au/water-erosion/management-dispersive-sodic-soils-experiencing-waterlogging>

23 NSW DPI (2009) Chapter D5. Sodic soil management. http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0009/127278/Sodic-soil-management.pdf

24 MT Grzesiak (2009) Impact of soil compaction on root architecture, leaf water status, gas exchange and growth of maize and triticale seedlings. Plant Root, 3, 10–16.

25 Soilquality.org (2016) Optimising soil nutrition, Queensland. Soilquality.org. <http://www.soilquality.org.au/factsheets/optimising-soil-nutrition-queensland>



Photo 6: A distinct compacted layer in a sandy loam. Note fractures in hard pan through which roots prefer to grow.

Source: Soilquality.org

IN FOCUS

The impact of soil moisture and soil compaction on the growth of triticale roots

The effects of different soil moisture (i.e. soil drought and waterlogging) and soil compaction (1.33 g/cm^{-3} and 1.50 g/cm^{-3}) on the growth and morphological traits of the root system were studied in four breeding forms and seven cultivars of triticale. Morphological changes, including the restriction of root extension, expansion and proliferation of laterals roots, occur in plants grown in different soil moisture and in compacted soil.

The results demonstrated a relatively broad variation in the habit of the triticale root system. Plants grown in compacted soil and in soil with low or high water content showed a smaller number and less dry matter of lateral branching than plants grown in control conditions. The harmful effects of compacted soil and drought conditions on the growth of roots was greater when compared with that of plants exposed to waterlogging. The observed effects of all treatments were more distinct in drought-sensitive strains. The drought-resistant forms were more characterised by extensive rooting and by smaller alterations in the root morphology under the stress conditions compared with drought-sensitive ones (Photo 7). Results confirm that the breeding forms with a high drought susceptibility (CHD-12 and CHD-173) were found to be also more sensitive to periodic soil-water excess. A more efficient water use and a lower shoot to root (S:R) ratio were found to be major reasons for the greater resistance to stress of the breeding forms CHD-220 and CHD-247. The reasons for the different response of the examined breeding forms and cultivars to drought or waterlogging may be a more economical water balance and more favourable relations between the shoot and root dimensions in the drought-resistant forms and cultivars.²⁶

²⁶ S Grzesiak, MT Grzesiak, W Filek, T Hura, J Stabryla (2002) The impact of different soil moisture and soil compaction on the growth of triticale root system. Acta Physiologiae Plantarum, 24 (3), 331–342.

SECTION 1 TRITICALE

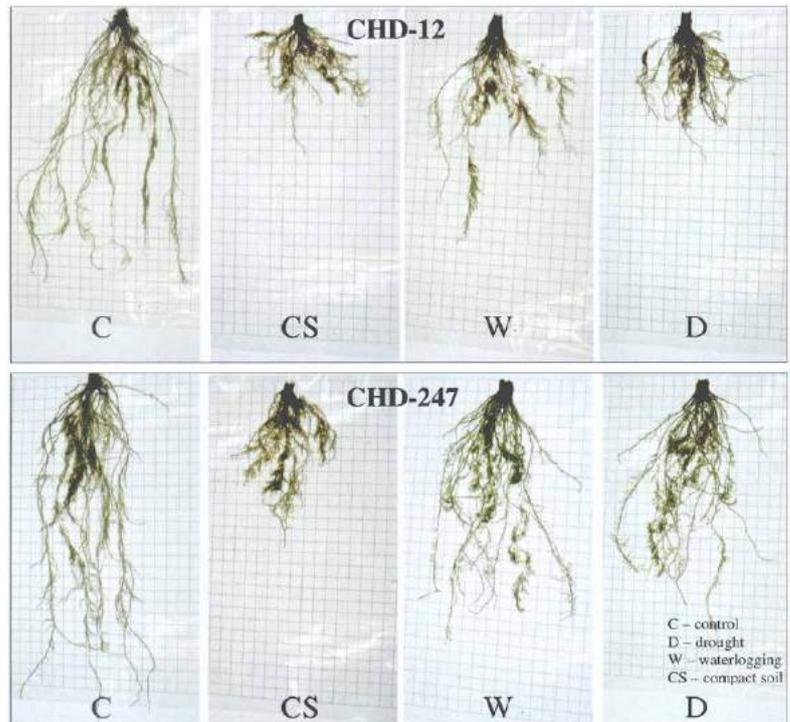
[TABLE OF CONTENTS](#)
[FEEDBACK](#)


Photo 7: Effects of compacted soil (CS), waterlogging (W) and soil drought (D) on root growth of drought-resistant (CHD-247) and drought-sensitive (CHD-12) triticale seedlings that are three weeks old.

Deep ripping to reduce soil compaction

Key points:

- Deep ripping of compacted soils is most likely to improve grain yields on sandy soils and where compaction has occurred on upper parts of the soil profile through machinery traffic or livestock trampling.
- Deep ripping is less effective on heavy clay soils unless combined with gypsum on sodic soils prone to waterlogging.
- Deep ripping will provide little benefit if other subsoil constraints such as salinity, sodicity or acidity are also present.
- Advances in machinery, such as 'slotting' and deep placement equipment to simultaneously introduce ameliorants at depth with ripping, could increase the financial and agronomic effectiveness of this approach to managing subsoil constraints.

Soil compaction can occur in many cropping soils and may be traffic or livestock induced or naturally occurring. By limiting the ability of crops to gain access to water and nutrients, soil compaction can reduce crop growth, grain yields and quality. Deep ripping involves disturbing the soil with strong, narrow tynes, below the normal cultivation layer, often up to 40 cm, without inverting the soil. By breaking up the soil, deep ripping can free the way for roots to penetrate the soil and access water and nutrients, leading to yield increases. However, it is only effective on certain soil types and is only likely to be financially viable when combined with strategies to ameliorate other subsoil constraints such as nutrient deficiency or toxicity, or sodicity.²⁷

MORE INFORMATION

[Deep ripping - Factsheet](#)

[Digging deep and controlling compaction](#)

27 GRDC (2009) Deep ripping—Factsheet. <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2009/06/grdc-fs-deepripping>

Solodic soils

Solodic soils are leached, formerly saline soils that usually occur in semi-arid tropical environments, in which the A horizon of the soil has become slightly acid, and the B horizon is enriched with sodium-saturated clay.

In one test conducted in the Windera area of the South Burnett because of poor crop growth, two soils (a prairie and a solodic) were screened in a nutrient experiment. Triticale (var. Currency) and barley (var. Grimmet) were grown in pots as test crops. The results showed that barley and triticale suffered severe nitrogen, sulfur and copper deficiencies when grown in the solodic soil. In the prairie soil, both crops were severely nitrogen-deficient, and the barley lacked copper. Soil tests identified sulfur levels as low, and copper and boron levels as low or very low. The plants did not appear to respond to added boron. The tolerance of a range of winter cereals to these nutrient deficiencies was ranked by the effect on grain yield when grown in unfertilised soil: in descending order triticale (var. Currency), oats (var. Minhafer), barley (var. Grimmet), and wheat (var. Hartog).²⁸

Subsoil constraints

Key points:

- Subsoil constraints are chemical, physical or biological properties of the subsoil that limit plant growth.
- Poor crop growth despite good starting moisture and adequate rainfall may indicate subsoil constraints.
- Good agronomic management helps minimise the water and other physiological stresses imposed by subsoil constraints.

Subsoil constraints are any soil physical or chemical characteristics located below the seedbed limiting the ability of crops or pastures to access water and nutrients. Subsoil constraints include salinity, sodicity, high soil strength and toxic concentrations of aluminium (Al) and boron (B) although a range of other factors, such as bicarbonate toxicity, nutrient deficiencies and water-logging have also been identified.

Managing subsoil constraints

Good agronomic management helps minimise the water and other physiological stresses imposed by subsoil constraints (Table 5).²⁹ In paddocks where subsoil constraints exist, successful cropping can be achieved by:

- Maximising fallow efficiency with short fallows.
- Controlling weeds effectively.
- Using suitable rotations that minimise disease.
- Matching nutrients to realistic yield expectations.
- Using appropriate species and cultivars.
- Sowing crops at the best time.
- having a thorough understanding of the extent of the problem—what levels? in the whole paddock or in zones that can be targeted?

28 JC Dwyer (1989) Glasshouse assessment of plant nutrient status of prairie and solodic soils from the South Burnett region. Project report. Department of Primary Industries, Queensland.

29 Soilquality.org (2017) Subsoil constraints, Queensland. Soilquality.org, <http://www.soilquality.org.au/factsheets/subsoil-constraints-queensland>

Table 5: Some management options for soils with high chloride and sodium concentrations.

Low constraints	Medium constraints	High constraints
<600 mg Cl/kg, <500 mg Na/kg in top 1 m of soil	600–1,200 mg Cl/kg, 500–1,000 mg Na/kg in top 1 m of soil	>1,200 mg Cl/kg, >1,000 mg Na/kg in top 1 m of soil
Manage crown rot and nematodes	Consider tolerant cultivars	Match inputs to realistic yield
Try opportunity cropping to use available water	Manage crown rot and nematodes	
	Avoid legumes and durum wheat	
	Try opportunity cropping to use available water	

Source: Soilquality.org

Soil testing

Key points:

- Soil testing is a guide that gives growers a snapshot of the nutrition of a soil type in paddock at a point in time.
- The approach taken will be defined by the purpose of the investigation, variability in the area sampled, and the analysis and accuracy required.
- Sampling depth will depend on if a grower is conducting a shallow or deep test. Shallow tests are usually conducted from 0–10 or 15 cm, whilst deep tests are to a depth of 60–90 cm, depending on testing equipment available
- Samples should be air dried or kept below 4°C prior to analysis. For biological measurements it is best to analyse as soon as possible.

Before deciding how to soil sample be clear about the purpose of sampling. Different sampling approaches may be required depending on what a grower is sampling for, the soil type, the management unit (e.g. paddock), soil spatial variability (e.g. changes in soil type), the accuracy of result required, and the value given to the information provided (Photo)³⁰ So before starting, define very clearly the questions that are being asked when planning to sample soil. Consult a professional soil scientist, agronomist or analytical laboratory to be sure that soil samples are taken at the right time, from the right depth, in the right place, and in the appropriate number, and are stored in such way that the analysis won't be compromised

30 Soilquality.org (2017) Soil sampling for soil quality, South Australia. Soilquality.org, <http://www.soilquality.org.au/factsheets/soil-sampling-for-soil-quality-south-australia>

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 8: To be meaningful, soil sampling needs to take into account spatial variation in the soil condition. Differences in soil type, nutrient status and other soil properties may be exhibited within a paddock.

Source: Soilquality.org

Sampling strategy

Soil properties and fertility often vary considerably, even over short distances, necessitating a sampling strategy which either integrates this variation through creating a composite sample (sampling across) or describes it through including replicate samples (sampling within). Describing the variation requires a defined sample within each different soil patch and having replicate samples analysed separately. This kind of approach might be required where there are consistent zones within a paddock such as under controlled-traffic systems, perennial row or tree crops, or raised-bed systems. More often, the variation within the field is integrated into a single sample by creating a composite. Examples of these are illustrated in Figure 3. Figure 3A shows a random sampling that integrates the variation across the field, but samples are strategically located so that the location of samples reflects the representation of the different soil types. The sampling type in Figure 3B uses a transect method to integrate the variation across the field, and in Figure 3C equal numbers of samples are taken from each zone and the area samples kept separate to obtain different soil analyses for each zone.

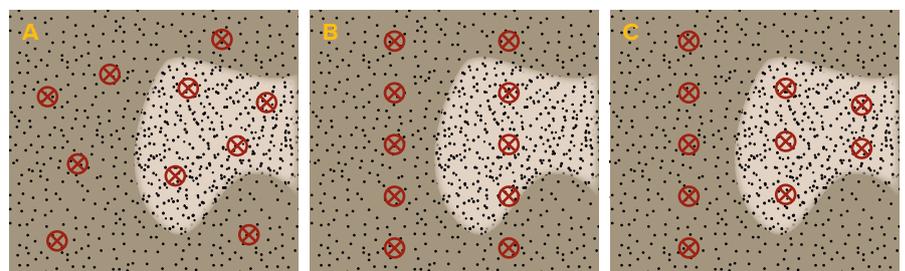


Figure 3: Sampling strategies used to create a composite sample that integrates variation across different soil types (A and B); and a strategy to describe variation by sampling zones and analysing samples separately (C). A: haphazard samples strategically located to approximate the relative representation of different soil types. B: samples taken along transects intersecting different soil types. C: equal numbers of samples from each zone.

Source: Soilquality.org

Sampling equipment

Manual sampling is often used where sampling is only required to a depth of 10–15 cm and bulk density is not required. Small pogo type samplers enable quick sampling for qualitative determinations such as nutrient concentrations or the presence of disease. To avoid contamination of the sample, ensure that sampling equipment is cleaned.

For deeper samples, mechanical (hydraulic) samplers are usually required for most soil types. If using these for soil carbon sampling be careful not to contaminate samples with lubricating oil.

Sampling depth

Sampling for soil fertility or biological activity is typically done to a depth of 10–15 cm as this is where most of the organic matter and nutrient cycling occurs.

However, for mobile nutrients such as nitrate, sulfur or potassium, deeper sampling may be required.

When assessing soil carbon for accounting or budgeting purposes, a sampling depth of 30 cm is required to conform with standard accounting procedures. When sampling below 10 cm, soil samples are usually stratified by depth increments (e.g. 10 cm, 20 cm, 30 cm), although this depends on the objectives. When characterising a soil for the first time, sampling corresponding to the different soil-layer depths (horizons) is often useful. Plant litter on the soil surface is not usually included in soil samples, while plant root material is usually included, although it is generally sieved out prior to analysis.

Sample handling

Samples can be stored in polythene bags and should generally be dried or kept cool prior to analysis. Air drying (<40°C) is usually sufficient and storage below 4°C usually arrests most biological activity. Dried samples can be broken up if clods are present, and any stones removed. If the amount of material collected is too great to manage and ship then it can be reduced in size by careful quartering, ensuring that there is no discrimination against particular particle sizes. Samples are typically put through a 2 mm sieve prior to analysis.³¹

1.1.3 Paddock selection for forage cereals

Selecting a paddock for forage cereal production will depend on how it will be used on the farm. If it is to provide additional grazing, choose a well-drained paddock that can resist pugging or compaction damage from livestock. A paddock that has higher fertility and is well drained should be chosen to provide maximum dry-matter production. Choose a paddock that is not too large i.e. that can be stocked at adequate rates to ensure a uniform-like grazing down of the crop. Ensure the paddock has good water or a number of watering points if the paddock is of a reasonable size.

It is best to select a paddock that has a low level of pasture grasses or was not planted to a cereal in the previous year to avoid the risk of cereal-disease transmission. Grasses can be hosts for such diseases as take-all, *Rhizoctonia* root rot, *Fusarium* blight, Crown rot and *Pythium* root rot. In traditional cereal-growing areas, pasture grasses can be removed from the paddock in the year prior to cereal establishment by using herbicides to ‘winter clean’ the pasture or by green manuring to prepare the seedbed. However, a summer forage crop (e.g. brassica, maize, sorghum, millet) will help to reduce grasses.³²

³¹ Soilquality.org (2017) Soil sampling for soil quality, South Australia. Soilquality.org, <http://www.soilquality.org.au/factsheets/soil-sampling-for-soil-quality-south-australia>

³² Agriculture Victoria (2008) Establishing forage cereals. Note AG1269. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/forage-cereals/establishing-forage-cereals>

1.1.4 Weed burden and herbicide history

A high weed burden will influence the likelihood of cropping success. The species present or likely to occur based on previous years should influence the choice of crop species and variety to ensure that effective in-crop control measures are available.

Strategic and integrated weed management over a rotation can greatly increase the likelihood of being able to control weeds across all crops. For example, a grower planting paddocks to wheat in the first year of a rotation should have a vigilant strategy for the control and prevention of seedset of key broadleaf weeds prior to a rotation to canola or legume crops.

The use of pre-emergent herbicides should be considered, as well as cultural control methods such as species choice and row width.

Part of the management of herbicide resistance includes the rotation of herbicide groups. Therefore, consider the history of herbicide use in each paddock. Herbicide residues (e.g. sulfonylurea, triazines) may be a problem in some paddocks. Remember that plant-back periods begin after significant rainfall occurs.

Employ non-herbicide weed control options, such as harvest weed seed management, as part of a weed strategy.

For more information, see [Section 6: Weed Control](#).

1.1.5 Fallow moisture and management

Paddocks that have been well managed during fallow periods significantly lower the risk of poor crop and financial performance. A growing crop has two sources of water: the water stored in the soil during the fallow, and rainfall while the crop is growing. Growers have some control over the stored soil water, so it should be measured before planting. Long-range forecasts and tools such as the Southern Oscillation Index (SOI) indicate the likelihood of the season being wet or dry, and are a useful adjunct in deciding what to plant. Timely weed control can reduce moisture and nutrition loss, prevent an increase in the seedbank, and decrease the risk of disease being carried over. Absence (or restriction) of grazing maintains soil friability and groundcover. Prolonged grazing periods may create crop emergence problems through induced surface compaction.³³

1.2 Paddock rotation and history

Paddock choice can determine the amount of disease, weed and nutrient pressure on the crop. Increasing interest in crop sequencing is providing more financial and agronomic data to help growers to choose crops and paddocks each year. Crop rotation is a key strategy for managing Australian farming systems, and improvements in legume and oilseed varieties and their management have facilitated this shift. Leading growers and advisers advocate sustainable crop sequences as a valuable strategy for farming systems. In many of Australia's grain-growing regions, broadleaf crop options have been seen as riskier and less profitable than cereals. This perception has been driven, in part, by fluctuating prices and input costs associated with the broadleaf crop in the year of production, and difficulties in marketing. However, when the profitability of the entire rotation is assessed, it is often more profitable to include broadleaf crops in the sequence.³⁴

1.2.1 Triticale as a rotation crop

Besides its use as a feed grain, triticale can be used as a forage crop for ruminants and as a cover crop for an undersown pasture.

³³ N Border, K Hertel, P Barker (2007) Paddock selection after drought. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/content/agriculture/emergency/drought/drought-publication-archive/paddock-selection-after-drought>

³⁴ GRDC (2011) Choosing rotation crops: short-term profits, long-term payback. Factsheet. GRDC, <http://www.grdc.com.au/~media/9219D55FFB4241DC9856D6B4C2D60569.pdf>

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

When added to a rotation, triticale may increase yields of other crops in the rotation, reduce costs, improve the distribution of labour and equipment use, provide better cash flow, and reduce weather risk. Additionally, the production of triticale may provide environmental benefits such as erosion control and improved nutrient cycling.³⁵

Triticale yields more than its wheat and rye ancestors in two types of marginal conditions: in soils where acidity and phosphorus deficiency and foliar diseases are dominant; and in the arid and semi-arid zones where drought affects crop production.³⁶

Traits observed that suggest higher yields in triticale than in wheat include greater early vigour, a longer phase of spike formation with same duration to flowering, reduced tillering, increased remobilisation of carbohydrates to the grain, early vigorous root growth, and higher transpiration-use efficiency.³⁷ Triticale can have some disadvantages too (Table 6).

Table 6: Advantages and disadvantages of triticale.

Advantages	Disadvantages
Triticale is a hardy, relatively low input cereal crop with good disease resistance, particularly to some rusts. It is as high a quality feed grain as wheat.	It is prone to shattering. There is a spot about a quarter to a third of the way down from the tip on the rachis that is very weak. ³⁹
It is a tall crop bred for strong straw strength which can be useful in rocky paddocks or circumstances where crops have been known to lodge.	Stripe rust may be a problem in triticale (although there are now options to treat seed to provide seedling protection against stripe rust).
Triticale is more durable than wheat when grazed; which means it will remain healthier, and stand up to weeds, diseases and cold weather better than wheat.	Triticale grain is softer than wheat and barley grain. Soft grain is more prone to attack from weevils and other grain-storage insects. ⁴⁰
Many growers use triticale as a disease break in their rotations and value the benefits of triticale for its contribution to soil conservation. It assists in maintaining soil health helping to reduce nematodes such as <i>Pratylenchus neglectus</i> and <i>P. thornei</i> (root lesion nematodes) and <i>Heterodera avenae</i> (cereal cyst nematode), and a number of fungi and bacteria in some varieties.	It can be difficult to find a market for triticale.
The extensive root system of triticale binds sandy soils, and the fibrous stubble reduces wind and water erosion. ³⁸	Triticale seed will carry-over into the following crop more than other cereals. It is more noticeable as a volunteer
	Triticale stubbles are slower to break down than other cereal stubbles. This can be problematic in tight rotations or in areas where burning stubbles is an issue. Soil nitrogen tie-up is often longer in triticale stubbles as well.

35 LR Gibson, C Nance, DL Karlen (2005) Nitrogen management of winter triticale. Iowa University, <http://farms.ag.iastate.edu/sites/default/files/NitrogenManagement.pdf>

36 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

37 S Bassu, S Asseng, F Giunta, R Motzo (2013) Optimizing triticale sowing densities across the Mediterranean Basin. Field Crops Research, 144, 167–178.

38 KV Cooper, RS Jessop, NL Darvey (2004) Triticale in Australia. In M Mergoum, H Gómez-Macpherson (eds), Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

39 N Herdrich, Triticale for eastern Washington dryland area. Alternative crops. Washington State University, <http://pnw-ag.wsu.edu/AqHorizons/crops/csr2no1.htm>

40 Agriculture Victoria (2012) Growing triticale. Note AG0497. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>

SECTION 1 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

VIDEOS

WATCH: [The importance of crop rotation](#)



Benefits of cereals as a rotation crop

Cereals present the opportunity to utilise residual N effectively. They also offer good options for broadleaf control, and also do not host many pulse crop and oilseed diseases. A major benefit of winter cereal crops is the high levels of groundcover they provide, helping the grower manage soil loss in following fallows and some subsequent pulse crops.

Disadvantages of cereals as a rotation crop

Growing cereals in continuous production is no longer a common practice because of the rising incidence of:

- Difficult-to-control and herbicide-resistant weeds, particularly grass weeds.
- Disease build-up, e.g. crown rot, yellow (tan) spot, nematodes.
- Nitrogen (N) depletion and declining soil fertility.

1.2.2 Long-fallow disorder

Soils naturally contain beneficial fungi that help the crop to access nutrients such as phosphorus (P) and zinc (Zn). The combination of the fungus and crop root is known as arbuscular mycorrhizae (AM). Many species of fungi have this association with the roots of crops. Many that are associated with crops also form structures called vesicles in the roots. The severe reduction or lack of AM shows up as long-fallow disorder: the failure of crops to thrive despite adequate moisture.

Ongoing drought in the 1990s and beyond has highlighted long-fallow disorder, where AM died out because there were too few or no host-plant roots because of long fallow periods. As cropping programs restart after dry years, an unexpected yield drop is likely because levels of AM have dropped, making it difficult for the crop to access nutrients and resulting in poor crop growth.⁴¹ Plants seem to remain in their seedling stages for weeks and development is very slow.

The benefits of good AM levels are:

- improved uptake of P and Zn
- improved crop growth
- improved N₂ fixation
- greater drought tolerance
- improved soil structure
- greater disease tolerance

In general, the benefits of AM are greater at lower soil P levels, because AM increase a plant's ability to access this nutrient. Crops with higher dependency benefit more from AM (Table 7).⁴²

⁴¹ DAF Qld (2010) Nutrition: VAM and long fallow disorder. Department of Agriculture and Fisheries Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/nutrition-vam>

⁴² DAF Qld (2010) Nutrition: VAM and long fallow disorder. Department of Agriculture and Fisheries Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/nutrition-vam>

Table 7: The dependency of various crop species on mycorrhizae, with values decreasing as the phosphorus level in the soil increases.

Mycorrhiza dependency	Potential yield loss without mycorrhiza (%)	Crop
Very high	Greater than 90	Linseed
High	60–80	Sunflower, mungbeans, pigeon peas, maize, chickpeas
Medium	40–60	Sudan, sorghum, soybeans
Low	10–30	Wheat, barley, triticale
Very low	0–10	Panicum, canary
Nil	0	Canola, lupins

Source: DAF Qld

1.3 Fallow weed control

Paddocks with well-managed fallow periods significantly lower the risk of poor crop and financial performance. The best form of weed control is rotation and the careful selection of paddocks largely free of winter weeds, e.g. double-cropped from sorghum or cotton, or areas with a sequence of clean winter fallows.

When sowing dual-purpose varieties early, choose a paddock with low weed numbers and control weeds (Photo 9)⁴³ before the first grazing. Strategic grazing can be used to help manage weeds.⁴⁴



Photo 9: Spraying is part of managing fallow before sowing a dual-purpose triticale.

Photo: Bill Gordon

Paddocks generally have multiple weed species present at the same time, making weed control decisions more difficult and often involving a compromise after assessment of the prevalence of key weed species. Knowing the paddock

⁴³ B Gordon (2013) Review speed and boom height to improve spray deposition. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS105/Review-speed-and-boom-height-to-improve-spray-deposition>

⁴⁴ Waratah Seed Co. (2010) Triticale: planting guide. Waratah Seed Co., http://www.porkcra.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [IWM: Double knock applications—extent of herbicide resistance in the north](#)



and controlling weeds as early as possible are important for good control of fallow weeds.⁴⁵

For advice on individual paddocks, contact a local agronomist.

The benefits of fallow weed control are significant, and include:

- Conservation of summer rain and fallow moisture, including moisture stored from last winter or the summer before in a long fallow, is integral to winter cropping, and particularly so as the climate moves towards summer-dominant rainfall.
- The highest return on investment in summer weed control (according to modelling studies) is for lighter soils or in situations where there is soil water that would support continued weed growth.⁴⁶

The Northern Grower Alliance explored methods to control summer grasses. Key findings include:

- Glyphosate-resistant and tolerant weeds are a major threat to reduced-tillage cropping systems.
- Although residual herbicides will limit re-cropping options and do not provide complete control, they are a key part of successful fallow management.
- Double-knock herbicide strategies (i.e. the sequential application of two different weed controls) are useful but the herbicide choices and optimal timings vary with weed species so care must be taken if double-knock is to be successful.
- Other weed management tactics, e.g. crop competition, can be incorporated to assist herbicide control.
- Cultivation may need to be considered as a salvage option to avoid seedbank salvage.⁴⁷

1.3.1 The green bridge

The green bridge provides a between-season host for insects and diseases (particularly rusts), which pose a threat to subsequent crops and can be expensive to control later in the season (Photo 10)⁴⁸.



Photo 10: *Broad-leaved weeds and grasses form a green bridge in a paddock.*

Source: DAFWA

45 S Peltzer (n.d.) Does long fallow have a place in Western Australia's cropping belt? Yes according to Daniel and Tim Critch of Mullewa. Agronomo, <https://static1.squarespace.com/static/588df4351b10e309aeea0904/t/5a27787d24a6949cbc4b4320/1512536205147/12-Autumn-2015.pdf>

46 GRDC (2012) Summer fallow: make summer weed control a priority. Factsheet. GRDC.

47 R Daniel (2014) Weeds and resistance considerations for awnless barnyard grass, chloris and fleabane. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Weeds-and-resistance-considerations-for-awnless-barnyard-grass-chloris-and-fleabane>

48 DAFWA (2016) Control of green bridge for pest and disease management. DAFWA, <https://www.agric.wa.gov.au/grains/control-green-bridge-pest-and-disease-management>

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [GCTV5: Managing summer fallow](#)



MORE INFORMATION

GRDC factsheet, [The essential crop management tool: green bridge control is integral to pest and disease management](#)

Key points for controlling the green bridge:

- An outright kill of the weeds and volunteers is the only certain way to stop them from hosting diseases and insects.
- Diseases (e.g. stripe rust) and insects (e.g. Russian wheat aphid) can bred up and spread from the green bridge, jeopardising crops and current control methods, including the effectiveness of chemicals and genetic breeding for resistance.
- Effective control of pest and disease risks requires neighbours to work together to eradicate weeds and crop volunteers simultaneously.
- Weed growth during summer and autumn depletes soil moisture and nutrients that would otherwise be available to following crops and can have an allelopathic effect.⁴⁹

1.3.2 Management strategies

How farming country is managed in the months or years before sowing can be more important in lifting water-use efficiency (WUE) than in-crop management is. Of particularly high impact are strategies that increase soil capture and storage of fallow rainfall to improve crop reliability and yield.

Practices such as controlled-traffic farming and long term no-till seek to change soil structure to improve infiltration rates and thereby increase plants' access to stored water. This occurs when compaction zones are removed.

Shorter-term management decisions can have an equal or even greater impact on how much plant-available water (PAW) is stored at sowing. These include decisions such as crop sequence and rotation that dictate the length of the fallow and amount of stubble cover, how effectively fallow weeds are managed, stubble management, and decisions about whether to till at critical times.

Although many factors influence how much PAW is stored in a fallow period, good weed management consistently has the greatest impact.⁵⁰

1.3.3 Stubble retention

Key points:

- Triticale stubble is coarser than either wheat or barley stubble.⁵¹
- Retaining stubble has several advantages for soil fertility and productivity.
- Retaining stubble can decrease erosion, increase water infiltration rates and decrease evaporation rates
- The benefits of stubble retention are enhanced by reduced tillage and leguminous crop rotations.

Stubble retention has several advantages for soil fertility and productivity (Photo 11).

49 GRDC (2009) The essential crop management tool: green bridge control is integral to pest and disease management. Factsheet, GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2010/01/grdc-fs-greenbridge>

50 GRDC (2014) Summer fallow weed management. GRDC, <https://grdc.com.au/Resources/Publications/2014/05/Summer-fallow-weed-management>

51 Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, <http://www.farmtrials.com.au/trial/13801>



Photo 11: *Triticale sown into stubble.*

Source: T Kaspar in MCCC

Summer rainfall and warmer conditions promote the decomposition of stubble.

Reducing erosion risk

One of the main benefits of stubble retention is reduced soil erosion (Figure 4).⁵² Retaining stubble decreases erosion by lowering wind speed at the soil surface and by decreasing run-off. At least 50% ground cover is required to reduce erosion; this is generally considered to be achieved by 1 t/ha of cereal stubble, 2 t/ha of lupin stubble or 3 t/ha of canola stubble. A study at Wagga Wagga, NSW, demonstrated that stubble retention reduced soil losses by almost two-thirds compared to burnt paddocks. It also increased infiltration of rainfall.

In order to protect the soil from erosion, crops need to be managed so that at least 30–40% groundcover is maintained throughout the year, but especially during the summer months when there is a greater chance of high-intensity rainfall. The amount of cover produced by crops will vary according to seasonal conditions and crop variety. However, as a general rule of thumb, a 1.5 t/ha grain yield should typically provide 90% stubble cover. The amount of cover may decrease over the fallow period, depending on whether the site is subsequently burnt, grazed or cultivated.

⁵² Soilquality.org (2017) Benefits of retaining stubble, Queensland. Soilquality.org, <http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-in-qld>

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

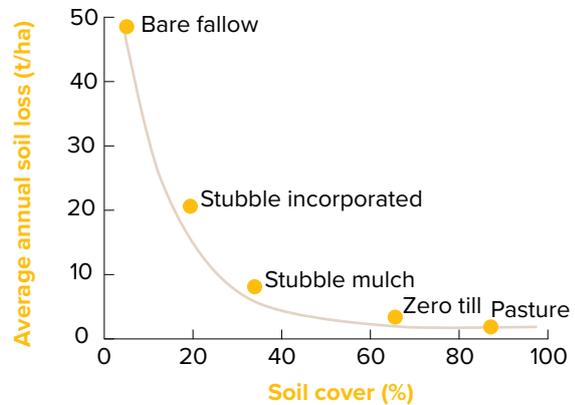


Figure 4: Soil loss observed depending on the percentage of surface cover from sites on the eastern Darling Downs.

Source: Soilquality.org

Increasing soil water content

A major advantage of retaining stubble is that it increases soil-water content by decreasing run-off and increasing infiltration (Figure 5).⁵³ The actual benefits realised depend on the timing and intensity of rainfall as well as the quantity and orientation of the stubble. Late summer–early autumn rains have more chance of improving the germination and establishment of the next crop. In addition, increased infiltration of water over summer can result in greater nitrogen mineralisation and availability for the subsequent crop.

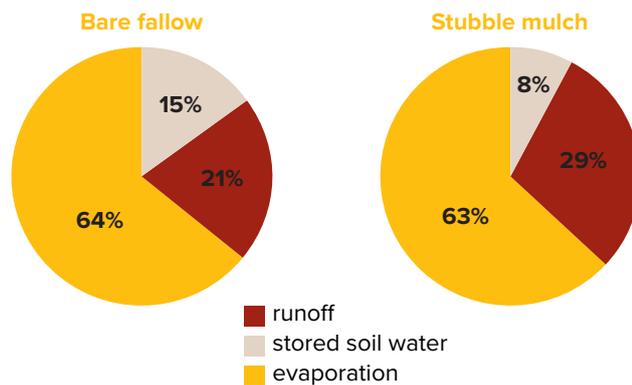


Figure 5: When stubble is retained, more water is stored in the soil, mostly because there is less run-off.

Source: Soilquality.org

Increasing soil carbon

Retaining stubble increases the input of carbon to soil. Stubble is approximately 45% carbon by weight and represents a significant input of carbon to soil. However, it can take decades for the practice of retaining stubble to increase the amount of soil organic carbon. In cropping trials with ley pasture rotations at Wagga Wagga,

i MORE INFORMATION

[Developments in stubble retention in cropping systems in southern Australia](#)

⁵³ J Carson, K Flower, S Nuir, A Jenkins, S Alt (2013) Benefits of retaining stubble, NSW. Soilquality.org, <http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw>

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

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WATCH: [GCTV15: Stubble height—part 1 and part 2](#)



WATCH: [Southern farm groups cutting through stubble issues](#)

GRDC Northern 'stubble initiative' workshop

researchers showed that after 10 years, stubble retention generated 2 t/ha more soil organic carbon than burnt-stubble plots to a depth of 10 cm in a red chromosol. After 25 years the inclusion of a clover pasture in the rotation in the same trial had a greater effect on soil organic carbon increases, even with tillage, compared to stubble retention. Retaining stubble may only increase soil carbon where it is coupled with cultivation, but not with direct drilling.

The carbon to nitrogen ratio (C:N) of residues is an important factor in determining the contribution they will make to carbon sequestration, as the ratio governs how quickly residues decompose. Pulse residues (C:N 20:1 to 41:1) decompose faster than wheat residues (C:N 45:1 to 178:1). Faster decomposition may improve nutrient availability for the following crop, but reduce the sequestration of carbon from residues into soil.

Other benefits of stubble retention

Retaining stubble returns nutrients to the soil, the amounts depend on the quality and quantity of stubble, in particular nitrogen and sulfur. The addition of organic matter with retained stubbles supports soil life, and can improve soil structure, infiltration and water-holding capacity. These benefits are greater when integrated with no-till practices.⁵⁴

Management practices affecting stubble cover

Stubble burning, grazing and cultivation are the main management practices that reduce stubble cover. A single-tillage operation using a chisel plough, for example, can reduce stubble coverage by 30–40 % (Table 8)⁵⁵. It is recommended that stubble cover be maintained as long as possible in the fallow, and that planting and fertilising machinery be adapted to minimise disturbance. Where cultivation is required in order to control herbicide resistant weeds, this should be carried out as a one-off operation.⁵⁶

Table 8: *Estimated reduction in wheat or barley stubble cover from different tillage operations.*

Implement	Residue buried by each tillage operation (%)	
	Fresh stubble	Old (brittle) stubble
Disc plough	60–80	80–90
Chisel plough	30–40	40–60
Blade plough	20–30	30–50
Boomspray	Negligible	Negligible

Source: DEEDI

1.4 Fallow chemical plant-back effects

Plant-back periods are the obligatory times between the herbicide spraying date and safe planting date of the next crop.

Some herbicides have a long residual, this will differ between different soil types. The residual is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original amount, what remains can persist for long periods (e.g. sulfonylureas such as chlorsulfuron). This is shown in the Table 9 where known.⁵⁷ Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, as the sulfonylureas

⁵⁴ Soilquality.org. Benefits of retaining stubble, NSW. Soilquality.org, <http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw>

⁵⁵ DEEDI (2011) Measuring and managing stubble cover: photostandards for cereals. Department of Employment, Economic Development and Innovation, https://www.grainsbmp.com.au/images/documents/Stubble_cover_final.pdf

⁵⁶ Soilquality.org. Benefits of retaining stubble, Queensland. Soilquality.org, <http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-in-qld>

⁵⁷ B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW DPI, http://www.dpi.nsw.gov.au/_data/assets/file_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

SECTION 1 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

VIDEOS

WATCH: [Over the Fence south: Jim Cronin](#)



WATCH: [Stubble and soil binding of pre-emergent herbicides for annual ryegrass control in winter crops](#)



are. Labels display the plant-back periods, which are usually listed under a separate plant-back heading or under a heading such as 'Protection of crops' in the general instructions section.⁵⁸

Part of the management of herbicide resistance includes rotating herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonyl urea, triazines) may be a problem in some paddocks. Remember that plant-back periods begin after rainfall occurs.⁵⁹

Table 9: Residual persistence of common pre-emergent herbicides.

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Logran® (triasulfuron)	19	High. Persists longer in high pH soils. Weed control commonly drops off within 6 weeks.
Glean® (chlorsulfuron)	28–42	High. Persists longer in high pH soils. Weed control longer than Logran.
Diuron	90 (range 1 month to 1 year, depending on rate)	High. Weed control will drop off within 6 weeks, depending on rate. Has been observed to have long-lasting activity on grass weeds such as black grass or stink grass (<i>Eragrostis</i> spp.) and to a lesser extent broadleaf weeds such as fleabane.
Atrazine	60–100, up to 1 year if dry	High. Has been observed to have long-lasting (>3 months) activity on broadleaf weeds such as fleabane.
Simazine	60 (range 28–149)	Med–high. In high pH soils, 1 year. Has been observed to have long-lasting (>3 months) activity on broadleaf weeds such as fleabane.
Terbyne® (terbuthylazine)	6.5–139	High. Has been observed to have long-lasting (>6 months) activity on broadleaf weeds such as fleabane and sow thistle.
Triflur® X (trifluralin)	57–126	High. With lower rate, 6–8 months; higher rates longer. Has been observed to have long-lasting activity on grass weeds such as black or stink grass (<i>Eragrostis</i> spp.)
Stomp® (pendimethalin)	40	Medium, 3–4 months
Avadex® Xtra (triallate)	56–77	Medium, 3–4 months
Balance® (isoxaflutole)	1.3 (metabolite 11.5)	High. Reactivates after each rainfall. Has been observed to have long-lasting (>6 months) activity on broadleaf weeds such as fleabane and sow thistle.
Boxer Gold® (profluroxifen)	12–49	Medium. Typically quicker to break down than trifluralin, but tends to reactivate after each rainfall.
Sakura® (pyroxasulfone)	10–35	High. Typically quicker breakdown than trifluralin and Boxer Gold; however, weed control persists longer than Boxer Gold.

Note that residual persistence is from broad-acre trials and paddock experiences.

Source: NSW DPI

58 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW DPI, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

59 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW DPI, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

1.4.1 Conditions required for breakdown

Most of the herbicide residues will be found in the topsoil. Warm, moist soils are required to break down most herbicides through the processes of microbial activity. For the soil microbes to be most active they need good moisture and a soil temperature range of 18–30°C. Temperatures above or below this range can adversely affect soil microbial activity, and slow herbicide breakdown. Soil type and pH also have an influence on the rate at which chemicals degrade. Very dry soil also reduces the rate of breakdown. To make matters worse, when the soil profile is very dry, a lot of rain is required to rebuild then maintain topsoil moisture for the microbes to be active for any length of time.

In those areas that do not experience conditions which will allow breakdown of residues until just prior to sowing, it is best to avoid planting a crop that is sensitive to the residues potentially present in the paddock, and opt for a crop that will not be affected.

If dry areas do get rain and the temperatures become milder, then they are likely to need substantial rain (more than is stated on the label requirement) to wet the subsoil, in order for the topsoil to remain moist for a week or more and allow the microbes to be active in the topsoil.⁶⁰

Plant-back periods for fallowing herbicides

Herbicide plant-back restrictions should be taken into account when spraying fallow weeds prior to sowing winter crops (Table 10). Many herbicide labels place time and/or rainfall restrictions on sowing certain crops and pastures after application, so as to avoid potential seedling damage. Crops such as canola, pulses and legume pastures are the most sensitive to herbicide residues, but cereal crops can also be affected.

When treating fallow weeds, especially in late summer or autumn, consideration must be given to the planned crop or pasture for the coming year. In some cases, next year's crop or pasture may influence the grower's herbicide choice this season.

The following points are especially relevant:

- Phenoxy herbicides such as 2,4D Ester, 2,4D Amine and Dicamba, require 15 mm of rainfall to commence the plant-back period when applied to dry soil.
- Group B herbicides such as Ally®, Logran® and Glean®, break down more slowly as soil pH increases. Recently applied lime can increase the soil surface pH to a point where the plant-back period is significantly extended.
- Lontrel®, Grazon® and Tordon® products break down very slowly under cold or dry conditions, and this can significantly extend the plant-back period.

Keeping accurate records of all herbicide treatments and planning crop sequences well in advance can reduce the chance of crop damage resulting from the presence of herbicide residues.⁶¹

60 Dow AgroSciences. Rotational crop plant-back intervals for southern Australia. Dow AgroSciences, http://msdssearch.dow.com/PublishedLiteratureDAS/dh_0931/0901b80380931d5a.pdf?filepath=au&fromPage=GetDoc

61 RMS Agricultural Consultants (2016) Plant-back periods for fallow herbicides in southern NSW. RMS, <http://www.rmsag.com.au/2016/plant-back-periods-for-fallow-herbicides-in-southern-nsw/>

SECTION 1 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 10: Indicative plant-back intervals for a selection of relevant herbicides. Recommendations for wheat can generally be applied to triticale, however for sure to check product labels and instructions.

Product	Rate	Plant-back period	Wheat	Barley	Oats	Canola	Legume pasture	Pulse crops
2–4-D Ester 680*	0–510 mL/ha	(days)	1	1	1	14	7	7
	510–1,150 mL/ha		3	3	3	21	7	14
	1,150–1,590 mL/ha		7	7	7	28	10	21
Amicide Advance*	0–500 mL/ha	Days	1	1	1	14	7	7
	500–980 mL/ha		3	3	3	21	7	14
	980–1,500 mL/ha		7	7	7	28	10	21
Kamba 500*	200 mL/ha	Days	1	1	1	7	7	7
	280 mL/ha		7	7	7	10	14	14
	560 mL/ha		14	14	14	14	21	21
Hammer 400 EC								No residual effects
Nail 240 EC								No residual effects
Goal								No residual effects
Striker								No residual effects
Sharpen	26 g/ha	Weeks	-	-	-	16	-	-
Lontrel	300 mL/ha	Weeks	1	1	1	1	36	36
Garlon 600		Weeks	1	1	NS	NS	NS	NS
Ally**		Weeks	2	6	36	36	36	36
Logran #		Months	-	-	-	12	12	12
Glean**		Months	-	9	6	12	12	12
Grazon Extra, Grazon DS		Months	9	9	NS	9	24	24
Tordon 75D, Tordon 242		Months	2	2	NS	4	9	6
Tordon Fallow Boss		Months	9	9	NS	12	20	20

* 15 mm rainfall required to commence plant-back period ** Period may extend where soil pH is greater than 7 # Assumes 300 mm rainfall between chemical application and sowing NS Not specified

Source: RMS

1.4.2 Herbicide residues in soil: an Australia-wide study

The move to conservation tillage and herbicide-tolerant crop cultivars means that, more than ever before, many farmers rely on herbicides for weed control. Despite the provision of plant-back guidelines on herbicide product labels, site-specific factors such as low rainfall, constrained soil microbial activity and unfavourable pH may cause herbicides to persist in the soil beyond usual expectations. Because of the high cost of herbicide residue analysis, information about herbicide residue levels in Australian grain cropping soils is scarce.

In addition, little is known about how herbicides affect soil biological processes and what this means for crop production. This is especially the case for repeated applications over multiple cropping seasons. In Australia, herbicides undergo a rigorous assessment by the Australian Pesticides and Veterinary Medicines Association (APVMA) before they can be registered for use in agriculture. However,

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

relatively little attention is given to the soil biology on the farm—partly because we are only now beginning to grasp its complexity and importance to sustainable agriculture. Although a few tests such as earthworm toxicity tests and effects on soil respiration are mandatory functional services provided by soil organisms such as organic matter turnover, nitrogen cycling, phosphorus solubilisation and disease suppression are usually overlooked.

GRDC has co-funded a five-year project (DAN00180) to better understand the impact of greater herbicide use on the most important soil biological processes; the project will conclude in 2018. The national project, coordinated by the NSW Department of Primary Industries, and with partners in Western Australia, South Australia, Victoria and Queensland, is focussed on the effect of at least six classes of herbicides on the biology and function of five key soil types across all three grain-growing regions.⁶²

There are already some results from the project. A field survey of herbicide residues in 40 cropping soils (13 in NSW and Qld, 15 in SA, 12 in WA) prior to sowing and pre-emergent herbicide application was conducted in 2015 (Table 11). The researchers are most interested in the effects of the herbicides that were most frequently detected. Recommendations are given to minimise potential impacts of herbicide residues on productivity and soil sustainability. We also provide detail plans for future research and the development of management tools for growers to monitor and predict herbicide persistence in soils.

The average and maximum estimated loads of glyphosate, trifluralin, diflufenican and diuron were all substantially higher in paddocks in WA compared with those in SA, NSW and Queensland. This probably reflects the lighter soil types, lower level of organic matter, dry summers and cool winters, which contribute to lower microbial activity and constrain herbicide breakdown. The higher load of atrazine in SA paddocks is probably a consequence of the higher persistence of s-triazine herbicides in alkaline soils; and the higher values for 2,4-D in the NSW–Queensland soil profiles was due to a high value in a single paddock which had recently been sprayed.

Notably, in a number of paddocks (especially in WA but also in other states), they found a higher load of glyphosate than was applied in the previous spray, demonstrating a degree of accumulation of glyphosate and its metabolite AMPA over time.

62 GRDC (n.d.) DAN00180: Does increased herbicide use impact on key biological processes?, GRDC, http://projects.grdc.com.au/projects.php?action=view_project&project_id=2416

Table 11: Residue loads (average and maximum) of herbicide active ingredients (a.i.) in the 0–30 cm soil profile of paddocks, by region.

Herbicide	Estimated average load across all sites (kg a.i./ha)*			Estimated maximum load detected (kg a.i./ha)*		
	NSW–Qld	SA	WA	NSW–Qld	SA	WA
AMPA	0.91	0.95	0.92	1.92	1.97	2.21
Glyphosate	0.56	0.48	0.79	2.05	1.05	1.75
Trifluralin	0.08	0.11	0.53	0.14	0.26	1.34
Diflufenican	0.01	0.03	0.04	0.02	0.05	0.09
Diuron	0.14	0.05	0.17	0.16	0.05	0.29
2, 4-D	0.20	0.02	0.01	1.00	0.05	0.02
MCPA	0	0	0	0	0	0
Atrazine	0.02	0.03	0.02	0.03	0.05	0.02
Simazine	0	0.04	0	0	0.05	0
Fluroxypyr	0.03	0	0	0.03	0	0
Dicamba	0	0	0	0	0	0
Triclopyr	0	0.04	0.01	0	0.07	0.01
Chlorsulfuron	0	0	0	0	0	0
Sulfometuron-methyl	0	0	0	0	0	0
Metsulfuron-methyl	0	0	0	0	0	0
Triasulfuron	0	0	0	0	0	0

* Calculated by multiplying mass concentration (mg/kg) detected by area and average bulk density (derived from Soilquality.org) for each soil layer

Source: GRDC

Conclusions

From this survey, the researchers have concluded that:

- Glyphosate, trifluralin and diflufenican are routinely applied in grain-cropping systems and their residues, plus the glyphosate metabolite AMPA, are frequently detected at significant levels at the commencement of the winter cropping season.
- The risk to soil biological processes is generally minor when herbicides are used at label rates and given sufficient time to dissipate before re-application.
- However, given the frequency of glyphosate application, and the persistence of trifluralin and diflufenican, further research is needed to define critical thresholds for these chemicals so that growers can avoid damaging soil function and crop production.⁶³

For more information on herbicide residues, see [Section 6: Weed control](#).

MORE INFORMATION

[Herbicide residues in soils: are they an issue?](#)

[Weed control in winter crops](#)

63 M Rose, L Van Zwieten, P Zhang, D Nguyen, C Scanlan, T Rose, G McGrath, T Vancov, T Cavagnaro, N Seymour, S Kimber, A Jenkins, A Claassens, I Kennedy (2016). Herbicide residues in soils: are they an issue? GRDC Update Paper. GRDC, <https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/herbicide-residues-in-soils-are-they-an-issue-northern>

1.5 Seedbed requirements

Seedbed preparation for triticale is very similar to that for wheat. As with all cereals, triticale should be planted into a firm seedbed onto moisture.⁶⁴ A good seedbed should be weed, disease and insect free. To minimize weeds, ensure a knockdown spray prior to sowing is implemented. Planting early will help with the quick establishment of a triticale stand, and may stave off early weed pressure.⁶⁵

When shallow sowing, the previous crop's residue will have a greater tendency to interfere with good seed-to-soil contact. Make sure good seed-to-soil contact occurs.

Ploughing buries plant residues so that they do not obstruct sowing. However, ploughing disrupts the soil structure and increases oxidation of the organic material. Without ploughing, the organic material and the soil structure are retained, but the straw can cause problems with sowing and can also transmit diseases, which can also occur if the material is ploughed in.⁶⁶

Cereals can be conventionally sown or direct drilled into a weed-free seedbed from March to mid-June.

Pre-irrigation is favoured over irrigating after sowing, as seeds can swell and burst. Sowing after pre-irrigation should be done as soon as the soil conditions allow. For a 1 April pre-irrigation, this delay may range from one week on light soils to 3–4 weeks on some heavy clay soils.

Following the initial irrigation, subsequent irrigations should be at a cumulative evaporation, less the rainfall interval of 75 mm on grey soils and 50 mm on red soils.⁶⁷

1.5.1 Tillage

Tilling mixes and buries soil amendments and crop residues, eliminates existing vegetation, reduces pest populations, promotes mineralisation of soil organic matter, and creates a seedbed that facilitates mechanical planting and seed-to-soil contact.

The use of minimum soil disturbance has advantages for the production of triticale.⁶⁸

Research shows that one-time tillage with a chisel or offset disc in long-term, no-tillage system helped to control winter weeds, and slightly improved grain yields and profitability, while retaining many of the soil quality benefits of no-till farming systems (Photo 12).⁶⁹ Although tillage reduced soil moisture at most sites, this did not adversely affect productivity. This could be due to good rainfall received after tilling and before seeding that year. The occurrence of rain between tilling and sowing or immediately after sowing is necessary to replenish soil water lost from the seed zone. This suggests the importance of the timing of tillage and of considering the seasonal forecast. Note that these results are from one season (2012), and so are inconclusive. As research continues, and captures the effects of variances in seasonal conditions, more conclusive results will emerge.

64 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

65 UVM Extension Crops and Soils Team (2011) Triticale. University of Vermont, <http://northerngraingrowers.org/wp-content/uploads/TRITICALE.pdf>

66 Vaderstad (2015) Seedbed preparation. Vaderstad, <http://www.vaderstad.com/knowhow/seed-beds/seedbed-creation>

67 Agriculture Victoria (2015) Managing winter cereals. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/irrigated-pastures/managing-winter-cereals>

68 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

69 GRDC (2014) Strategic tillage. Factsheet. GRDC, <https://grdc.com.au/Resources/Factsheets/2014/07/Strategic-tillage>

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [GCTV11: Strategic tillage— does no-till mean never till?](#)



WATCH: [Over the Fence south: Andrew Simpson](#)



Photo 12: Strategic tillage can control herbicide-resistant weeds and those that continue to shed seed throughout the year. Here it has been used for control of barnyard grass in fallow.

Source: GRDC

On the downside, tillage can also result in more soil erosion and surface-water eutrophication.⁷⁰

1.6 Soil moisture

Triticale performs well under rain-fed conditions throughout the world and excels when produced where there is good soil fertility and irrigation.⁷¹ It is grown in areas with an annual average rainfall of about 300 mm to at least 900 mm. Very little triticale is irrigated.⁷²

1.6.1 Dryland

Water availability is a key limiting factor for cereal production in the grainbelt of Australia. Varieties with improved adaptation to water-limited conditions are actively sought, and studies have been carried out to identify the physiological basis of the adaptive traits underpinning this advantage.

Technologies to support decision-making

In this context, several technologies provide a level of information that is useful in supporting decisions about paddock and crop management without excessive investment.

Devices for soil monitoring

In-situ devices that have relatively small zones of measurement and rely on good contact between their sensor and the soil to measure soil water are at a disadvantage in shrink–swell soils where soil movement and cracking are typical. This is more important in dryland than in irrigated systems, as seasonal soil water levels vary from above the capacity of the paddock to wilting point or even lower. This means that high levels of error are likely, although this can be mitigated by using more devices to increase the number of measurements made so as to achieve confidence in results.

MORE INFORMATION

[GRDC, Strategic tillage in no-till systems](#)

[Organic carbon](#)

[Microbial biomass](#)

[Rhizoctonia](#)

⁷⁰ MR Ryan, SB Mirsky, DA Mortensen, JR Teasdale, WS Curran (2011) Potential synergistic effects of cereal rye biomass and soybean planting density on weed suppression. *Weed science*, 59 (2), 238–246.

⁷¹ M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

⁷² KV Cooper, RS Jessop, NL Darvey (2004) Triticale in Australia. In M Mergoum, H Gómez-Macpherson (eds), Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

However, this comes at an increased capital cost. Some devices (e.g. capacitance, and time domain reflectometry) also have an upper measurement limit, beyond which they are inaccurate. This may be a problem on high-clay soils where moisture content at drained upper limit is likely to be >50% volumetric, the common limit for these devices.

By comparison, the use of a portable electromagnetic induction (EMI) device to measure bulk electrical conductivity and calculate soil water has a number of advantages. The EMI is quick to use, allowing for greater replication, it measures the soil moisture of a large volume of soil (to 150 cm depth), is not affected by cracking or soil movement, and does not require installation of an access tube, thus making it available for use on multiple paddocks. However, it is unsuitable for use in saline soils and does not apportion soil water to particular layers within the soil profile.⁷³

Despite the extensive range of monitoring instruments now available, measuring paddock soil moisture is still a considerable challenge. Among the suite of instruments on offer, one that is increasingly being used by researchers and agronomists is the EM38, an EMI tool. It is proving to be useful in precision agriculture and environmental monitoring, and is now commonly used to provide rapid and reliable information on soil salinity and soil management zones, both of which relate well to crop yield. It is also used to monitor soil water in the root-zone, providing an efficient means of monitoring crop water use and plant-available water (PAW) in the soil profile throughout the growing season. This helps managers make better-informed decisions about the application, timing and conservation of irrigation water and fertiliser. EM38 datasets have also proved valuable in testing and validating water-balance models that are used to extrapolate to other seasons, management scenarios and locations. Soil calibrations or qualitative assessments done with the EM38 can be used to reckon estimates of soil water in the root-zone. This information is vital in farm-management decisions based on accurate knowledge of soil PAW.⁷⁴

Modelling of soil water

Simulation of the water balance can be considered as an alternative to field-based soil-water monitoring. Considering the error inherent in field measurements and issues with the installation of sensing devices, there is a reasonable argument that the modelling of the water balance, when initialised with accurate plant-available water capacity (PAWC) and daily climate information, is likely to be as accurate as taking direct measurements. *APSIM* and *Yield Prophet* successfully predict soil water and they could be considered for both fallow and cropping situations. *CliMate* is a logical choice for managing water in fallow periods.⁷⁵

1.6.2 Irrigation

Effective irrigation will influence the entire growth process, from seedbed preparation, germination and root growth, through nutrient utilisation and plant growth and regrowth, to yield and the quality of the yield.

The key to maximising irrigation efforts is uniformity. The producer has a lot of control over how much water to supply and when to apply it, but it is the irrigation system that determines uniformity. Deciding which irrigation systems is best for a particular operation requires a knowledge of equipment, system design, plant species, growth stage, root structure, soil composition, and land formation. Irrigation systems should encourage plant growth while minimising salt imbalances, leaf burn, soil erosion, and water loss. Water will be lost through evaporation, wind drift, run-off, and water (and nutrients) sinking deep below the root-zone.

Proper irrigation management takes careful consideration and vigilant observation.

⁷³ N Dalgliesh, N Huth (2013) New technology for measuring and advising on soil water. GRDC Update Paper. GRDC, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/New-technology-for-measuring-and-advising-on-soil-water>

⁷⁴ J Foley (2013) A 'how to' for getting soil water from your EM38 field measurements. GRDC Update Paper. GRDC, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/A-how-to-for-getting-soil-water-from-your-EM38-field-measurements>

⁷⁵ N Dalgliesh, N Huth (2013) New technology for measuring and advising on soil water. GRDC Update Paper. GRDC, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/New-technology-for-measuring-and-advising-on-soil-water>

MORE INFORMATION

[Farming systems in the northern cropping region: an economic analysis](#)

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Irrigation allows primary producers to:

- Grow more pastures and crops.
- Have more flexibility in their systems and operations as the ability to access water at times when it would otherwise be hard to achieve good plant growth (due to a deficit in soil moisture) is imperative. Producers can then achieve higher yields and meet market and seasonal demands, especially if rainfall events do not occur.
- Produce higher quality crops and pastures as water stress can dramatically impact on the quality of farm produce.
- Lengthen the growing season (or start the season earlier).
- Have 'insurance' against seasonal variability and drought.
- Stock more animals per hectare and practice tighter grazing management, due to the reliability of pasture supply throughout the season.
- Maximise benefits of fertiliser applications. Fertilisers need to be watered into the ground in order to best facilitate plant growth.
- Use areas that would otherwise be less productive. Irrigation can allow farmers to open up areas of their farms where it would otherwise be too dry to grow pasture or crops. This also gives them the capability to carry more stock or to conserve more feed.
- Take advantage of market incentives for unseasonal production.
- Be less reliant on supplementary feeding (i.e. grain, hay) in grazing operations due to the more consistent supply and quality of pastures grown under irrigation.
- Improve the capital value of their property. Since irrigated land can potentially support higher intensity crops, pasture and animal production, it is considered more valuable. The value of the property is also related to the water licensing agreements or water rights.
- Save costs or obtain greater returns. These occur from the more effective use of fertilisers and greater financial benefits as a result of more effective agricultural productivity (both quality and quantity) and for out-of-season production.⁷⁶

Irrigation has also been found to be effective in increasing both shoot Zn content and Zn efficiency of cereal cultivars. It has been suggested that plants become more sensitive to Zn deficiency under rain-fed than irrigated conditions.⁷⁷

The main commercial triticale varieties are relatively tall compared with newer wheat varieties, increasing the likelihood of lodging. However, in reality, in most of the newer varieties lodging is not considered a problem, although it is more likely to occur with high rates of nitrogen fertiliser and under irrigated conditions (Table 12).⁷⁸

76 Agriculture Victoria (2015) About irrigation. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/farm-management/soil-and-water/irrigation/about-irrigation>

77 H Ekiz, SA Bagci, AS Kiral, S Eker, I Gültekin, A Alkan, I Cakmak (1998) Effects of zinc fertilisation and irrigation on grain yield and zinc concentration of various cereals grown in zinc-deficient calcareous soils. *Journal of Plant Nutrition*, 21 (10), 2245–2256. https://www.researchgate.net/publication/249076820_Effects_of_Zinc_fertilisation_and_irrigation_on_grain_yield_and_zinc_concentration_of_various_cereals_grown_in_zinc-deficient_calcareous_soils

78 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy, Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

Table 12: Lodging scores in NVT trials, 2008.

Variety	Score
Bogong	0/5
Jaywick	3/5
Tahara	3/5
Tobruk	0/5
Canobolas	0/5
Berkshire	1/5
JRCT 101	0/5
Yukuri	5/5
Rufus	5/5

Note: A score of 0 means the variety was not prone to lodging and a score of 5 means that the variety is prone to heavy lodging.
Source: Jessop and Fittler 2009

Inefficient irrigation can lead to water and nutrients draining through the root-zone, which is a waste of water and fertilisers, and leads to rising and contaminated water tables. Inefficient water use can also mean unnecessary pumping from rivers.⁷⁹

IN FOCUS

Dry matter accumulation and changes in forage quality during primary growth and regrowth of irrigated winter cereals

Selected cultivars of oats (three), barley (two), wheat (three), cereal rye (one) and triticale (three) were grown under irrigation at Trangie, NSW, in 1978 and 1980. Dry-matter accumulation and changes in the moisture, nitrogen and phosphorus content and dry-matter digestibility of forage were monitored at intervals of about 21 days during uninterrupted primary growth (June–September 1980). In a split-plot design the crops were cut at 80 days, at 80 and 122 days, and at 80, 122 and 164 days after sowing. Regrowth was sampled two or three times to determine dry-matter yield and quality.

Most cultivars accumulated 16–20 t/ha of dry matter by the end of sampling in late September, although cereal rye yielded only 14 t/ha. Early maturing Minhaffer oats produced the highest yield when uncut, but regrew poorly after cutting. Under a 42-day cutting interval, oats and barley yielded 12–13 t/ha, winter wheat yielded 10–11 t/ha, and triticale yielded 10–12 t/ha. The nitrogen and phosphorus content of all forages decreased in a linear way during primary growth. Oats and wheat had been similarly digestible, and began to decrease rapidly 40–50 days before heads emerged in mid-August. The early maturing barley and triticale cultivars were less digestible than the oats. With regular cutting, the nitrogen content and digestibility of all cultivars was maintained above 2.7% and 72% respectively.

Dry-matter accumulation was described by mathematical equations which allowed cultivars under different cutting regimes to be compared. They also allowed dry matter and digestible dry matter yields from different systems of cutting to be predicted for irrigated cereals in western New South Wales.⁸⁰

⁷⁹ R Swinton, G Creighton (2009) Irrigation essentials for north coast farmers in NSW. NSW DPI, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0010/349705/Irrigation-essentials-for-North-Coast-farmers-in-NSW.pdf

⁸⁰ DK Muldoon (1986) Dry matter accumulation and changes in forage quality during primary growth and three regrowths of irrigated winter cereals. *Animal Production Science*, 26 (1), 87–98.

SECTION 1 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

MORE INFORMATION

[Irrigation essentials for north coast farmers in NSW](#)

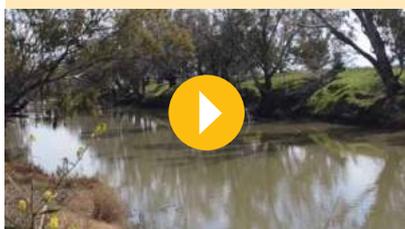
NSW DPI, [Irrigation](#)

GRDC Update Paper, [The future of irrigation: what's in store?](#)

GRDC Update Paper, [Understanding soils, irrigation layouts and agronomy effects of non-rise crop yields](#)

VIDEOS

WATCH: [Over the Fence North: Irrigation investment pays in herbicide resistant weed fight](#)



The future of irrigation

Climate change is likely to lead to reductions in rainfall in some areas. It is predicted that the effects will be amplified by much greater reductions in run-off: i.e., a 10% drop in rainfall will lead to a 20–40% reduction in run-off. The effect will be larger in drier catchments, making the water supply systems in these catchments more vulnerable. The experience of the Millennium Drought has shown that reductions in run-off under persistent climate change (~10 year drought) are larger than reductions that occur for short droughts with similar rainfall reductions in many catchments.⁸¹

1.7 Yield and targets

Australia's climate, and in particular our rainfall, is among the most variable on earth; consequently, crop yields vary noticeably from season to season. In order to remain profitable, crop producers must manage their agronomy, crop inputs, marketing and finance to match each season's yield potential.

The average grain yield of triticale is about 2.5 t/ha, although yields vary locally from less than 1 t/ha in lower-rainfall areas and areas with soil problems to more than 7 t/ha in higher-rainfall areas with more fertile soils.⁸²

In dry springs, triticale yields are 10–15% below wheat, due to triticale's longer grain-filling period.⁸³ However, under ideal conditions, researchers have found that triticale can out-yield wheat and barley, and sometimes oats.⁸⁴

Observed traits suggested for the higher yields in triticale than wheat include greater early vigour, a longer spike-formation phase with same duration to flowering, reduced tillering, increased remobilization of carbohydrates to the grain, early vigorous root growth and higher transpiration-use efficiency.⁸⁵

In trials in NSW, researchers compared yield performances for grain-only triticale (Table 13).⁸⁶ No recent data is available for north-western NSW as only a limited number of trials were conducted from 2008 to 2015.

⁸¹ A Western, M Saft, M Peel (2016) The future of irrigation: what's in store? GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/The-future-of-irrigation-whats-in-store>

⁸² KV Cooper, RS Jessop, NL Darvey (2004) Triticale in Australia. In M Mergoum, H Gómez-Macpherson (eds), Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

⁸³ Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, <http://www.farmtrials.com.au/trial/13801>

⁸⁴ Agriculture Victoria (2012) Growing triticale. Note AG0497. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>

⁸⁵ S Bassu, S Asseng, R Richards (2011) Yield benefits of triticale traits for wheat under current and future climates. Field Crops Research, 124 (1), 14–24.

⁸⁶ P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI, <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>

SECTION 1 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 13: Grain-only yield performance experiments, 2008–2015, compared with Fusion (which = 100%).

Variety	North-east Fusion (which = 4.14 t/ha)	Number of trials	South-east Fusion (which = 4.57 t/ha)	Number of trials	South-west Fusion (which = 6.09 t/ha)	Number of trials
Astute	104	6	105	10	–	–
Berkshire	95	15	93	29	100	6
Bison	101	6	101	10	–	–
Bogong	99	15	96	29	104	6
Canobolas	97	13	95	26	106	5
Chorley	89	15	87	29	87	6
Fusion	100	11	100	22	100	5
Goanna	87	10	86	18	91	4
Hawkeye	95	15	95	29	102	6
Jaywick	92	15	93	29	103	6
KM10	87	4	89	7	–	–
Rufus	85	15	84	29	87	6
Tahara	84	15	83	29	86	6
Tobruk	85	5	85	11	–	–
Tuckerbox	76	13	76	25	85	5
Yowie	86	11	86	22	96	5
Yukuri	74	15	75	29	95	6

▲Outclassed: Berkshire, Bogong, Canobolas, Chorley, Rufus, Tahara and Tobruk (all stripe rust) *Includes some irrigation trials
The table presents data of NVT 'production value' multi-environmental trials on regional mean basis from 2008–2015.

Source: NSW DPI

IN FOCUS

Yield and yield structure of triticales compared with wheat in northern New South Wales

The yields and yield structure of cultivars of triticales and bread wheats (with a range of phasic development patterns in both species) were compared in two field experiments at Narrabri in northern New South Wales. The experiments were performed on a grey cracking clay soil with irrigation to prevent severe moisture stress. Triticales, both early and midseason types, appeared to have reached equivalent yields to well-adapted wheat varieties. Averaged over the two experiments and all sowings, the triticales yielded 19% better than the bread wheats. Triticales were generally superior to wheat in all components of yield of the spike (1,000-grain weight, grain number, spikelet and spikelet number, spike), although the wheats produced more spikes per unit area. The triticales also had higher harvest indexes than the wheats.⁸⁷

Before planting, identify the target yield required to be profitable:

- Do a simple calculation to see how much water needed to achieve this yield.

⁸⁷ G Sweeney, RS Jessop, H Harris (1992) Yield and yield structure of triticales compared with wheat in northern New South Wales. *Animal Production Science*, 32 (4), 447–453.

- Know how much existing soil water there is (treat this water like money in the bank).
- What the nutritional status of the paddock is
- Think about how much risk your farm can take.
- Consider how this crop fits into your cropping plan, and consider whether the longer-term benefits to the system outweigh any short-term losses.

Avoiding a failed crop saves money now and saves stored water for future crops.⁸⁸

Estimating crop yields

Accurate, early estimation of grain yield is an important skill to have. Farmers require accurate yield estimates for a number of reasons:

- Crop insurance.
- Delivery estimates.
- Planning harvest and storage requirements.
- Cash-flow budgeting.

Extensive personal experience is essential for estimating yield at early stages of growth. As crops near maturity, it becomes easier to estimate yield with greater accuracy.

Estimation methods

There are many methods available for farmers and others to estimate the yield of various crops. Some are straightforward, whereas others are more complicated. The method below can be undertaken relatively quickly and easily. The steps are:

1. Select an area that is representative of the paddock. Using a measuring rod or tape, measure out an area 1 m² and count the number of heads (or pods).
2. Do this five times to get an average of the crop.
3. Count the number of grains in at least 20 heads (or pods), and average.
4. Determine the grain weight for the crop concerned.

The accuracy of yield estimates depends on taking an adequate number of counts so as to get a representative average for the paddock. The yield estimate will only be a guide and assumptions made from the estimates contain a degree of uncertainty. This type of yield estimation is one of the easiest and quickest to complete and should be able to be used in a number of situations on a grain-growing property. As grain losses before and during harvest can be significant, factor in an allowance for 5–10% loss in final calculations.⁸⁹

Yield Prophet

Scientists have aimed to support farmers' capacity to achieve yield potential by developing the Agricultural Production Systems Simulator (APSIM), a model of farming systems that simulates the effects of environmental variables and management decisions on crop yield, profits and ecological outcomes.

Yield Prophet delivers information from APSIM to farmers (and consultants) to aid them in their decision-making. It is an online crop-production model that gives users real-time information about their crops. This tool provides growers with integrated production-risk advice and monitoring decision-support relevant to farm management. By matching crop inputs with potential yield in a given season, by using scenario analysis of different management options, Yield Prophet subscribers may avoid over- or under-investing in their crop. Yield Prophet has enjoyed a measure of acceptance and adoption amongst innovative farmers and has made valuable impacts in terms of assisting farmers to manage climate variability at a paddock level.

⁸⁸ J Wish (2013) Impact of stored water on risk and sowing decisions in western NSW. GRDC Update Paper, 23 July 2013. GRDC, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Impact-of-stored-water-on-risk-and-sowing-decisions-in-western-NSW>

⁸⁹ Agriculture Victoria (2015) Estimating crop yields: a brief guide. Note AG1420. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/estimating-crop-yields-a-brief-guide>

i MORE INFORMATION

[Yield Prophet](#)

[Optimising performance of current northern cropping farming systems](#)

The simulations provide a framework for farmers and advisers to:

- forecast yield
- manage climate and soil water risk
- make informed decisions about N and irrigation applications
- match inputs with the yield potential of their crop
- assess the effect of changed sowing dates or varieties
- assess the possible effects of climate change

How does it work?

Yield Prophet generates crop simulations that combine the essential components of growing a crop including:

- A soil test sampled prior to planting.
- A soil classification selected from the Yield Prophet library of ~1,000 soils, chosen as representative of the production area.
- Historical and current climate data taken from the nearest Bureau of Meteorology (BOM) weather station.
- Paddock-specific rainfall data recorded by the user (optional).
- Individual crop details.
- Fertiliser and irrigation applications during the growing season.

1.7.1 Seasonal outlook

Queensland

The Science Delivery Division of the Department of Science, Information Technology and Innovation (DSITI) produces a [monthly climate statement](#) which interprets seasonal climate outlook information for Queensland. The monthly climate statement is based on DSITI's own information and also draws on information from national and international climate agencies.

DSITI's assessment of the probability of rain is based on the state of the ocean and atmosphere, and their similarity with previous years. In particular, it monitors the current and projected state of the El Niño–Southern Oscillation (ENSO), [sea-surface temperature \(SST\) anomaly maps](#) and the Southern Oscillation Index (SOI). Based on this information, it uses two systems to calculate rainfall probabilities for Queensland:

- DSITI's [SOI phase system](#), which produces seasonal rainfall probabilities based on [phases](#) of the Southern Oscillation Index.
- The department's experimental [SPOTA-1](#) (Seasonal Pacific Ocean Temperature Analysis, version 1), which monitors Pacific Ocean SSTs from March to October each year to provide long-lead outlooks for summer rains from November to March.

Outlooks based on both the SOI-Phase system and SPOTA-1 are free, although a password is required to access the experimental SPOTA-1 information.⁹⁰

The Queensland Alliance for Agriculture and Food Innovation produces seasonal outlooks for wheat producers in Queensland. These short, free reports are written in an easy-to-read style.⁹¹

New South Wales

The NSW seasonal conditions report is issued each month and contains information on, among other things, rainfall, water storages, crops, and livestock. It is available to landholders to help them make informed decisions on how they manage operations, and prepare for seasonal conditions and drought. Seasonal conditions reports are

⁹⁰ DSITI (2015) Seasonal climate outlook. Queensland Government, <https://www.longpaddock.qld.gov.au/seasonalclimateoutlook/>

⁹¹ Queensland Alliance for Agriculture and Food Innovation (2017) Crop outlook. University of Queensland, <https://qaafi.uq.edu.au/industry/crop-outlook>

MORE INFORMATION

Download CropMate for iPhones from the [App Store](#) or on iTunes.

Download CliMate from the [Apple iTunes store](#) or visit the [CliMate website](#)

[Climate Analogues](#)

[Climate Change in Australia, Cluster reports](#)

Bureau of Meteorology, [Climate outlooks: monthly and seasonal](#)

[Climate Kelpie](#)

also used by the [Regional Assistance Advisory Committee](#) to make recommendations on potential support for farm businesses, families and communities.⁹²

CropMate

CropMate is an online tool that was developed by NSW Department of Primary Industries. It can be used in pre-season planning to analyse average temperature, rainfall and evaporation. It provides seasonal forecasts and information about influences on climate, such as the impact of the SOI on rainfall. The CropMate decision tool provides estimates of soil water and N, frost and heat risk, as well as gross margin analyses of the various cropping options.

CliMate

Australian CliMate is a suite of climate analysis tools delivered on the web, or via iPhone, iPad and iPod Touch devices. CliMate allows growers to interrogate climate records to ask questions about rainfall, temperature, radiation, and derived variables such as heat sums, soil water and soil nitrate, and well as El Niño–Southern Oscillation status. It is designed for decision makers such as farmers whose businesses rely on the weather.

One of the CliMate tools, How's the Season?, uses weather records from 1949 to the present to assess the progress of the current season (rainfall, temperature, heat sums and radiation) compared with the average and with all years. It explores the readily available weather data, compares the current season with the long-term average, and graphically presents the spread of experience from previous seasons. (The other tools available are How Often?, How Hot/Cold?, How Wet/N?, How Likely?, How's El Niño?, and How's the Past?)

Crop progress and expectations are influenced by rainfall, temperature and radiation since planting. How's the Season? provides an objective assessment, based on long-term records, to these questions:

- How is the crop developing compared to previous seasons, based on heat sum?
- Is there any reason why my crop is not doing as well as usual because of below-average rainfall or radiation?
- Based on season's progress (and starting conditions from How Wet/N?), should I adjust inputs?

For inputs, How's the Season? asks for the weather variable to be explored (rainfall, average daily temperature, radiation, heat sum with base temperatures of 0, 5, 10, 15 and 20°C), a start month and a duration.

As outputs, text and two graphical presentations are used to show the current season in the context of the average and all years. Departures from the average are shown in a fire-risk chart as the departure from the average in units of standard deviation.⁹³

Climate Analogues

The tool Climate Analogues is used to help understand what the climate in a region might be like in the future. It is one of several tools developed by Climate Change in Australia, in which CSIRO and the Bureau of Meteorology have joined forces to make climate-change projections based on natural resource management regions. Climate Analogues uses annual average rainfall and maximum temperature to match the proposed future climate of a location of interest with the current climate in another location. For example, based on plausible assumptions about changes in temperature and rainfall, the future climate of Melbourne might be like the current climate of a location identified by this tool. Results should capture sites of broadly similar annual maximum temperature and water balance.⁹⁴

⁹² NSW DPI (n.d.) Seasonal conditions reports. NSW DPI, <https://www.dpi.nsw.gov.au/climate-and-emergencies/droughthub/information-and-resources/seasonal-conditions>

⁹³ Australian CliMate, <https://climateapp.net.au/>

⁹⁴ Climate Change in Australia (2016) Climate Analogues. CSIRO and BOM, <http://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/analogues-explorer/>

1.7.2 Fallow moisture

For a growing crop there are two sources of water: the water stored in the soil during the previous fallow, and the rainfall that occurs while the crop is growing. Growers have some control over the stored soil water, by measuring how much water is available before planting the crop. Even though long-range forecasts and tools such as the SOI cannot guarantee that rain will fall when it's needed, they are useful for indicating the likelihood of the season being wet or dry.⁹⁵

HowWet N?

Another CliMate tool, HowWet/N? is a program that uses records from a nearby weather station to estimate how much PAW has accumulated in the soil and the amount of organic N that has been converted to an available nitrate during a fallow. HowWet/N? tracks daily soil moisture, evaporation, run-off and drainage. Accumulation of available N in the soil is calculated based on surface soil moisture, temperature and soil organic carbon.

HowWet/N?:

- Estimates how much rain has been stored as plant-available soil water during the most recent fallow period.
- Estimates the N mineralised as nitrate-N in soil.
- Provides a comparison with previous seasons.

This information aids in the decision about what crop to plant and how much N fertiliser to apply. Many grain growers are in regions where stored soil water and nitrate at planting are important in crop management decisions.

The questions this tool answers are:

- How long should a fallow period be for particular areas and sequences? (If the soil is almost full, maybe the fallow can be shortened.)
- Given the soil type and local rainfall to date, what is the relative soil moisture and nitrate-N accumulation over the fallow period compared with most years? (Relative changes are more reliable than absolute values.)
- Based on estimates of soil water and nitrate-N accumulation over the fallow, what adjustments are needed to the N supply?

Inputs:

- A selected soil type and the weather station.
- An estimate of soil cover and starting soil moisture.
- Rainfall data input by the user for the stand-alone version of How Often?

Outputs:

- A graph showing plant-available soil water for the current year and for all other years, and a table summarising the recent fallow water balance.
- A graph showing nitrate accumulation for the current year and all other years.

Reliability

HowWet/N? uses standard water-balance algorithms from HowLeaky? and a simplified nitrate mineralisation based on the original version of HowWet/N? Further calibration is needed before accepting with confidence absolute value estimates.

Soil descriptions are based on generic soil types with standard organic carbon (C) and C:N ratios, and as such should be regarded as indicative only. They are best used as a measure of relative water accumulation and nitrate mineralisation.⁹⁶

⁹⁵ J Whish (2013) Impact of stored water on risk and sowing decisions in western NSW. GRDC Update Paper. GRDC, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Impact-of-stored-water-on-risk-and-sowing-decisions-in-western-NSW>

⁹⁶ Australian CliMate. How Wet/N, https://climateapp.net.au/A04_HowWetN

1.7.3 Water Use Efficiency

Water Use Efficiency (WUE) is the measure of a cropping system's capacity to convert water into plant biomass or grain. It includes the use of water stored in the soil and rainfall during the growing season. It relies on:

- The soil's ability to capture and store water.
- The crop's ability to access water stored in the soil and rainfall during the season.
- The crop's ability to convert water into biomass.
- The crop's ability to convert biomass into grain.

Triticale uses water more efficiently than oats and rye do.⁹⁷ One study showed that triticale had similar Water Use Efficiency and resulting yield to wheat under varying soil moisture conditions.⁹⁸

Researchers in Australia found that the total water use of triticale was less than that of wheat and rye, particularly at the higher rates of N. WUE of triticale was also higher at all levels of N, and increased with increasing N application, whereas the WUE in wheat and rye didn't increase after 50 kg N/ha.⁹⁹

One study in a Mediterranean climate attributed high Water Use Efficiency and yield to triticale's stomatal conductance.¹⁰⁰

Water Use Efficiency can be considered at several levels:

- Fallow efficiency, the efficiency with which rainfall during a fallow period is stored for use by the following crop.
- Crop WUE, the efficiency with which an individual crop converts water transpired (or used) to grain.
- Systems WUE, the efficiency with which rainfall is converted to grain over multiple crops and fallows.

Ways to increase yield

In environments where yield is limited by water availability, there are four ways of increasing yield:

- Increase the amount of water available to a crop (e.g. good summer weed control, stubble retention, long fallow, sowing early to increase rooting depth).
- Increase the proportion of water that is transpired by crops rather than lost to evaporation or weeds (e.g. early sowing, early N, vigorous crops and varieties, narrow row spacing, high plant densities, stubble retention, good weed management).
- Increase the efficiency with which crops exchange water for carbon dioxide to grow dry matter, i.e. transpiration efficiency (e.g. early sowing, good nutrition, varieties with high transpiration efficiency).
- Increase the total proportion of dry matter that is grain, i.e. improve the harvest index (e.g. early-flowering varieties, delayed N, wider row spacing, low plant densities, minimising losses to disease, varieties with high harvest index).¹⁰¹

97 M Mergoum, HG Macpherson (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Organisation.

98 PK Aggarwal, AK Singh, GS Chaturvedi, SK Sinha (1986) Performance of wheat and triticale cultivars in a variable soil–water environment II. Evapotranspiration, Water Use Efficiency, harvest index and grain yield. *Field Crops Research*, 13, 301–315.

99 JB Golding (1989). Restricted tillering in triticale cv. currency-an impediment to grain yield? Fifth Australian Agronomy Conference, <http://www.regional.org.au/au/asa/1989/contributed/crop/p1-20.htm>

100 R Motzo, G Pruneddu, F Giunta (2013) The role of stomatal conductance for water and radiation use efficiency of durum wheat and triticale in a Mediterranean environment. *European Journal of Agronomy*, 44, 87–97.

101 JB Passioura, JF Angus (2010) Improving productivity of crops in water-limited environments. Chapter 2 in DL Sparks (ed.) *Advances in Agronomy*, Vol. 106. Academic Press. pp. 37–75, <http://www.sciencedirect.com/science/article/pii/S0065211310060025>

SECTION 1 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

VIDEOS

WATCH: [GCTV12: Water Use Efficiency Initiative](#)



WATCH: [GCTV10: Grazing stubbles and Water Use Efficiency](#)



The French–Schultz approach

The French–Schultz model is widely used to provide growers with a benchmark of potential crop yield based on available soil moisture and likely rainfall during growth.

In this model, potential crop yield is estimated as:

Potential yield (kg/ha) = WUE (kg/ha/mm) x (crop water supply (mm)–estimate of soil evaporation (mm))

where crop water supply is an estimate of water available to the crop, i.e. soil water at planting plus in-crop rainfall, minus soil water remaining at harvest.

The French–Schultz model has been useful in giving growers performance benchmarks. Where yields fall well below these benchmarks, it may indicate something wrong with the agronomy of the crop or a major limitation in the environment. For example, there could be hidden problems in the soil, e.g. root diseases, or soil constraints affecting yields. Another possibility is that apparent underperformance could be simply due to seasonal rainfall distribution patterns, which are beyond the grower's control.¹⁰²

A practical WUE equation for farmers to use developed by James Hunt from CSIRO is:

$$WUE = (\text{yield} \times 1000) / \text{available rainfall}$$

where available rain = (25% Nov.–Mar. rain) + (GSR)–60 mm evaporation.

Agronomist's view

MORE INFORMATION

[Water Use Efficiency: optimizing farming systems performance and balancing fallow length and sowing decisions](#)

[Water Use Efficiency of grain crops in Australia: principles, benchmarks and management](#)

[Making the most of available water in wheat production](#)

Challenging the French–Schultz model

The application of the French–Schultz model for the Northern Region has been challenged in recent times.

In the wheatbelt of eastern Australia, rainfall shifts from winter-dominated in the south (South Australia and Victoria) to summer-dominated in the north (northern NSW and Queensland). The seasonality of rainfall, together with frost risk, drives the choice of cultivar and sowing date, resulting in flowering times varying between October in the south and August in the north.

In eastern Australia, crops are therefore exposed to contrasting climatic conditions during the critical period for grain formation; i.e. a window of ~20 days before and 10 days after flowering, which affects yield potential and WUE.

Understanding how these climatic conditions affect crop processes and how they vary from south to north and from season to season can help growers and consultants to set more realistic target yields across sites, locations and seasons.

Researchers have analysed some of the implications for management and breeding of the shift from winter to summer rainfall between southern and northern regions. They advise caution in the use of simple rules of thumb (French–Schultz) for benchmarking WUE, and discuss the importance of more integrative and dynamic modelling approaches to explore alternatives to increase WUE at the levels of the single crop and the whole farm systems; i.e. \$/ha/mm.¹⁰³

¹⁰² GRDC (2009) Water Use Efficiency: Converting rainfall to grain. Factsheet. GRDC, https://grdc.com.au/data/assets/pdf_file/0029/225686/water-use-efficiency-north.pdf

¹⁰³ D Rodriguez, V Sadras (2008) Farming systems design and Water Use Efficiency (WUE): Challenging the French & Schultz WUE model. GRDC Update Paper, 13 June 2008. GRDC, <https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2008/06/Farming-systems-design-and-water-use-efficiency-WUE-Challenging-the-French-Schultz-Wue-model>

1.7.4 Nitrogen-use efficiency

Key points:

- Improving nitrogen-use efficiency begins with identifying and measuring meaningful NUE indices and comparing them with known benchmarks and contrasting N management tactics.
- There are a number of causes of inefficiency. Identification of the most likely groups is useful in directing targeted measurement and helping identify possible strategies for improvement.
- Good record keeping is essential.
- Recent has shown that triticale has a higher biomass and straw yields, lower harvest index and higher total N uptake than wheat. Consequently, triticale had higher N uptake efficiency and higher N use efficiency.¹⁰⁴

Nitrogen-use efficiency (NUE) is how well soil nitrate-N is converted into grain N. The nitrate-N comes from fertiliser, crop residues, manures, and soil organic matter, but it is how well and quickly this fertiliser is converted into grain that is generally of greatest concern to growers. Efficiency is reduced by some seasonal conditions, crop diseases, losses of N from the soil as gases, N leaching, or immobilisation of N into organic forms.

The type of soil type, the intensity of rainfall and the timing of fertiliser application largely determine N losses from dryland cropping soils. Insufficient rainfall after a surface application of N fertilisers can result in losses from the soil through volatilisation. The gas lost in this case is ammonia. Direct measurements of ammonia losses have found that they are generally less than 15% of the N applied, and even less with in-crop situations. An exception can occur with the application of ammonium sulphate to soils with free lime at the surface, where losses have been found to be over 25% of the N applied. Recovery of N applied in-crop requires sufficient rainfall for plant uptake from an otherwise dry surface soil.

A balance of nutrients is essential for profitable yields. Fertiliser is commonly needed to add the essential nutrients P and N, although the lack of other essential plant nutrients may also limit production in some situations. Knowledge of the nutrient demand of crops is essential in determining nutrient requirements. Soil testing and nutrient audits assist in matching nutrient supply to crop demand.¹⁰⁵

In recent research, it was found that triticale had higher biomass and straw yields, lower harvest index and higher total N uptake than wheat. Consequently, triticale had higher efficiency of both the uptake and use of N.¹⁰⁶

Optimising nitrogen-use efficiency

Nitrogen fertilisers are a significant expense for broadacre farmers, so optimising the use of fertiliser inputs is important in reducing this cost. There are four main sources of nitrogen available to crops: stable organic nitrogen, rotational nitrogen, ammonium, and nitrate. To optimise plants' ability to use soil nitrogen, growers should first be aware of how much of each source there is. The best method of measuring these nitrogen sources is soil testing.¹⁰⁷

1.7.5 Double-crop options

Double cropping is growing a winter and summer crop following one another. This is often part of opportunity cropping which involves making the best use of rainfall by planting crops according to soil-moisture reserves. In some instances this will involve

MORE INFORMATION

[The fundamentals of increasing nitrogen use efficiency](#)

¹⁰⁴ S Roques, D Kindred, S Clarke (2016) Triticale out-performs wheat on range of UK soils with a similar nitrogen requirement. The Journal of Agricultural Science, 155) 261–281.

¹⁰⁵ G Schwenke, P Grace, M Bell (2013) Nitrogen use efficiency. GRDC Update Paper, 16 July 2013. GRDC, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Nitrogen-use-efficiency>

¹⁰⁶ S Roques, D Kindred, S Clarke (2016) Triticale out-performs wheat on range of UK soils with a similar nitrogen requirement. The Journal of Agricultural Science, 155, 1–21.

¹⁰⁷ R. Quinlan (2017) Optimising soil nutrition. Soilquality.org, <http://www.soilquality.org.au/factsheets/optimising-soil-nutrition>

i MORE INFORMATION

[High profit farming in northern Australia](#)

double-cropping, at other times long fallows might be used to build up soil moisture for a more reliable crop.

Cool-season annual forages such as triticale are well-suited to double cropped forage.¹⁰⁸ Planting cool-season annuals following a grain harvest is an economical way to produce high-quality forage. Two types of cool-season annual forages that are well-suited to produce double-cropped forage are small-grain cereal grasses, such as triticale, oats, cereal rye and wheat, and brassicas, which include turnip and radish that are suited to the southern parts of the northern region.

For autumn forage, the general concept is to take advantage of the potential growing degree-days following a grain harvest. Ideally, planting a forage double crop would occur as soon as possible following grain harvest since the growing degree-days available for plant growth rapidly decline through the late summer into early autumn. The risk of failure increases with later planting dates. However, establishment costs are often low enough for many of these forages that the successful years often outweigh the years in which failure occurs.¹⁰⁹

For the more northern parts of the northern region, double cropping options would include following a sorghum crop with chickpeas as a autumn plant or the growing of mungbeans following a winter cereal crop.

1.8 Disease status of paddock

Crop sequencing and rotation are important components of long-term farming systems and contribute to the management of soil nitrogen status, weeds, pests and diseases.

Crop sequencing is only a part of the integrated management of diseases. Other practices include:

- Maintaining sufficient distance from last year's paddock of the same crop, and maintaining sufficient distance from a paddock with residue infected with a pathogen of the intended crop.
- The use of high-quality, fungicide-treated seed.
- Planting within the planting window, variety selection.
- In-crop fungicide treatments.¹¹⁰
- Growing more tolerant crops or varieties

Paddock risk can be determined by one or both of these methods:

- Visually assessing the levels of crown rot and root-lesion nematode (RLN) (see section 1.9) in a prior cereal crop, paying attention to basal browning.
- Having soil samples analysed at a testing laboratory.
- Assessing volunteer plants for any visual signs of disease
- Assessing stubble for any visual signs of disease (e.g. yellow leaf spot or taan spot)
- Testing seed for disease
- controlling volunteers and any green bridge

1.8.1 Testing soil for disease

In addition to visual symptoms, the DNA-based soil test PreDicta B™ can be used to assess the disease status of the paddock. Soil samples that include plant residues should be tested early in late summer to allow results to be returned before seeding.

108 ME Drewnoski, DD Redfearn (2015) Annual cool-season forages for late-fall or early-spring double-crop. No. G2262. NebGuide, <http://extensionpublications.unl.edu/assets/pdf/g2262.pdf>

109 ME Drewnoski, DD Redfearn (2015) Annual cool-season forages for late-fall or early-spring double-crop. No. G2262. NebGuide, <http://extensionpublications.unl.edu/assets/pdf/g2262.pdf>

110 M Ryley (2011) Diseases shared by different crops and issues for crop sequencing. GRDC Update Paper. GRDC, <http://elibrary.grdc.com.au/ark!33517/vhnf54 t/a9ft5hf>

This test is particularly useful when sowing susceptible wheat varieties, and for assessing the risk after a non-cereal crop.

PreDicta B

Cereal root diseases cost grain growers in excess of \$200 million a year in lost production. Much of this can be prevented.

PreDicta B (the B stands for broadacre) is a DNA-based soil testing service that identifies which soil-borne pathogens pose a significant risk to broadacre crops prior to seeding (Photo 13). It includes tests for:

- Take-all (*Gaeumannomyces graminis* var. *tritici* (Ggt) and *G. graminis* var. *avenae* (Gga)).
- Rhizoctonia barepatch (*Rhizoctonia solani* AG8).
- Crown rot (*Fusarium pseudograminearum* and *F. culmorum*).
- Blackspot of peas (*Mycosphaerella pinodes*, *Phoma medicaginis* var. *pinodella* and *Phoma koolunga*).

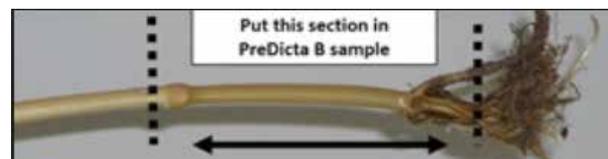


Photo 13: PreDicta B sample.

Source: GRDC

How to access the service

Growers can access PreDicta B diagnostic testing services through a SARDI-accredited agronomist. They will interpret the results and give advice on management options to reduce the risk of yield loss.

Samples are processed weekly between February and mid-May (prior to crops being sown) every year.

PreDicta B is not intended for in-crop diagnosis. SARDI provides a diagnostic service for that.

1.8.2 Effects of cropping history

The previous crop will influence levels of both soil- and residue-borne diseases. Important diseases to consider include take-all, crown rot, yellow leaf spot, stripe rust, and Wheat streak mosaic virus (Table 14).¹¹¹ Transmission from neighbouring paddocks and volunteers are key concerns with some diseases and insects e.g. aphids and Russian wheat aphid. Controlling the green bridge of over-summering cereals and weeds is an important strategy.

For diseases, there has been a focus on management of crown rot, RLN and yellow leaf spot in winter cereals, and the roles that rotational crops play, particularly the winter pulses. Crop sequences also affect the incidence and severity of major diseases of summer crops, especially those diseases that have several summer, and in some instances winter, crop hosts.

MORE INFORMATION

[PreDicta B](#)

[SARDI, Crop diagnostics](#)

¹¹¹ M Ryley (2011) Diseases shared by different crops and issues for crop sequencing. GRDC Update Paper. GRDC, <http://elibrary.grdc.com.au/ark!33517/vhnf54 t/a9ft5hf>

SECTION 1 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 14: Significant pathogens shared by different crops.

Pathogen/Nematode	Common name	Sorghum	Maize	Sunflower	Summer pulses	Cotton	Winter cereals	Winter pulses
<i>Pratylenchus thornei</i>	root-lesion nematode	-	-	-	✓✓ m,s	-	✓✓	✓✓ c,f
<i>Pratylenchus neglectus</i>	root-lesion nematode	✓✓				nt	✓✓	✓✓ c
<i>Fusarium graminearum</i>	head blight	✓	✓✓	-	-	-	✓✓	-
<i>Macrophomina phaseolina</i>	charcoal rot	✓✓	✓✓	✓✓	✓✓ m,s,g	✓	-	✓
<i>Sclerotinia sclerotiorum</i> , <i>S. minor</i>	sclerotinia rot	-	-	✓✓	✓✓ s,m,g	-	-	✓✓ c,f,p
<i>Sclerotium rolfsii</i>	basal rot	✓	✓	✓	✓✓ s,g	✓	-	-
<i>Fusarium verticillioides</i>	fusarium stalk and cob rot	✓	✓✓	-	-	-	-	-
<i>Fusarium semitectum</i>	fusarium head blight and stalk rot	✓✓	✓	-	-	-	-	-

Two ticks = major disease, one tick = recorded but generally a minor disease. c = chickpeas, f = faba beans, g = peanuts, m = mungbeans, p = field peas, s = soybeans, nt = not tested.

Source: GRDC

Paddock histories likely to result in high risk of disease e.g. crown rot, include:

- Durum wheat in the past 1–3 years.
- Winter cereal or a high grass burden from last season—crown-rot fungus survives in winter-cereal residues, dense stubble cover or where dry conditions have made residue decomposition slow.
- Break crops, which can influence crown rot in cereals by manipulating the amount of nitrogen (N) and moisture left in the soil profile.
- Paddocks that have high levels of N at sowing and/or low stored soil moisture at depth.¹¹²
- Wheat varieties grown in previous year (Photo 14).¹¹³

For more information, see [Section 9: Diseases](#).

MORE INFORMATION

GRDC, [Cereal Diseases: The Ute Guide](#)

¹¹² GRDC (2009) Crown rot in cereals: understanding the disease underpins effective management. Factsheet. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2009/05/crown-rot-in-cereals-fact-sheet-southern-western-regions>

¹¹³ R Brill, S Simpfendorfer (2013) Resistance of eighteen wheat varieties to the root lesion nematode *Pratylenchus thornei*, Trangie 2011. In NSW DPI Northern Grains Region Trial Results Autumn 2013, pp. 129–131, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0004/468328/Northern-grains-region-trial-results-autumn-2013.pdf



Photo 14: Diseased patches from previous crops vary in size from less than half a metre to several metres in diameter.

Source: DAFWA

1.9 Nematode status of paddock

Root-lesion nematodes (*Pratylenchus thornei* and *P. neglectus*) are migratory root endoparasites that are widely distributed in the cereal -growing regions of Australia. They can reduce grain yield by up to 50% in many current wheat varieties (Photo 15). *Pratylenchus neglectus* and *P. thornei* are the main RLNs causing yield loss in the northern agricultural region of Australia, and they often occur together.¹¹⁴

P. thornei is the most damaging species and occurs commonly in the Northern Region. *P. neglectus* occurs less frequently than *P. thornei* but is still quite common. *P. neglectus* is common in southern NSW.

The roots of triticale in nematode-infested soil have been found to contain fewer nematodes than other cereals. Triticale is thus a useful rotational crop for areas infested with the root-lesion nematodes.¹¹⁵

¹¹⁴ DAF Qld (2010) Test your farm for nematodes. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/crop-diseases/root-lesion-nematodes/test-your-farm-for-nematodes>

¹¹⁵ V Vanstone, M Farsi, T Rathjen, K Cooper (1996) Resistance of triticale to root lesion nematode in South Australia. In *Triticale: Today and Tomorrow*, Springer Netherlands, pp. 557–560.

SECTION 1 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)


Photo 15: Paddock showing patches caused by root-lesion nematode.

Source: DAFWA

1.9.1 Testing soil for nematodes

PreDicta B

Among the soil-borne pathogens that PreDicta B can test for are these nematodes:

- Cereal cyst nematode (*Heterodera avenae*).
- Root lesion nematode (*Pratylenchus neglectus* and *P. thornei*).
- Stem nematode (*Ditylenchus dipsaci*).

See [section 1.8.1](#) above for details, including how to access the service.

1.9.2 Effects of cropping history

- Well-managed rotations are vital. Avoid consecutive host crops to limit populations.
- Choose varieties with high tolerance ratings to maximise yields in fields where RLN is present.
- Choose rotation crops with high resistance ratings, so that fewer nematodes remain in the soil to infect subsequent crops.

For more information, see [Section 8: Nematode control](#)

1.10 Insect status of paddock

Pests such as redlegged earth mites, blue oat mites, nematodes and, in some seasons, cutworms, pose a risk in some paddocks. Risk should be assessed based on paddock history (including recent control) and crop susceptibility. Controlling weeds in summer fallows and around paddocks can also minimise some of these pests.

Soil-dwelling insect pests can seriously reduce plant establishment and populations, and subsequent yield potential (Photo 16).¹¹⁶

MORE INFORMATION

GRDC Tips and Tactics, [Root-lesion nematodes, Northern Region](#)

¹¹⁶ cesar (2015) Impact of armyworm caterpillars ramps up, PestFacts. Issue 8. cesar, <http://www.cesaraustralia.com/sustainable-agriculture/pestfacts-south-eastern/past-issues/2015/pestfacts-issue-no-8-27th-august-2015/impact-of-armyworm-caterpillars-ramps-up/>



Photo 16: Armyworm on a severed stem (left) and the damage caused by a combination of armyworms and herringbone caterpillars to a cereal paddock (right).

Sources: Luke Maher, left, and James Mckee

Soil insects include: ¹¹⁷

- [cockroaches](#)
- [crickets](#)
- [earwigs](#)
- [black scarab beetles](#)
- [cutworms](#)
- [false wireworms](#)
- [true wireworms.](#)
- slatters
- slugs
- snails

Soil-insect control measures are normally applied at sowing. Since different insects require different control measures, the species of soil insects must be identified before planting. ¹¹⁸

1.10.1 Testing soil for insects

It is important to maintain a regular testing regime for the presence of insects in the soil. Recent seasons have seen a plethora of seemingly new pests and unusual damage in pulse and grain crops. For example, in the Northern Region, the most notable examples are:

- Detection of Russian Wheat Aphid in cereal crops in southern NSW.
- The Etiella moth, which has occurred in concentrations of up to 60/m² in vegetative and podding soybeans and mungbeans.
- Severe scarab damage in sorghum and winter cereals.
- The bean pod borer west of the Great Dividing Range.
- The appearance of soybean stem fly in regions adjoining the Darling Downs, well south of its 'normal' range.
- Plague numbers of a mysterious plant hopper in in mungbeans, sorghum and millet in the summer of 2014–15.

¹¹⁷ DAF Qld. Soil insects in Queensland. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/soil-insects>

¹¹⁸ DAF Qld. (2011) How to recognise and monitor soil insects. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects>

GRDC's advice to growers is to:

- Monitor crops frequently so as not to be caught out by new or existing pests.
- Look for and report any unusual pests or symptoms of damage— photographs are good.
- Remember that just because a pest is present in large numbers in one year doesn't mean it will necessarily be so next year— another spasmodic pest, may make its presence felt instead.
- Be aware of cultural practices that favour pests, and rotate crops each year to minimise the build-up of pests and plant diseases.¹¹⁹

Sampling methods should be applied in a consistent manner between paddocks and on each sampling occasion. Any differences can then be confidently attributed to changes in the insect populations, and not to different sampling techniques.

Soil sampling by spade

1. Take a number of spade samples from random locations across the paddock.
2. Check that all spade samples are deep enough to take in the moist soil layer. This is essential.
3. Hand-sort samples to determine type and number of soil insects.

Germinating-seed bait technique

Immediately following planting rain:

1. Soak insecticide-free crop seed in water for at least two hours to initiate germination.
2. Bury a dessertspoon of the seed under 1 cm of soil. For each 100 ha, bury the seed at each corner of a 5 m by 5 m square at five widely spaced sites.
3. Mark the position of the seed baits, as large populations of soil insects can destroy the baits.
4. One day after seedling emergence, dig up the plants and count the insects.

Trials have shown no difference in the type of seed used for attracting soil-dwelling insects. However, using the type of seed to be sown is likely to indicate the species of pests that could damage the proposed crop. The major disadvantage of the germinating-grain bait method is the delay between the seed placement and assessment.¹²⁰

Identifying insects

The South Australian Research and Development Institute (SARDI) Entomology Unit provides an insect identification and advisory service. The unit identifies insects to the highest taxonomic level for species where this is possible, and can also give farmers biological information and guidelines for controlling them.¹²¹

GRDC's Insect ID ute guide is a comprehensive reference on the insect pests that commonly affect broadacre crops across Australia (Figure 6). It includes the beneficial insects that may help to control pests. Photos have been provided for multiple life-cycle stages, and each insect is described in detail, with information on the crops they attack, how they can be monitored, and other pests they may be confused with. Use of this app should result in better management of pests, increased farm profitability and improved chemical usage.¹²²

The app is available for Android phones and the iPhone.

119 H Brier, M Miles (2015) Emerging insect threats in northern grain crops. GRDC Update Paper, 31 July 2015. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Emerging-insect-threats-in-northern-grain-crops>

120 DAF Qld (2011) How to recognise and monitor soil insects. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects>

121 PIRSA. Insect diagnostic service, http://pir.sa.gov.au/research/research_specialties/sustainable_systems/entomology/insect_diagnostic_service

122 GRDC. Insect ID: The ute guide. GRDC, <https://grdc.com.au/Resources/Apps>

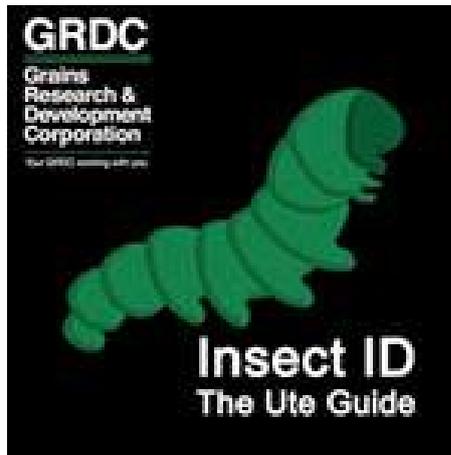


Figure 6: Icon of GRDC's insect ID app.

Source: GRDC

App features

The features of the app are:

- Region selection .
- Predictive search by common and scientific names.
- Comparison photos of insects side by side with insects in the app.
- Identification of beneficial predators and parasites of insect pests.
- The option to download content updates inside the app to ensure you're aware of the latest pests affecting crops for each region.
- Raises awareness of international biosecurity pests.

It is important to consider paddock history when planning for pest management. Resident pests can be easier to predict by using paddock history. Agronomic and weather data will also help to determine the likely presence (and numbers) of certain pests within a paddock. These will point towards the likely pest issues and allow growers to implement preventive options.¹²³ Reduced tillage and increased stubble retention have changed the cropping landscape with respect to soil-moisture retention, groundcover and soil biology, and these have also affected the abundance and types of invertebrate species being seen in crops. These systems increase invertebrate biodiversity but also create more favourable conditions for many pests such as slugs, earwigs, weevils, beetles and many caterpillars. In turn, they have also influenced beneficial species such as carabid and lady beetles, hoverflies and parasitic wasps.¹²⁴

See [Section 7: Insect control](#) for more information.

1.10.2 Effects of cropping history

Where paddock history, paddock conditions or pest numbers indicate a high risk of pest damage a grower might decide to use pre-seeding controls to reduce pest pressure, apply a seed dressing to protect the crop during the seedling stage and plan to apply a foliar insecticide if pest numbers reach a particular level.¹²⁵

Different soil insects occur under different cultivation systems and the way the farm is managed directly influences the type and number of these pests. Keep in mind the following:

MORE INFORMATION

[Pest Genie](#)

[Australian Pesticides and Veterinary Medicines Authority](#)

¹²³ R Jennings (2015) Growers chase pest-control answers. Ground Cover. No. 117. GRDC. <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-117-July-August-2015/Growers-chase-pest-control-answers>

¹²⁴ P Bowden, P Umina, G McDonald (2014) Emerging insect pests. GRDC Update Paper. GRDC. <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Emerging-insect-pests>

¹²⁵ G Jennings (2012) Integrating pest management. SANTFA, <http://www.santfa.com.au/wp-content/uploads/Santfa-TCE-Spring-12-Integrating-pest-management.pdf>

SECTION 1 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- Weedy fallows and volunteer crops encourage soil insect build-up.
- Insect numbers decline during a clean, long fallow due to lack of food.
- Summer cereals followed by volunteer winter crops promote the build-up of earwigs and crickets.
- Large amounts of stubble on the soil surface can promote some soil insects because they are a food source, but this can also mean that pests continue feeding on the stubble instead of moving to germinating crops.
- No-tillage cropping encourages beneficial predatory insects and earthworms.
- Incorporating stubble promotes black field earwigs.
- False wireworms are found at all intensities of cultivation, but numbers decline if stubble levels are very low.

Soil-insect controls are normally applied at sowing. Since different insects require different control measures, the species must be identified before planting. Soil insects are often difficult to detect as they hide under trash or in the soil. Immature insects such as false wireworm larvae are usually found at the interface of moist and dry soil.¹²⁶

For more information, see [Section 7: Insect Control](#).

¹²⁶ DAF Qld (2011) How to recognise and monitor soil insects. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects>

Pre-planting

Key messages

- Triticale breeding programs have aimed at improving grain yield and dry-matter production, producing winter habit triticales with a wider range of sowing dates, improving the grazing ability (having the growing point closer to the ground), and incorporating new sources of rust resistance.
- These breeding programs have produced a number of new varieties designed for particular uses and regions.
- Triticale is extensively used in dual-purpose cropping systems, with varieties bred specifically for them.
- It is important to ensure that seed quality is of a high standard. Check for damage and discolouration as affected seeds may have poor germination and emergence.
- The larger seed size of triticale means that emergence is consistently good; however, high-quality seed must be used.
- Consult local variety sowing guides for the best practices for your region; [Winter crop variety sowing guide–NSW 2017](#).

There are two types of triticale to choose from: grain-only, and dual-purpose (Photo 1).¹ Dual-purpose varieties can be sown very early, grazed during winter, and then shut up for forage conservation or grain recovery.²



Photo 1: *Triticale combines the high yield potential and good grain quality of wheat with the disease and environmental tolerance of rye.*

As far as amount of vegetative growth, triticale is very similar to that of a cereal rye plant, growing 90–150 cm in height. It also has an extensive fibrous root system that makes it an excellent choice for preventing erosion, scavenging for nutrients, and also for building soil structure.

Triticale has excellent grazing and forage values. It has a heavy residue on the surface, much like that of cereal rye, if allowed to reach maturity, thus also making it a good choice for weed suppression.³ Triticale is also tolerant to waterlogging.

1 Seed Technology (n.d.) Triticale. Seed Technology. <http://seedtech.ie/index.php/en/products/cereals/triticale>

2 Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

3 Advance Cover Crops (n.d.) Triticale. Advance Cover Crops. http://www.advancecovercrops.com/portfolio_item/triticale/

2.1 Triticale as a dual-purpose crop

Key points:

- Advantages of dual-purpose crops include capitalising on early rainfall, flexibility in enterprise mix, and improved and spread out cash-flow.
- Dual-purpose crops require a high standard of management.
- Ideal grazing facilities would allow for an excellent water supply, shelter belts and rotational grazing, and drafting cattle into similar weight ranges before being placed onto grazing crops. Try to minimise handling and ensure that all animal health issues are addressed. ⁴
- Triticale feed grain has similar nutritional qualities as wheat and can be fed to livestock in the same way.
- It is recommended to split the variety selection and sowing time of dual purpose cereals where possible. This will spread the period when grazing can occur and also the risk of crop failure due to dry conditions or disease.

Dual-purpose crops hold great potential for farmers to utilise early-season sowing opportunities to provide extra grazing for livestock and yet maintain grain yield. With good management, the period of grazing can increase net crop returns, and give a range of system benefits including widening sowing windows, reducing crop height, filling critical feed gaps, and spelling pastures. Over 10 years of experiments, simulation studies and collaborative on-farm validation across Australia have demonstrated that a wide range of cereal and canola varieties can be successfully grazed and recover sufficiently to produce an acceptable grain yield. The combined livestock and grain gross margins can exceed grain-only crops, and increase whole-farm profitability. ⁵

The Australian dual-purpose cereal crop (which includes triticale, wheat, oats, barley and cereal rye) is increasing in importance because of factors such as higher-value animal industries. The ability of several recent variety releases to provide valuable winter grazing, as well as a grain yield similar to grain-only crops, helps farmers to improve winter feed supply. ⁶

When a dual-purpose triticale is grown with the intention of providing winter grazing and then optimising grain production, the time of stock removal or lock-up is important. Locking-up grazing stock early in the season is important to allow for the grain crop to recover. For more information about grazing timing see [Section 2.1.3. When to graze](#), below.

Dual-purpose crops can be a vital part of a mixed farming operation. Although, reliable dual-purpose crops require a high standard of agronomy, including timely sowing, careful choice of variety, good sub soil moisture, and high soil fertility, there are pay-offs. They also take a lot of pressure off the remaining grazing base (pastures), commonly giving them a chance to get away and be in an improved position to provide good feed when the dual-purpose crop is locked up for grain. ⁷

2.1.1 Benefits of growing dual-purpose or winter-forage crops

Minimises risks

Dual-purpose or winter-forage crops can protect against several natural hazards:

⁴ K Harris (2016) Dual purpose crops. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Dual-purpose-crops>

⁵ J Kirkegaard, S Sprague, J Lilley, L Bell L (2016) Managing dual purpose crops to optimise profit from grazing and grain yield north. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Managing-dual-purpose-crops-to-optimise-profit-from-grazing-and-grain-yield-north>

⁶ GRDC (2007) Dual-purpose crops: Adaptable triticale steps up. Ground Cover. No. 66. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-66-January-February-2007/Dualpurpose-crops-Adaptable-triticale-steps-up>

⁷ R Freebairn (2016) GRDC Update Papers: Profitable dual purpose cereals in the north and central west (A Purlewaugh case study). <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Profitable-dual-purpose-cereals-in-the-north-west>

- Floods or large amounts of rainfall close to grain harvest, which have caused or can cause severe damage to ripening crops and downgrade grain quality
- Minimise the risks associated with dry periods in late winter–spring.
- Being able to sow early when moisture is available that may not still be there when the main season crop is due to be planted or if seasonal conditions are too wet in the main sowing window. This spreads the risk; giving an opportunity to sow in an earlier window than main season wheat.

Capitalises on early rainfall

These crops can help the grower make the most of early rainfall because:

- Grazing or dual-purpose crops can be planted in late February and up till late March to capitalise on late-summer rain. It also spreads workloads.
- Early-sown crops will provide quality feed from mid-May in most seasons, provided that paddock nutrition is correctly addressed.

Flexibility in enterprise mix

Dual-purpose or winter-forage crops mean that the farm business:

- Isn't totally vulnerable to fluctuations in grain prices, export markets, grain-quality issues, and downgrading because of weather damage.
- Can tap into the profits from weight gains available with buying and selling cattle thus spreading cash flow throughout the year
- Capitalise on cattle prices at feedlots, which are usually higher when grain prices are down—grain is a major input cost for feedlots and therefore it has a major impact on feedlot margins.
- Can delay the decision to lock up dual-purpose crops until late July—during a normal average season when late winter–early spring feed reserves (pastures) are looking good, dual-purpose crops can be locked up, top-dressed, or controlled for weeds if necessary, and kept for grain production.
- Can elect to continue to graze the crop, taking into account cattle and grain prices, levels of stored soil moisture, and the seasonal outlook.

Improved cash-flow

Cash flow is increased because:

- Dual-purpose crops offer the benefit of generating early income from the start of the grazing period.
 - » Cattle are often sold in late July, after 70 days of grazing and after achieving a weight gain of 90–120 kg/head;
 - » i.e. budget 70 days × average 1.6 kg/head/day for a good crop
- Producers don't need to finish the cattle—the best returns are often obtained from backgrounding cattle for local feedlots. A good idea is for growers to speak with the feedlot before they buy cattle; alternatively, there may be an opportunity to background cattle on behalf of a feedlot, being paid for the weight gain only.
- A well-managed forage crop can provide sufficient early-season feed for up to 5 weaners/ha.
- Cash flow is generated in different times of the year to straight grain income. For grain recovery in dual-purpose crops in the southern part of the Northern region, growers should budget 50% of un-grazed crops although in good seasons this number can be much higher.⁸

MORE INFORMATION

[Dual purpose crops](#)

⁸ K Harris (2016) Dual purpose crops, GRDC Update Paper, GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Dual-purpose-crops>

IN FOCUS

Dual purpose cereal crops - NSW trials

With the support of the Grains Research and Development Corporation, NSW DPI managed a series of dual-purpose cereal cropping trials at Somerton, Purllewaugh, Cowra and Culcairn between 2008–2012. The main points made from these trials are:

- Oats and barley produced more dry matter than wheat or triticale across sites and seasons.
- Triticale produced the highest grain yield following grazing.
- No single variety excelled in terms of ranking in the top 10 for both dry-matter production and grain yield. Urambie barley was the best overall performer, followed by El Alamein and Endeavour; triticales and Tennant, a winter wheat.
- Dual-purpose varieties should always be selected based on individual enterprise needs.

Dual purpose cereal trials have been conducted by the NSW Department of Primary Industries for over 40 years. Two trial sites located in northern NSW between 2008–2012 included a range of wheat, oat, barley, triticale and cereal rye varieties, both commercial and experimental lines, which amounted to 127 different entries over the five-year period.

Somerton trial sites were located at “Clermont Park” in 2008–2012, while Purllewaugh sites were located at “Naparoo” in 2008, 2009, 2010, 2012 and “Kurrajong Vale” in 2011. The trials were sown each year in the first three weeks of April. In each year dry matter assessments were conducted around the end of June for dry matter 1 and at the beginning of August for dry matter 2. Dry matter assessments were followed by a ‘crash’ grazing using both sheep and cattle to remove the dry matter evenly across all plots. The second dry matter assessments did not occur at either site in 2008–09 due to the dry seasons. Following the final grazing in each trial animals were excluded for the remainder of the season to allow grain recovery to be assessed in late November/ Early December. Trial plots were harvested using a KEW plot header.

Dry matter and grain yield data for each of the four species, wheat, oats, barley and triticale were compared, across varieties for an indication of their respective performances (Table 1).

Species selection should be based on the priority end use for each individual paddock. The best early dry matter production was provided by oats. Oats were also comparable to barley by providing the best total dry matter production over the length of the season. Triticale was significantly superior to all other species for final grain recovery. Wheat produced the least amount of dry matter but the second highest grain yield. Oats in comparison had the poorest grain recovery of all species. Barley appeared to give the best balance between dry matter production and grain recovery. It should be noted that wheat has a higher return price for the sale of the grain.

SECTION 2 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 1: Species mean dry matter and grain yields from 2008–2012 trials.

Species	Dry matter 1 yield (t/ha)	Dry matter 2 yield (t/ha)	Grain yield (t/ha)
Barley	2.796	3.313	3.076
Oats	2.923	3.307	2.390
Triticale	2.502	3.074	3.975
Wheat	2.384	2.982	3.304

* Data for dry matter 2 was only available for 2010–2012.
Source: GRDC.

A total of 40 varieties were selected from the overall 127 varieties that data was collected for. The dry matter assessment and grain yield results for 8 barley, 13 oat, 5 triticale and 14 wheat varieties are presented in Table 2.

No one variety was ranked in the top 10 for both dry matter production and grain yield. The barley variety Urambie was the most consistent performer for grazing and grain recovery ranking number 11 for dry matter production at 6.12 t/ha and number 5 for grain yield at 3.72 t/ha. Three other strong performers were the two triticale varieties; El Alamein (6.08 t/ha dry matter and 4.14 t/ha grain yield) and Endeavour (5.91 t/ha DM and 4.08 t/ha grain yield); and Tennant, a winter wheat that produced 5.78 t/ha DM and 3.57 t/ha.

Table 2: Across sites and seasons, variety performance of commercially available dual purpose triticale varieties tested in Somerton and Purlough trials between 2008–2012.

Variety	Dry matter 1 yield (t/ha)	Dry matter 2 yield (t/ha)	Total dry matter (t/ha)	Grain yield (t/ha)	Trial number
Crackerjack (D)	1.93	3.63	5.56	4.27	5
El Alamein (AT573) (D)	2.66	3.41	6.08	4.14	7
Endeavour (D)	2.50	3.41	5.91	4.08	9
Tobruk (D)	2.75	2.82	5.56	4.58	7
Tuckerbox (D)	1.79	3.05	4.84	3.49	4

Source: GRDC.

The triticale varieties came to the fore when grain yield was taken into consideration with all five triticale varieties ranking in the top 10 for grain yield (Table 3).⁹

⁹ L Serafin, M Gardner, J Fleming, D Pottier, S Harden (2013) GRDC Update Papers: Dual Purpose Cereals: Varieties and management for the Northern Slopes and plains. <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Dual-Purpose-Cereals-Varieties-and-Management-for-the-Northern-Slopes-and-Plains>

SECTION 2 TRITICALE

TABLE OF CONTENTS

FEEDBACK

MORE INFORMATION

[Dual purpose cereals: varieties and management for the northern slopes and plains](#)

GRDC factsheet, [Dual-purpose crops](#)

[Optimising grazing and grain yield in dual-purpose crops, North Region](#)

[Dual purpose cropping](#)

[Dual purpose crops: do they have a fit in your system and how can they be managed to optimise forage and grain production](#)

Table 3: The top 10 ranked varieties for grain yield from Somerton and Purlough dual purpose cereal trials between 2008–2012

Variety	Species	Grain yield (t/ha)	Grain yield Ranking
Tobruk(Δ)	T	4.58	1
Crackerjack(Δ)	T	4.27	2
El Alamein (AT573)(Δ)	T	4.14	3
Endeavour(Δ)	T	4.08	4
Urambie(Δ)	B	3.72	5
SQ(Δ) Revenue(Δ)	W	3.61	6
Marombi(Δ)	W	3.59	7
Tennant(Δ)	W	3.57	8
Na(Δ)aroo(Δ)	W	3.55	9
Tuckerbox(Δ)	T	3.49	10

* Species included are B = Barley, O = Oats, T = Triticale and W = Wheat.

Earlier trials in NSW also compared yield outcomes of dual-purpose triticale varieties (Table 4).¹⁰

Table 4: Dual-purpose yield-performance experiments 2004–2009 in triticale varieties.

Compared with Endeavour(Δ); = 100%.

Variety North	First grazing DM Endeavour(Δ); = 2.63 t/ha	Second grazing DM Endeavour(Δ); = 2.39 t/ha	Grain recovery Endeavour(Δ); = 2.41 t/ha
Breakwell(Δ);▲	99	97	85
Crackerjack(Δ);▲	103	87	100
Endeavour(Δ);	100	100	100
Tobruk(Δ);▲	76	111	111
South	Endeavour(Δ); = 2.19 t/ha	Endeavour(Δ); = 2.23 t/ha	Endeavour(Δ); = 2.98 t/ha
Breakwell(Δ);▲	93	102	83
Crackerjack(Δ);▲	101	85	90
Endeavour(Δ);	100	100	100
Tobruk(Δ);▲	76	108	110

▲ Outclassed: Breakwell(Δ), Crackerjack(Δ) and Tobruk(Δ); (stri(Δ)e rust)

Source: NSW DPI

VIDEOS

WATCH: [Over the Fence: Grazing crops—reaping big rewards and returns](#)



PODCAST

LISTEN: [Dual purpose cropping: a farmer's perspective](#)

2.1.2 Choice of variety is critical

Winter habit is a characteristic where the growing point remains at ground level until a sufficient amount of cold weather triggers plants to change to spring habit, referred to as vernalisation. Vernalisation is the induction of a plant's flowering process by exposure to the prolonged cold of winter. After vernalisation, plants have acquired the ability to flower, but they may require additional seasonal cues or weeks of

¹⁰ P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI, <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>

i MORE INFORMATION

[Profitable dual purpose cereals in the north and central west: a Purlewaugh case study](#)

growth before they will actually flower. Spring-habit varieties have no delay, and heads grow up the stem as soon as tillering occurs.

When animals graze below the growing point, which can be quite early for spring-habit types, the tiller dies and new tillers need to form. This can be slow, especially in the middle of winter and if the supply of soil water is low.

Varieties vary in their levels of winter habit: this means varieties with only a low level will switch to a spring habit with heads growing up the stem after a shorter period of cold winter weather than varieties with a high level. High levels of winter habit mean heads remain at ground level for a much longer period in a given environment.

The desirable level of winter habit is largely related to climate and the purpose of growing the crop. For example, if the purpose is mainly for early sowing and for long grazing time over winter and spring, a variety with a high level of winter habit may suit best.

A dual-purpose role is more likely to best suit a variety with moderate levels of winter habit. This allows early sowing with no running to head too early, nor loss of tillers, and a period of 30 to 100 days of grazing before it is locked up for grain recovery. Desirable length of grazing is variable and is not only related to variety type but also to sowing time (more if early) and seasonal conditions.

Climate also has a big role in choosing how much winter habit a variety should have. Colder areas have winter habit that is satisfied faster, therefore varieties with greater winter habit are needed. In warmer environments, varieties with less winter habit are needed, unless they will be used only for grazing.

Varieties with winter habit tend to grow slower at first than spring-habit types. This is often of little consequence if sowing earlier, as the crop tends to make it up with better recovery after grazing in winter and early spring.¹¹

2.1.3 When to graze

Managing the timing and intensity of grazing dual purpose cereals is critical to achieving maximum dry matter and grain yield. In order to achieve this some knowledge of individual varieties growth rates is useful. The rate of growth of each variety needs to be monitored carefully to ensure grazing is timely.

Grazing can commence once the plants are adequately anchored with secondary roots. This is to prevent stock from removing plants from the ground (Photo 2). Identifying when to commence grazing is easier than identifying when to cease grazing.



Photo 2: Triticale grazed by cattle and used to clean up a paddock.

Source: [EverGraze](#)

¹¹ R Freebairn (2016) Profitable dual purpose cereals in the north and central west: a Purlewaugh case study, GRDC Update Paper, GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Profitable-dual-purpose-cereals-in-the-north-west>

SECTION 2 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Dual-purpose varieties can be sown early for winter grazing (30–100 grazing days). The ideal grazing time is when the canopy is closed (growth stages GS21–GS29, Figure 1). Continuous grazing is better than rotational grazing for fattening stock. Maintain adequate plant material (1,000–1,500 kg DM per ha) to give continuous and quick regrowth of the crop. Do not graze below 5 cm with prostrate varieties and below 10 cm for erect varieties.¹² The higher grazing height is particularly important with the erect-growing varieties. Over-grazing greatly reduces the plant’s ability to recover.¹³

The crop must be monitored regularly (at least twice a week) for stem elongation and the appearance of the first node. This indicates that the plant has gone into reproductive mode and grazing from this time onwards will reduce grain yield. Once the crop reaches this stage grazing should cease.¹⁴

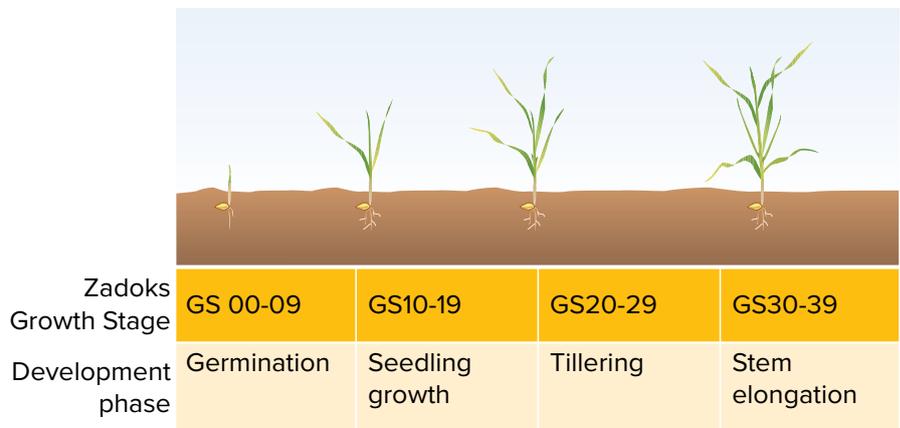


Figure 1: Zadoks cereal growth stages. The ideal grazing period for dual purpose triticale is between GS21-GS29. Stock should be removed from the paddock at the stem elongation phase (GS30).

Source: GRDC.

Once a variety reaches Zadoks growth stage 30 it is changing from vegetative to reproductive phase. Beyond this stage nodes may be felt inside the stem of the plant indicating that the developing head has now moved above ground level. At this stage livestock should be removed and the paddock locked up for grain recovery or hay production. If livestock are allowed to continue grazing beyond this point, developing heads may be grazed off leading to significant reductions in grain yield and tiller death. Growth stage assessment should always be carried out of the primary tiller as it is the most advanced.

The time taken to reach growth stage 30 varies with variety, temperature, grazing intensity and several other factors. Quick maturing varieties offer a reduced length of grazing, while long season varieties are often slow to produce dry matter and slower to reach growth stage 30 (Table 5).¹⁵

12 Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, <http://www.farmtrials.com.au/trial/13801>

13 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI, <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>

14 Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcrrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

15 L Serafin, M Gardner, J Fleming, D Pottie, S Harden (2013) GRDC Update Papers: Dual Purpose Cereals: Varieties and management for the Northern Slopes and plains. <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Dual-Purpose-Cereals-Varieties-and-Management-for-the-Northern-Slopes-and-Plains>

SECTION 2 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

MORE INFORMATION

[Yorke Peninsula and Mid-North trials highlight benefits of grain and graze](#)

[Effect of cutting on early sown triticale and wheat](#)

[Dual Purpose Triticale Improvement Program](#)

[Triticale: grazing guide](#)

Table 5: Somerton dual purpose cereal trial 2011 growth stage records in crop (planted 19th April, 2011).

Variety	Zadoks growth stage 27th June, 2011	Zadoks growth stage 16th August, 2011	Zadoks growth stage 14th September, 2011
Crackerjack(Δ)	26	39	64
El Alamein (AT573)	23	33	53
Endeavour(Δ)	24	32	51
Tuckerbox	27	39	64

Source: GRDC.

2.1.4 Breeding dual-purpose triticale

Grain producers on the south-western slopes of NSW have expressed the importance of dual-purpose triticale varieties, as they want to graze the crop through autumn and winter and have a subsequent grain crop, to increase their gross margin per hectare and also provide an insurance against harvest failure.

There is a high demand for feed grain in the southern part of the Northern region, especially for triticale from the dairy and pig industries. The reduced transport costs and the slightly higher price for triticale compared to other feed grains makes triticale an attractive proposition. Triticale is particularly suited to some areas due to its tolerance of acid soils and the high levels of exchangeable aluminium in these soils, especially where the subsoil is acidic and cannot be easily corrected by liming.

With support from the GRDC, the University of Sydney has been working to improve the productivity of dual-purpose triticales through plant breeding. This involves improving the grain yield and dry-matter production, producing winter triticales so there is a wider range of sowing dates, improving the grazing habit (so that the growing point is closer to the ground), and incorporating new sources of rust resistance. Shorter triticales are also produced to reduce the amount of stubble after harvest, suiting conservation-tillage farming practices, and also to improve grain yield.

The breeding program is also addressing grain quality, with the aim of improving ruminant productivity on triticale feed.¹⁶

2.1.5 Triticale grain for livestock

The major uses for triticale grain are as a feed supplement in the dairy industry, as a component in feeds used in beef feedlots, and as a constituent of compound rations for intensive pig and poultry farming. In livestock diets, triticale has a similar role to other cereals: it is primarily a good source of energy, as it has a moderate amount of protein and high amounts of starch and other carbohydrates.¹⁷

A key physical feature of triticale is that it is a soft grain; it has a hardness index almost half that of wheat and barley. This is an advantage in that less mechanical energy is required to mill triticale than wheat and barley prior to inclusion in livestock diets.

On the farm, triticale can be fed to livestock in the same way wheat or barley would be.¹⁸ It is well suited to feeding dairy cows, with the benefits stated in Table 6.

¹⁶ University of Sydney (2012) Triticale. Plant Breeding Institute. University of Sydney, http://sydney.edu.au/agriculture/plant_breeding_institute/key_work_results/triticale.shtml

¹⁷ EA Oelke, ES Oplinger, MA Brinkman (n.d.) Triticale. In Alternative Field Crops Manual. University of Wisconsin, <https://www.hort.purdue.edu/newcrop/afcm/triticale.html>

¹⁸ Agriculture Victoria (2012) Growing triticale. Note AG0497. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>

SECTION 2 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

MORE INFORMATION

[Triticale: stock feed guide](#)

[A guide to the use of triticale in livestock feeds](#)

[Assessing stock feed additives and mineral supplements](#)

Table 6: Average composition of cereal feed grains.

	Triticale	Wheat	Barley	Sorghum
Available energy				
Pigs DE (MJ/kg as fed)	13.5	13.8	12.9	14.6
Poultry AME (MJ/kg as fed)	12.8	12.7	11.4	14.3
Cattle ME (MJ/kg DM)	12.6	12.7	12.4	10.5
Crude protein (% as fed)	12.9	10.4	11.3	9.7
Lysine (% as fed)	0.44	0.31	0.38	0.20
Methionine (% as fed)	0.20	0.15	0.16	0.12
Threonine (% as fed)	0.42	0.29	0.37	0.27
Starch (%DM)	63	66	58	74
ND fibre (%DM)	15.9	15.9	21.3	12.7

Data derived from AusScan calibrations of Australian feed grains and "Feeding Standards for Australian Livestock-Pigs (CSIRO, 1987)

2.1.6 Triticale as a cover crop

A cover crop is planted primarily to manage soil erosion, soil fertility, soil quality, water, weeds, pests, diseases, biodiversity and wildlife in an agro-ecosystem. One approach used in southern cropping regions involves annual crops being sown into established lucerne, a practice known as lucerne inter-cropping (Figure 2).¹⁹ The benefits of doing this include reducing the risk of rainfall leakage during the cropping phase, as well as eliminating the costs of lucerne removal and re-establishment.

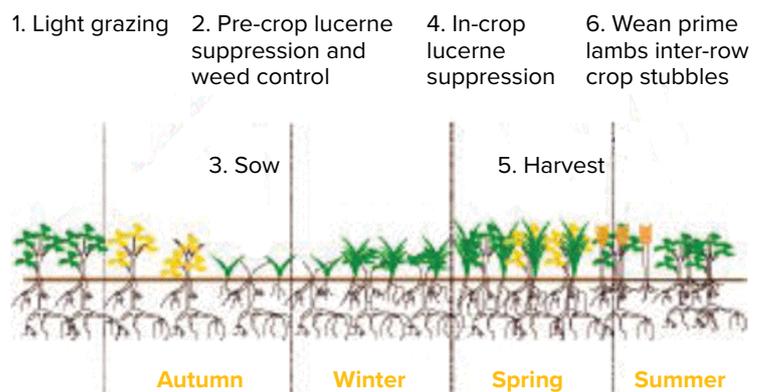


Figure 2: Lucerne inter-cropping practice.

Source: Agriculture Victoria

¹⁹ Agriculture Victoria (2015) Farmers' experiences. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/managing-dryland-lucerne/farmers-experiences>

i MORE INFORMATION

[Farmers' experience with lucerne inter-cropping](#)

AGT, [Astute](#)

Under-sowing lucerne

Triticale is one of the most commonly used cereals for undersowing with Lucerne (Photo 3).²⁰ Triticale has poor tillering capacity and good tolerance to shattering. This makes it a useful cereal as a cover crop to establish under-sown lucerne or medic, but seeding rates may need to be reduced.²¹

Only use a grain variety that is early maturing and choose a paddock with a low weed seed bank because of limited options for herbicides with varying species.

When under-sowing:

- Use a grain-only variety with the earliest available maturity suited to your region
- Sow the triticale at lower seeding rate (15–30 kg/ha) than used for optimising grain yield (60–100 kg/ha)
- Choose a paddock with low weed numbers as the combination of species can dramatically reduce herbicide options.
- Expect a reduction in grain yield.²²



Photo 3: A paddock of cereal under-sown with lucerne.

Photos: Andy Howard

2.2 Varietal performance and ratings yield

[Astute](#) is a new mid-season triticale that is an alternative for [Hawkeye](#), [Bison](#), first listed in 2015, became fully available in 2016. [Cartwheel](#) (which was tested as AT674) was also new for 2016.

[Astute](#)

[Astute](#) is a fully-awned variety suited to medium–high-yielding environments, and with excellent agronomic characteristics for grain production. It is rated:

- stem rust: R-MR
- stripe rust:
 - » [Tobruk](#) pathotype: not known
 - » Yr17-27: R-MR
- leaf rust: R-MR

It was bred by AGT (as TSA0466) to produce a very high-yielding triticale which would be the choice for growers looking to maximise the production from their triticale crops in high-potential environments. [Astute](#) combines broad adaptation, resistance to rust and CCN, good physical grain quality, and top-end yield capabilities.

[Astute](#) is suited to high yield potential areas of NSW and Victoria, with a very similar flowering time to [Hawkeye](#) and [Fusion](#). It is very tolerant of acid soils.

20 Agriculture Victoria (2015) Farmers' experiences. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/managing-dryland-lucerne/farmers-experiences>.

21 Agriculture Victoria (2012) Growing triticale. Note AG0497. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>

22 Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcrrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

SECTION 2 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

MORE INFORMATION

[Berkshire\(D\) brings home the bacon](#)

[Bogong\(D\) and Fusion\(D\) inseparable in 2014 trials](#)

[Bogong\(D\) and Canobolas\(D\)—SA, Vic, NSW](#)

[Big win for triticale](#)

Berkshire(D)

Berkshire(D) is a mid-season, awned variety with good straw strength. This variety has now been outclassed. It is rated:

- stem rust: R
- stripe rust:
 - » Tobruk(D) pathotype: MS
 - » Yr17-27: MR-MS
- leaf rust: R-MR*

* Provisional rating

This variety was purpose bred for high yield and feed quality traits for pigs by the University of Sydney and Pork CRC; it was registered in 2009. Its characteristics are:

- Improved digestible energy—13 MJ/kg compared to Tahara at 12 MJ/kg.
- Reduced fibre content—5% to 10% less than Tahara.
- Excellent yield—equivalent to best grain-only varieties currently available.
- Good straw strength.
- Quick to mid-season maturity.
- Moderately resistant to WA and Jackie strains of stripe rust.

Bison(D)

An early- to mid-season reduced-awn variety, Bison(D) is best suited to low–medium-yielding environments. It was intended as a replacement for Rufus. Bison(D) is an older variety.

Its characteristics are:

- Early-mid maturing, feed quality triticale.
- Tall plant type, with reduced awns and excellent disease resistance.
- Suited to central western NSW, southern NSW, northern Victoria, and SA.
- Moderately resistant to yellow leaf spot, and resistant–moderately resistant to *Septoria tritici* blotch.
- Tolerant to acid soils.

Bogong(D)

Bogong(D) (tested as H127) was released by the University of New England, Armidale, in 2008. It is a grain variety with early- to mid-season flowering (similar to Treat). It is fully awned and stiff-strawed. It has good resistance to all common field strains of rust. Bogong(D) has been one of the top-yielding varieties in evaluation trials across all environments in the seven seasons to 2015, up to 15% above Tahara. It is a widely adapted spring variety that is moderately susceptible to CCN.²³

Canobolas(D)

This is an early- to mid-season awned variety with stiff straw, shorter than Tahara. It was bred by the University of New England, and registered in 2009. It is a widely adapted spring variety and tolerates acid soil. It is rated:

- stem rust—R
- stripe rust—MRMS#
- leaf rust—RMR.

Trials in Trangie, NSW in 2014 found that Canobolas(D) although sown later than ideal, out-yielded some barley varieties and also provided better weed suppression. Canobolas(D) has a quick erect growth features that assist in early weed competition. It was also the tallest variety at maturity reaching a greater height than the weeds.²⁴

²³ C Jeisman (2015) Triticale variety sowing guide 2015. PIRSA, http://www.pir.sa.gov.au/_data/assets/pdf_file/0003/237909/triticale.pdf

²⁴ G Brooke, L Jenkins, R Graham, G McMullen (2015) Cereal variety × weed competition—Trangie 2014. NSW DPI, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0011/578288/northern-grains-region-trial-results-autumn-2015.pdf

SECTION 2 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

MORE INFORMATION

AGT, [Chopper](#)

GRDC, [Fusion](#)

[Goanna](#)

PODCAST

[LISTEN: Ground Cover Radio 110: Triticale program further lifts crop productivity](#)

Chopper

Chopper is a fully awned, semi-dwarf spring variety which resists lodging in high-yielding environments; it is significantly shorter than all other currently available triticale varieties (15% shorter than Tahara). It matures very early: 3–4 days earlier than Speedee, and 7–15 days earlier than Tahara. The variety was released in 2010. It has good grain quality, and performs best in short growing seasons or late-sowing situations. This variety has now been outclassed. It is rated:

- stem rust: MR-MS
- stripe rust:
 - » Tobruk pathotype: MS-S
 - » Yr17-27: MR-MS
- leaf rust: R-MR*
- CCN: R

* Provisional rating

Fusion

Fusion is a mid-season (similar to Tahara), fully awned, grain-only spring triticale. It has moderate plant height, slightly taller than Hawkeye and Jaywick, and similar height to Rufus. It yields well in dry or sudden finishes. Very tolerant of acid soils. It is rated:

- stem rust: R
- stripe rust:
 - » Tobruk pathotype: MR#
 - » Yr17-27: R-MR
- leaf rust: R-MR*
- CCN:R

mixed population, some plants are more susceptible to stripe rust.

*Provisional rating

It was released in 2012. Fusion produces large grain with low screening losses. Hectolitre weight is similar to that of Hawkeye and Jaywick, the benchmark varieties for this attribute. Its desirable sowing time is similar to Hawkeye and Tahara. Fusion is a fully awned triticale variety. It was released in 2012.

Goanna

Goanna is an early- to mid-season, fully awned, grain-only spring triticale, with a similar heading time to Treat, Tickit, Rufus and Hawkeye. It is a tall, white-chaffed variety. It is rated:

- stem rust: R
- stripe rust:
 - » Tobruk pathotype: MR-MS
 - » Yr17-27: R-MR
- leaf rust: R-MR*
- CCN: R.

It was released in 2011.

KM10

KM10 is a fast-growing early- to mid-season awned variety. It has excellent early forage production in all rainfall zones. It tends to have a smaller grain, and is ideally suited to grain production in short-season environments. It is rated:

- stem rust: R
- stripe rust:

- » Tobruk(Δ) pathotype: no data
- » Yr17-27: R-MR
- leaf rust: MR-MS
- CCN—susceptible.

It was released in 2014.

Tahara

A variety that has been widely grown for many years because of its reliability across a range of environments, Tahara is now outclassed by newer options. It may lodge in high-yielding situations. It is very tolerant of acid soils. Tahara is suited to most districts with rainfall up to 550 mm. It is rated:

- stem rust: R
- stripe rust:
 - » Tobruk(Δ) pathotype: MS
 - » Yr17-27: MR-MS
- leaf rust: R-MR*
- CCN—resistant

*Provisional rating

Its resistance makes it a valuable disease-break option. Released 1987 by the Victorian Department of Agriculture, Tahara has long been the benchmark variety for use in cereal rotations in most districts up to 500 mm average annual rainfall.

Yowie

Yowie is a medium to tall mid-season spring grain triticale that has slightly later heading than Tahara. It is fully awned and white-chaffed. It is rated:

- stem rust: R
- stripe rust:
 - » Tobruk(Δ) pathotype: MR-MS, MS#
 - » Yr17-27: MR
- leaf rust: R-MR*
- CCN: R.

mixed population, some plants are more susceptible to stripe rust.

*Provisional rating

It was released in 2010, and has shown similar yield performance to other triticale varieties in the National Variety Trials.

Hawkeye(Δ)

Hawkeye(Δ); (tested as TSA0108) was released by AGT in 2007, and is a broadly adapted, mid-maturing variety with high yield potential. It produces large grain with low screenings (similar to Tahara) and good test weight (like Treat), and is considered to be a high-yielding alternative to Tahara. It has very good acid soils tolerance.

Jaywick(Δ)

Jaywick(Δ); (tested as TSA0124) was released by AGT in 2007 and is a broadly adapted, mid-maturing variety with high yield potential. It produces large grain with low screenings and good test weight. It is considered a slightly earlier, higher-yielding alternative to Tahara. It has CCN resistance, and moderate to good resistance to all rusts.

MORE INFORMATION

Yowie

i MORE INFORMATION

[Endeavour](#)

[Tobruk](#)

2.2.1 Dual-purpose triticales

These varieties can be grazed early and then allowed to produce grain or cut for hay.

Cartwheel

Cartwheel is a long-season, dual-purpose triticale that is suitable for sowing from early March to early April. It is considered to be a stripe-rust resistant replacement for Tobruk. It has good early forage production when sown in March, and recovers from grazing to give excellent grazing in winter. Straw strength is good and has shorter stature than Tobruk. Grain yield after grazing is equivalent to that of Tobruk. It is rated:

- stem rust: R
- stripe rust:
 - » Tobruk pathotype: no data
 - » Yr17-27: R
- leaf rust: R.

Endeavour

Endeavour is a long-season variety with similar maturity to Breakwell. It is semi-awnless and has good straw strength, with excellent dry-matter production and excellent grain recovery after grazing. It is very tolerant of acid soils. It is rated:

- stem rust: R
- stripe rust:
 - » Tobruk pathotype: R-MR
 - » Yr17-27: R
- leaf rust: R-MR*
- CCN: R

*Provisional rating

It was registered in 2008.

Rufus

Rufus is a mid-season-maturing variety, with a tall growth habit and reduced awns, making it favoured for hay production. Grain yields in higher-rainfall regions have been superior to Tahara, but may also cause lodging. It is rated:

- stem rust: R
- stripe rust: MR-MS#
- leaf rust: R
- CCN: R.

It was released in 2005 by the University of New England.

Tobruk

With a strong winter habit Tobruk is a dual-purpose triticale, or a long-season grain-only variety with excellent grain yield. This variety, which was released in 2007, flowers earlier than Breakwell; and Endeavour. This variety has now been outclassed. It is rated:

- stem rust: R
- stripe rust
 - » Tobruk pathotype: MS-S"
 - » Yr17-27: MR
- leaf rust: R.

"Susceptible to head infection

Its characteristics are:

- Strong winter habit.
- Excellent yield after grazing compared to all other varieties in the NSW mixed cereal trials.
- Easy threshing.

Tuckerbox

Tuckerbox is a late-medium season, tall, high-tillering variety. It is a reduced-awn head type, and may be grown for forage or grain. It is very tolerant of acid soils. It was released in 2009. It is rated:

- stem rust: MR
- stripe rust:
 - » Tobruk(Δ) pathotype: MR-MS
 - » Yr17-27: MR
- leaf rust: R-MR
- CCN: R

Yukuri

Yukuri was bred by the University of New England in 2004, and is a late-medium season variety and a reduced-awn head type. It is suitable for forage and grain production in environments with 450 mm+ rainfall. Yukuri is susceptible to CCN.

Crackerjack(Δ)

Crackerjack(Δ) is a medium-season, dual-purpose variety. Optimum sowing time is from mid April. It has excellent establishment and early vigour, excellent grain recovery after grazing, and produces grain with a high test weight. It is tall when mature, and can be prone to lodging if not grazed.

2.2.2 Forage varieties

SF Bolt

SF Bolt is for forage only. It was bred in New Zealand for lower acid detergent fibre (ADF) and higher metabolizable energy level (ME) to make it suitable for grazing, green chop or whole-crop silage. It can be autumn or spring sown. There is very limited data on its performance in NSW.

2.2.3 Triticale trials

In trials in NSW, researchers compared yield performances for grain-only triticale (Table 7).²⁵ No recent data is available for north-western NSW as only a limited number of trials were conducted from 2008 to 2015.

²⁵ P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI, <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>

SECTION 2 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 7: Grain-only yield performance experiments, 2008–2015, compared with Fusion^(b) (which = 100%).

Variety	North-east Fusion ^(b) = 4.14 t/ha	Number of trials	South-east Fusion ^(b) = 4.57 t/ha	Number of trials	South-west Fusion ^(b) = 6.09 t/ha	Number of trials
Astute ^(b)	104	6	105	10	–	–
Berkshire ^{(b)▲}	95	15	93	29	100	6
Bison ^(b)	101	6	101	10	–	–
Bogong ^{(b)▲}	99	15	96	29	104	6
Canobolas ^{(b)▲}	97	13	95	26	106	5
Chopper ^{(b)▲}	89	15	87	29	87	6
Fusion ^(b)	100	11	100	22	100	5
Goanna	87	10	86	18	91	4
Hawkeye ^(b)	95	15	95	29	102	6
Jaywick ^(b)	92	15	93	29	103	6
KM10	87	4	89	7	–	–
Rufus▲	85	15	84	29	87	6
Tahara▲	84	15	83	29	86	6
Tobruk ^{(b)▲}	85	5	85	11	–	–
Tuckerbox	76	13	76	25	85	5
Yowie	86	11	86	22	96	5
Yukuri	74	15	75	29	95	6

▲Outclassed: Berkshire^(b), Bogong^(b), Canobolas^(b), Chopper^(b), Rufus, Tahara and Tobruk^(b) (all stripe rust)
^(b)Includes some irrigation trials
 The table presents data of NVT 'production value' multi-environmental trials on regional mean basis from 2008–2015.
 Source: NSW DPI

MORE INFORMATION

[Triticale variety trials NSW 2015 - NVT](#)

[Triticale variety trials SA 2015 - NVT](#)

Grain-quality characteristics and feed value for livestock are similar for all triticale varieties and are influenced more by seasonal conditions than by varietal differences (Table 8 ²⁶).

SECTION 2 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 8: Agronomic and disease characteristics of triticale varieties.

Variety	Grazing production	Straw strength	Maturity	Resistances					Cereal cyst nematode	RLN P. neglectus	Acid soils-sensitivity to aluminium
				Stem rust	Leaf rust	Tobruk pathotype	Stripe rust Yr 17-27 pathotype				
Dual-purpose											
Cartwheel(D)	quick-early	very good	mid-late	R	R-MR ^P	-	R	-	-	-	
Crackerjack(D) 2	quick-early	moderate	mid-late	-	-	-	-	-	-	-	
Endeavour(D)	quick-early	very good	late	R	R-MR ^P	R-MR	R-MR	R	-	V. tol	
Tobruk(D)▲	quick-early	very good	mid-late	R	R-MR ^P	MS-S ^a	MR	-	-	-	
Tuckerbox	quick-early	-	mid	MR	R-MR ^P	MR-MS	MR	R	-	V. tol	
Grain only											
Astute(D)	NR	very good	early-mid	R-MR	R-MR	-	R-MR	-	-	V. tol	
Berkshire(D)▲	NR	good	early-mid	R	R-MR ^P	MS	MR-MS	-	-	-	
Bison(D)	NR	good	early-mid	R-MR	R-MR	-	R	R	R	V. tol	
Chopper(D)▲	NR	very good-good	very early	MR-MS	R-MR ^P	MS-S	MR-MS	R	MR	-	
Fusion(D)	NR	medium-good	mid	R	R-MR ^P	MR ^b	R-MR	R	R	V. tol	
Goanna	NR	good	early-mid	R	R-MR ^P	MR-MS	R-MR	R	-	-	
Hawkeye(D)	NR	good	mid	R-MR	R-MR ^P	MR, MS-S ^b	MR, MS ^b	R	R	V. tol	
KM10	NR	good	very early	R	MR-MS	-	R-MR	S	-	-	
Tahara▲	NR	moderate	early-mid	R	R-MR ^P	MS	MR-MS	R	R	V. tol	
Yowie	NR	good	mid	R	R-MR ^P	MR-MS, MS ^b	MR	R	-	-	

NR	Not recommended
R	Resistant
R-MR	Resistant to Moderately resistant
MR	Moderately resistant
MR-MS	Moderately resistant to Moderately susceptible
MS	Moderately susceptible
MS-S	Moderately susceptible to Susceptible
S	Susceptible
S-VS	Susceptible to Very susceptible
VS	Very susceptible
V. tol	Very tolerant
P	Provisional rating
▲	Outclassed
a	Susceptible to head infection
b	mixed population, some plants are more susceptible to stripe rust.
-	Unknown or no data

Where ratings are separated by '&' the first is correct for the majority of situations, but different pathotypes are known to exist at a low level and the latter rating reflects the response to these pathotypes.

Source: [NSW DPI](#)

2.3 Planting-seed quality

Before determining seed-sowing rates, seed-germination levels need to be known. For purchased seed this will be stated on the bags supplied. Seed with approximately 80% germination or more is suitable for sowing. Seed produced in cooler tableland environments may tend to have poorer germination levels than seed produced in warmer regions, hence the need to check the germination rate.²⁷

But seed produced under higher temperatures can have slower germination, delayed emergence of the primary leaf, stunted growth, or even termination of the germination process (Photo 4).²⁸ In severe cases, seeds may die. During bulk storage, areas of excessive moisture can lead to the formation of microbe-induced 'hot spots' and since moisture moves from hotter to cooler areas, further local heating is caused, setting off a chain reaction.



Photo 4: Normal seed (left) compared to heat-damaged seed (right). Note the distinct colour difference.

Source: Grain SA

Seed impurities can occur from contamination through harvest, storage and machinery. Measurement of seed impurity will be included in a seed-purity certificate. Varieties that have been retained for multiple generations have a greater risk of seed impurity, with the build up of multiple chances for contamination. Ensuring that seed comes from clean, pure and even crops is imperative, and even so seed-purity tests should be carried out. Growers should conduct paddock audits prior to harvest to establish which paddocks best meet these criteria.

With dramatic increases in herbicide resistance, growers need to take seed purity into account when selecting paddocks for seed. This is because ryegrass and black oats now frequently appear in harvested grain samples, and have the potential to infest otherwise clean paddocks.²⁹

2.3.1 Seed size

Seed size is an important physical indicator of seed quality that affects vegetative growth and is frequently related to yield, market grade factors and harvest efficiency. A wide array of different effects of seed size has been reported for seed germination, emergence, and related agronomic aspects in many crop species. Generally, large seed has better field performance than small seed. Triticale has the largest seed size of all common small-grained cereal crops (Photo 5³⁰).

In triticale, higher germination and emergence has been noted with bigger seed size. Large seeds show a higher emergence potential than smaller seeds. Larger seeds

²⁷ RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report.pdf

²⁸ Grain SA (2012) Factors affecting wheat seed germination. Grain SA, <http://www.grainsa.co.za/factors-affecting-wheat-seed-germination>

²⁹ S Simpfendorfer, A Martin, M Sutherland (2012) Seed impurity undermines stripe rust resistance. 16th Australian Agronomy Conference, http://www.regional.org.au/au/asa/2012/disease/8325_simpfendorfer.htm#TopOfPage

³⁰ Alberta Agriculture and Forestry (2016) Triticale crop production. Revised. Alberta Agriculture and Forestry, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/fcd10571](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571)

SECTION 2 TRITICALE

TABLE OF CONTENTS

FEEDBACK

are capable of emerging from greater planting depths and have shown an enhanced ability to penetrate ground cover and survive burial by litter.³¹



Photo 5: *Triticale seed (left) is much larger than wheat seed (right).*

Source: Alberta Agriculture and Forestry

Early researchers of triticale found that plants from larger seed were superior in total germination, seedling dry weight, and in seedling establishment than those from small seed. Large seed of a given cultivar gave 51% higher field stand, 62% more seedling dry weight and 37.8% higher grain yield than plants from small seed.³²

Early seedling growth relies on stored energy reserves in the seed — the larger the seed, the greater the endosperm and starch reserves. Good seedling establishment is more likely if seed is undamaged, stored correctly, and comes from a plant that had adequate nutrition. Seed should not be kept when it comes from paddocks that were rain-affected at harvest. Seed grading is an effective way to separate good-quality seed of uniform size from small or damaged seeds and other impurities, such as weed seeds. Although size does not alter germination, bigger seeds have faster seedling growth, a higher number of fertile tillers per plant and potentially higher grain yield.

Seed size is usually measured by weighing 1,000 grains, known as the 1000-grain weight. Sowing rate needs to vary according to the 1,000-grain weight for each variety, in each season, in order to achieve desired plant densities.³³ To measure 1,000-grain weights, count out 10 lots of 100 seeds, then combine and weigh the whole lot. When purchasing seed, remember to request the seed-analysis certificate, which includes germination percentage, and the seed weight of each batch where available.

For a seed to emerge successfully from the soil, the seed should never be planted deeper than the plant's coleoptile length. The coleoptile is the pointed, protective sheath that encases the emerging shoot as it grows from the seed to the soil surface. Coleoptile length is an important characteristic to consider when planting a crop, especially in drier seasons when sowing deeper to reach soil moisture. Sowing varieties with short coleoptile lengths too deep can cause poor establishment,

³¹ S Ambika, V Manonmani, G Somasundaram (2014) Review on effect of seed size on seedling vigour and seed yield. *Research Journal of Seed Science*, 7, 31–38.

³² UR Bishnoi, VT Sapra (1975) Effect of seed size on seedling growth and yield performances in hexaploid triticale. *Cereal Research Communications*, 49–60.

³³ NSW DPI District Agronomists (2007) Wheat growth and development. Procrop Series. NSW DPI, <http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat-barley-and-other-winter-cereals/growth-and-development>

because the shoot will emerge from the coleoptile underground and it may never reach the soil surface.³⁴

2.3.2 Seed germination and vigour

Seed germination and vigour greatly influence establishment and yield potential. Germination begins when the seed absorbs water, and ends with the appearance of the radicle. It has three phases:

- water absorption (imbibition)
- activation
- visible germination³⁵

Triticale has excellent vigour due to its hybrid characteristics³⁶, and germination increases with increasing seed size. Seed vigour affects how well the seed or seed lot germinates and emerges. Loss of seed vigour is related to a reduction in the ability of the seeds to carry out all of the physiological functions that allow them to grow well. This process, called physiological ageing (or deterioration), starts before harvest and continues during harvest, processing and storage. Seed performance is progressively reduced due to changes in cell membrane integrity, enzyme activity and protein synthesis. These biochemical changes can occur very quickly (a few days) or more slowly (years), the timescale depending on genetic, production and environmental factors that are not yet fully understood. The end point of this deterioration is death of the seed (i.e. complete loss of germination).

However, seeds lose vigour before they lose the ability to germinate. That is why seed lots that have similarly high germination values can differ in their physiological age (the extent of deterioration) and so differ in vigour and therefore the ability to perform.³⁷

For more information on factors affecting germination, see [Section 4: Plant growth and physiology](#).

Grain retained for seed from a wet harvest is more likely to be infected with seed-borne disease. It is also more likely to suffer physical damage during handling, increasing the potential for disease. Seed-borne disease generally cannot be identified from visual inspection, and so requires laboratory testing.³⁸

For purchased seed, request a copy of the germination and vigour-analysis certificate from your supplier. For seed stored on the farm, you can send a sample to a laboratory for analysis.

While a laboratory seed test for germination should be carried out before seeding so growers can calculate seeding rates, a simple on-farm test can be done in soil at harvest and during storage:

- Use a flat, shallow, seeding tray (about 5 cm deep). Place a sheet of newspaper on the base to cover the drainage holes, and fill with clean sand, potting mix or freely draining soil (Photo 6).³⁹ Ideally, the test should be done indoors at a temperature of ~20°C or lower.
- Alternatively, lay a well-rinsed plastic milk container on its side and cut a window in it. Place unbleached paper towels or cotton wool in the container, and lay out the seeds on this. Moisten and place on a window-sill. Keep moist, and count the seeds.

34 J Pumpa, P Martin, F McCrae, N Coombes (2013) Coleoptile length of wheat varieties. NSW DPI, <http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat-barley-and-other-winter-cereals/coleoptile-length>

35 NSW DPI Agronomists (2007) Wheat growth and development. Procrop Series. NSW DPI, <http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat-barley-and-other-winter-cereals/growth-and-development>

36 AGF Seeds (2012) Triticale. AGF Seeds, <https://agfseeds.com.au/triticale/>

37 ISTA Vigour Test Committee (1995) Understanding seed vigour. International Seed Testing Association, <http://www.seedtest.org/upload/pri/product/UnderstandingSeedVigourPamphlet.pdf>

38 GRDC (2011) Saving weather damaged grain for seed, northern and southern regions. Retaining Seed Fact Sheet. GRDC, http://store.grain.com.au/wp-content/uploads/2013/06/GRDC_FS_RetainingSeed2.pdf

39 P Matthews, D Holding (n.d.) Germination testing and seed rate calculation. Pulse Point 20. NSW DPI, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0005/157442/pulse-point-20.pdf

SECTION 2 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- Randomly count out 100 seeds. Do not discard damaged ones, and sow 10 rows of 10 seeds at the correct seeding depth. This can be achieved by placing the seed on the smoothed soil surface and pushing in with a pencil marked to the required depth. Cover with a little more sand or soil and water gently.
- Keep the soil moist but not wet, as overwatering will result in fungal growth and possible rotting.
- After 7–10 days, most of the viable seeds will have emerged.
- Count only the normal, healthy seedlings. If there are 78 normal vigorous seedlings, for example, the germination percentage is 78%.
- Germination of 80% is considered acceptable for cereals.
- The results from a laboratory seed-germination test should be used for calculating seeding rates.⁴⁰

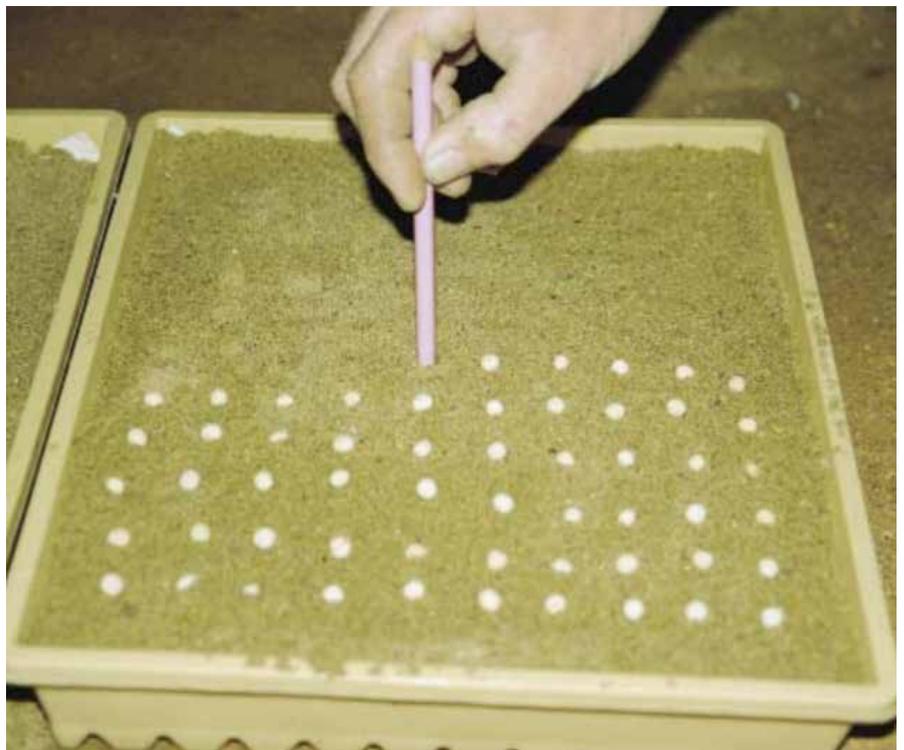


Photo 6: Use can use a pencil or straw to poke holes in a testing tray.

Source: NSW DPI

MORE INFORMATION

[Germination testing and seed rate calculation](#)

2.3.3 Seed storage

The aim of storage is to preserve the viability of the seed for future sowing and maintain its quality for market. A seed is a living organism that releases moisture as it respire.

Triticale is a softer grain than wheat and barley, which may make it easier to mill for livestock diets, but also means that it is more susceptible to insect damage in long-term storage.⁴¹ The ideal storage conditions are listed below.

- Temperature <15–20°C—high temperatures can quickly reduce seed quality and its ability to germinate. This is why germination and vigour testing prior to planting is so important.
- Moisture control—temperature changes cause air movements inside the silo, carrying moisture to the coolest parts of the seed. Moisture is carried upwards by

⁴⁰ GRDC (2011) Saving weather damaged grain for seed, northern and southern regions. Retaining Seed Fact Sheet. GRDC, http://storedgrain.com.au/wp-content/uploads/2013/06/GRDC_FS_RetainingSeed2.pdf

⁴¹ Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcra.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

SECTION 2 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [Over the Fence: Insure seed viability with aerated storage](#)



convection currents in the air; these are created by the temperature difference between the warm seed in the centre of the silo and the cool silo walls, or *vice versa*. Moisture carried into the silo head space may condense and fall back as free water, causing a ring of seed to germinate against the silo wall.

- Aeration slows the rate of deterioration of seed with 12.5–14% moisture content. Aeration markedly reduces grain temperature and evens out temperature differences that cause moisture movement.
- No pests—a temperature of <15°C stops all major grain insect pests from breeding, arresting activity at all stages of the life cycle so that they cause little to no damage.⁴²

For more information, see [Section 13: Storage](#).

2.3.4 Safe rates of fertiliser to sow with seed

Key points:

- Care must be taken to separate fertiliser and seed to prevent damage to emerging seedlings.
- Crops vary in their tolerance to fertiliser and fertilisers vary in toxicity.
- Seeding systems with narrow seed spread, wide row spacing and no seed/fertiliser separation are more susceptible to toxicity.
- There is greater potential for damage when high fertiliser rates are used, especially in lighter soil types or cooler, drier seeding conditions.
- Seedbed utilisation is a method of quantifying safe fertiliser rates for different seeding systems (see page 3).

Increased row spacing and zero-till seeding can result in more fertiliser being placed in the seeding row, causing damage to emerging seedlings. This risk can be reduced by increasing the spread of seed and fertiliser in the row, reducing in-furrow fertiliser rates or separating seed and fertiliser bands.

A productive triticale will require the application of phosphorous (P) and nitrogen (N) at sowing. Additional nitrogen is likely to be required for maximum dry-matter production for grazing and grain yield, particularly if the crop has been grazed. Consider applying 15–20 kg P/ha at sowing depending on the row spacing's of your machine. This is equivalent to 75–100 kg of mono-ammonium phosphate (MAP) per ha, which will also include 7.5–10 kg N/ha.⁴³

Soil testing, including deep nitrogen testing, is especially important following wet summers as the loss of nutrients by water-logging, leaching and summer weeds, may or may not be balanced by higher release of mineralised nutrients from the warm, moist soils. Where soil nutrient status is low, and soil moisture is high, there is the opportunity to use higher rates of fertiliser at seeding to meet the needs of the crop. While placing fertiliser in the seed row is an effective practice, germinating seeds are susceptible to damage by fertiliser. Care must be taken to create space between seed and fertiliser, especially with high fertiliser rates and under wide row spacing. If row spacing is increased but the fertiliser rate per hectare remains constant, then the amount of fertiliser in each row increases. The narrow seed spread typically created by disc seeders can also increase the potential for seedling damage by fertiliser.

The separation of seed from fertiliser is three-dimensional—along, across and down the furrow. The concept of seed bed utilisation (SBU) has been used to address this issue.

Factors to consider when selecting fertilisers and rates

There are several factors that contribute to the safe amount of fertiliser that can be placed with the seed.

42 NSW DPI Agronomists (2007) Wheat growth and development. Procrop Series, NSW DPI, https://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

43 Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcrrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

Fertiliser type

All fertilisers are relatively concentrated chemical compounds that can affect delicate germinating seeds in a couple of ways.

Osmotic effect - In chemical terms fertilisers are salts and can affect the ability of the seedling to absorb water by osmosis. Too much fertiliser (salt) near the seed and desiccation or 'burn' can occur. However, fertilisers vary in salt index or burn potential depending on composition. As a general rule, most common nitrogen and potassium fertilisers have a higher salt index than phosphorus fertilisers.

Potential to release ammonia - Fertilisers that have the potential to release free ammonia can cause ammonia toxicity in seed. Consequently, in-furrow placement of ammonium phosphate and urea-containing fertilisers is usually not advisable. A solution of urea and ammonium nitrate (UAN) can be applied successfully in-furrow but there is a risk of ammonia damage where high rates are used, especially in situations when germinating seedlings are stressed.

Efficiency enhancers - Some strategies to enhance fertiliser efficiency, such as the use of polymer coatings or urease inhibitors will slow the rate of ammonia production and make these products less likely to cause crop damage.

Soil type and environment

Soil conditions that tend to concentrate salts or stress the germinating seed increase the potential for damage. So, the safe limit for in-furrow fertilisation is reduced with lighter soil texture (sands) and in drier soil conditions. It is also reduced when environmental conditions such as cool temperatures induce stress and/or slow germination. These can result in prolonged fertiliser-seed contact, increasing the likelihood of damage. Good rain immediately after sowing can reduce the potential for damage as salts are diluted and ammonia is dissolved, which reduces the concentrations around the seed.

Machinery configuration

The type of sowing point, seed banding boot used and the spacing between the drill rows both affect the concentration of fertiliser near seed and the likelihood of damage.

Increasing seed bed utilisation (SBU) using seeding systems - When high SBU seeding systems were combined with high seed rate, the grain yield and crop/weed competition were both maximised. Practical options to achieve a high SBU include fitting paired row seeding boots to existing tillage systems, using greater soil disturbance ribbon sowing systems, or reducing row spacing. When tyne-based systems are used to achieve high SBU, stubble clumping is typically increased and uniformity of seeding depth decreased.

Row spacing - If the same fertiliser rate is used with different row spacings, then the amount distributed along each seeding row will increase as row spacing becomes wider. For example, the rate of fertiliser applied in a 30 cm row is basically double that of a 15 cm row. To avoid this increased fertiliser concentration in wide-row systems the safe rate of in-furrow fertiliser decreases as row spacing increases (Table 9).

SECTION 2 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 9: Approximate safe rates of N as urea, mono-ammonium phosphate (MAP) or di-ammonium phosphate (DAP) with the seed of cereal grains if seedbed has good moisture at or near paddock capacity).

Soil Texture	25 mm (1") seed spread ²			50 mm (2") seed spread ²		
	Row spacing			Row spacing		
	180 mm (7")	229 mm (9")	305 mm (12")	180 mm (7")	229 mm (9")	305 mm (12")
	SBU3			SBU3		
	14%	11%	8%	29%	22%	17%
Light (sandy loam)	20	15	11	40	30	22
Medium-Heavy (loam to clay)	25	20	15	50	40	30

Source: GRDC

Seedbed utilisation - The concept of SBU has been used to help quantify this issue. SBU is simply the seed/fertiliser row width divided by the seed row spacing, that is, the proportion of row space occupied by the seeds. The wider the lateral seed spread, for a specific row spacing, the greater the SBU. As SBU increases, so does the safe rate of in-furrow fertilisation. The greater the lateral scatter of seed and fertiliser in the seed band or row (along, across and to depth) the more fertiliser that can be safely applied with the seed. The type of planting equipment and seed opener influences the closeness of seed-fertiliser contact (Table 10). For example, minimal lateral spread is achieved by many disc openers, with lateral spread generally increasing with share width. Double shoot/ribbon seeding openers, where seed is spread across a wider furrow, achieve the greatest lateral spread. When the lateral seed spread = share width = row spacing, a 100 per cent SBU is achievable.

Table 10: Differences in seed bed utilization for a range of seeding points and boot combinations.

Seeding point	Common seed spread (mm)	% seed bed utilisation (SBU)		
		Row spacing (mm)		
		150	225	300
125 mm share	65	43	29	22
65 mm share	46	31	20	15
Single side band opener	36	24	16	12
Spear point	25	17	11	8
Inverted T	25	17	11	8

Source: GRDC

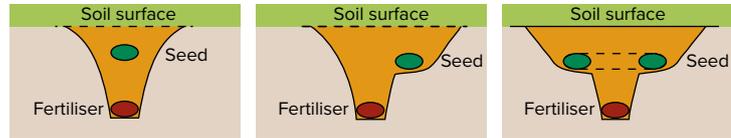
Openers with split banding systems can separate the seed and fertiliser laterally and vertically (Figures 3 A, B and C). The greater the angle of the fertiliser boot to the seed boot the greater the vertical separation potential between the seed and fertiliser. The width of spread must be checked under field conditions. It may vary with air velocity, ground speed, seeding depth and soil conditions. Along with seeding system crop type, fertiliser and environmental conditions must still be considered. Table 9 shows the safe rates of fertiliser urea for wheat. Seedbed moisture content is also an important factor, and damage is more likely with dry soils rather than moist soils. If the soils are dry or borderline, then rates should be at least halved from those in Tables 2.⁴⁴

⁴⁴ GRDC (2011) Fertiliser Toxicity—Fact sheet: Care with fertiliser and seed placement. <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2011/05/fertiliser-toxicity>

SECTION 2 TRITICALE

TABLE OF CONTENTS

FEEDBACK



A. Single outlet with centre banding

Pros: Sub-seed soil disturbance, fertiliser separation banded at depth.

Cons: High draft and breakout force required compared with tillage at seeding depth, seed placement quality variable.

B. Single outlet with side banding

Pros: Sub-seed soil disturbance, fertiliser separation banded at depth, improved seed placement, good moisture transfer to seed.

Cons: High draft and breakout force required, potentially higher soil and residue disturbance.

C. Dual outlet paired row and ribbon sowing systems

Pros: Sub-seed soil disturbance, fertiliser separation, good seed placement except over centre section, higher seed-bed utilisation.

Cons: High draft and breakout force required, higher soil and residue disturbance influencing seeding depth uniformity.

i MORE INFORMATION

[Care with fertiliser and seed placement—GRDC Factsheet](#)

Figure 3: Three arrangements of split seed and fertiliser banding with tillage below the seeding point that illustrate the different types of seed and fertiliser separation achieved.

Source: GRDC

Planting

Key messages:

- Triticale is not usually prone to infection from smuts and bunt. However, it is good insurance to apply a seed dressing to the grain when it is being graded.
- Triticale is generally sown at much the same time as other cereals. Optimal temperature for germination in triticale is 20°C.
- Triticale is more easily damaged by frost damage than wheat, so sowing should be planned to achieve flowering outside of the frost window if the crop is for grain only. Forage crops should be sown earlier when autumn moisture is adequate where grazing can help mitigate frost risk.
- Aim to achieve the same plant populations as for wheat; i.e. set the seeder 25–40% above the setting recommended for wheat, as triticale grain is larger.
- Depending on seed size, triticale should be sown at a seeding rate of 60–100 kg/ha (for grain only), 100–120 kg/ha (grain and grazing).
- The recommended sowing depth for triticale is 2–5 cm.

Most cultural practices needed for growing triticale can be taken directly from wheat. These include:

- managing for seedbed preparation
- seeding rate
- seeding depth
- seeding date
- seeding methods¹

3.1 Seed treatments

Fungicidal seed treatments are applied to triticale seeds to protect the crop from seed-borne diseases such as smuts, bunts and rusts, and also to control insects. Triticale is not usually prone to infection from smuts and bunt. However, it is good insurance to apply a seed dressing to the grain when it is being graded. Stripe rust may be a problem in some triticale varieties, so it is advantageous to treat seeds to provide seedling protection against this rust in high risk areas.²

Fungicidal seed dressings treatment should form an integral part of the triticale disease-management program. What products are used will vary with variety and sowing time. Seek local advice.³

When treating seed, always read the chemical label and calibrate the applicator. Seed treatments work best when they are used in conjunction with other disease-management practices such as crop and paddock rotation, using only clean seed, controlling the 'green bridge' in the paddock and planting resistant varieties. This is especially important when managing diseases such as stripe rust.

3.1.1 Emergence problems

there are risks with using seed treatments. Research shows that some can delay emergence by:

- Slowing the rate of germination.
- Shortening the length of the coleoptile, the first leaf and the sub-crown internode.

¹ Alberta Agriculture and Forestry (2016) Triticale crop production. Revised. Alberta Agriculture and Forestry, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/fcd10571](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571)

² Agriculture Victoria (2012) Growing triticale. Note AG0497. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>

³ Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcrrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

SECTION 3 TRITICALE

TABLE OF CONTENTS

FEEDBACK

i MORE INFORMATION

Cereal seed treatments 2018

A delay in emergence due to decreased vigour increases the exposure of seeds to pre-emergent attack by pests and pathogens, or to soil crusting, hostile soil temperatures, and potential damage from some pre-emergent herbicides such as Trifluralin or chlorsulfuron (Glean), which can also reduce the coleoptile length; these may lead to a failure to emerge at all. The risk of this occurring increases when seed is sown too deeply or into a poor seedbed, especially in varieties with shorter coleoptiles. As the amount of certain fungicides increases, the rate of germination slows; e.g. triazoles can cause a lot of damage to emerging crops.

Product registrations change over time, and products containing the same active ingredient may have different registration details in different states. Therefore, before using any chemical, always check the registration status for the way you intend to use it in your state; this is usually on the current product label.⁴

Sowing too deep is a common cause of emergence problems. The coleoptile, which surrounds the first leaf until the shoot emerges, protects and guides the shoot as it grows through the soil. If seed is sown deeper than the length of the coleoptile the plant can fail to emerge (Figure 1). Because coleoptile lengths vary from one variety to another, some varieties can tolerate deeper sowing. Coleoptile lengths also vary greatly from one batch of seed to another; in fact, the source of seed is often more critical than the variety in determining coleoptile length.⁵

Coleoptile length is influenced by seed size and several other factors, including variety, temperature, low soil water and certain seed dressings, such as those with the active ingredient triadimenol or flutriafol. Trifluralin and several Group B pre-emergent chemicals can also affect coleoptile length. Growers should read the label when using any seed-dressing fungicide for cereals, in order to see what affect it may have on coleoptile length.⁶

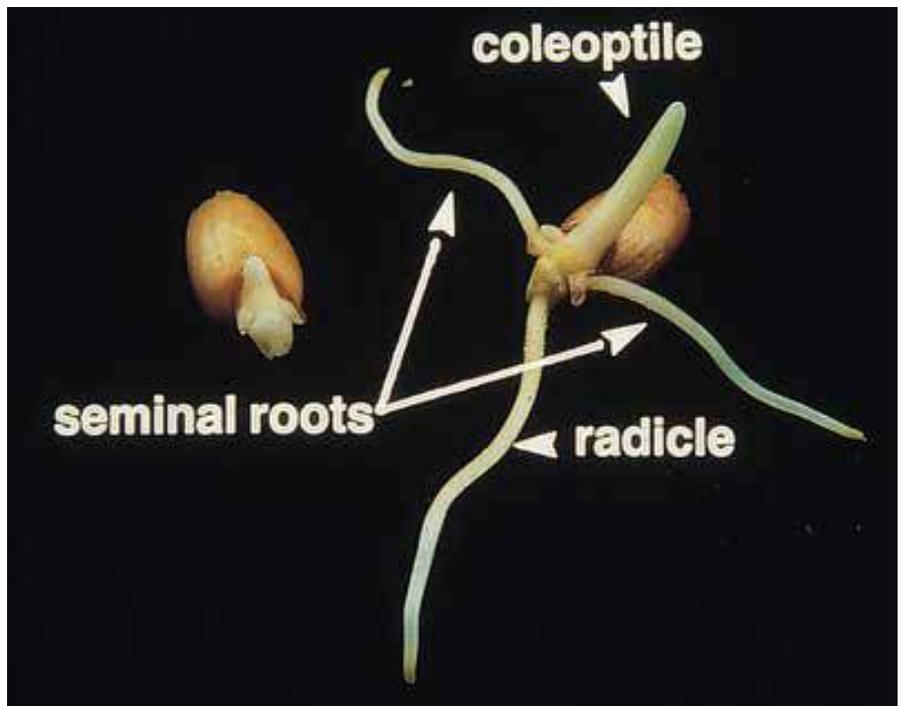


Photo 1: A larger seed will sprout a longer coleoptile, which is useful if for deeper planting allowing access to soil moisture in a dry season.

Photo: [David L. Hansen, University of Minnesota](#)

4 NSW DPI District Agronomists (2008) Wheat growth and development. Procrop Series. NSW DPI, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

5 H Wallwork (2017) Cereal seed treatments 2016. SARDI, http://pir.sa.gov.au/_data/assets/pdf_file/0005/237920/final_web_CerealSeed_Treatments_2017-18_booklet.pdf

6 J Pumpa, P Martin, F McCrae, N Coombes (2013) Coleoptile length of wheat varieties. NSW DPI, <http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat-barley-and-other-winter-cereals/coleoptile-length>

SECTION 3 TRITICALE

TABLE OF CONTENTS

FEEDBACK

MORE INFORMATION

GRDC factsheet, [Targeted nutrition at sowing](#)

VIDEOS

WATCH: [GCTV Extension Files: Wheat sowing strategies](#)



WATCH: [GCTV Extension Files: Early sowing opportunities](#)



WATCH: [Early sowing in the LRZ](#)



WATCH: [GCTV15: Optimal flowering—follow-up](#)



3.1.2 Fertiliser at seeding

The amount of nitrogen that can be safely placed alongside seed when planting will vary depending on the soil texture, the amount of seedbed utilisation, and moisture conditions. Higher amounts of nitrogen can be applied with the seed if it is a polymerised form of urea, where the nitrogen is released over several weeks. If soil moisture is marginal for germination, high rates of fertiliser should not be placed with the seed. Both nitrogen and phosphorous can be banded before seeding, but take care to avoid loss of seedbed moisture and protective crop residue.

Place phosphorous with or near the seed at seeding time, or band before seeding.⁷

For more information, see [Section 2.3.4 Safe rates of fertiliser to sow with seed](#).

3.2 Time of sowing

Key points:

- Early sowing can accelerate establishment and allow the crop to make full use of the growing season, but it can increase the risk of frost during critical growth stages and the risk of haying off in a dry finish.
- The flowering time of triticale is controlled by the interaction of several factors that can include temperature, day length, and the variety's need for cold temperatures.
- Most Australian triticale varieties flower in response to the accumulation of warm temperatures. Many varieties also have a cold-temperature requirement (vernalisation), and some varieties flower in response to longer days.
- Winter triticale can be sown earlier than spring triticale in suitable regions, as their cold requirement delays flowering.
- To minimise risk, varieties with a range of flowering dates and maturities should be sown, providing other criteria such as disease resistance are also met.
- The relationship between sowing date and crop development can interact with disease development and nutrient management.⁸

Triticale is generally sown at much the same time as other cereals. The optimum time of sowing depends largely on the variety being grown and the use of the crop; i.e. forage or grain (Table 1).⁹

Acting promptly when a sowing window is available has been proven to be critical to farming success over many seasons. Delayed sowing has generally shown to be costly, although to sow very early increases frost risk in some varieties. Dry sowing for a portion of the crop has been very successful, and can be considered for triticale (as well as other cereals).¹⁰

Long-season varieties such as Endeavour(®) and Tobruk(®) can be sown as early as mid-February if good rains allow and soil temperatures are not too high. Tobruk(®) should only be sown this early if it is going to be grazed. Main-season varieties such as the traditional Tahara and Berkshire(®) and the newer varieties of Astute(®) and Chopper(®), should be sown at the same time as main-season wheat, during May and early June.

In a study comparing the tolerance of cereal seeds to a range of temperatures, triticale was found to be more sensitive than wheat and barley to germination

⁷ Alberta Agriculture and Forestry (2016) Fall rye production. Agdex 117/20-1. Revised. Alberta Government, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/agdex1269/\\$file/117_20-1.pdf](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf)

⁸ GRDC (2011) Time of sowing. Factsheet. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2011/03/time-of-sowing>

⁹ P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI, <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>

¹⁰ Agriculture Victoria (2012) Growing triticale. Note AG0497. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>

SECTION 3 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

temperature.¹¹ Very low temperatures can damage triticale seedling during germination and emergence (Figure 3).¹²

Table 1: Suggested sowing times for triticale in NSW, 2017.

Variety	Weeks	February		March			April			May			June			July				
		3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2			
Endeavour(D)		>	★	★	★	★	★	★	★	<	<									
Cartwheel		>	★	★	★	★	★	★	★	<	<									
Tobruk(D▲)		>	★	★	★	★	★	★	★	★	★	★	★	★	<					
Crackerjack 2							>	★	★	★	★	★	<	<						
Tuckerbox										>	★	★	★	★	★	★	<			
Yowie										>	★	★	★	★	★	★	<			
Astute(D), Berkshire(D▲), Bison, Fusion, Goanna, Hawkeye, Rufus▲, Tahara▲											>	★	★	★	★	★	<			
Chopper(D▲), KM10												>	>	★	★	★	★	★	<	<

Aim to sow in the earlier part of the optimum time indicated to achieve maximum potential yield, particularly in western areas. Soil moisture, soil fertility and the likelihood of frost in a particular paddock at flowering influence the actual sowing date.

> Earlier than ideal, but acceptable.

★ Optimum sowing time.

< Later than ideal, but acceptable.

▲ Outclassed.

Source: NSW DPI

MORE INFORMATION

GRDC factsheet, [Time of sowing, Northern Region](#)

3.3 Targeted plant population

Key points:

- Know the germination percentage of the triticale seed to be sown.
- Plant a higher sowing rate of triticale seed than when planting wheat. This is because triticale has larger seeds than does wheat; in fact, it has the largest seed of the common small-grained cereals.
- Adjust seeding rates to achieve targeted plant densities for specific triticale uses and conditions.
- Keep in mind that optimum seeding rates vary depending on what the triticale will be used for.
- For mono-crop triticale forage production, recommended seeding rates are usually 25% higher than for grain production.¹³

The plant population, which is determined by seeding rate and establishment percentage, can be an important determinant of tiller density and, later, head density.¹⁴ Target plant densities should reflect the tillering capacity of the variety. For example, to achieve target tiller numbers, varieties that don't tiller much should be sown at higher plant densities than those that grow a lot of tillers (Photo 2). Target tiller numbers relate to the number of tillers that can be sustained to produce optimum yields. These often relate to rainfall, e.g. target tiller number for 500 mm rainfall zone is approximately 500 tillers/m².

Seed size influences plant density, too, with large seeds requiring a higher sowing rate than smaller seeds in order to target the same population. It should be

¹¹ T Buraas, H Skinnes (1985) Development of seed dormancy in barley, wheat and triticale under controlled conditions. *Acta Agriculturae Scandinavica*, 35 (3), 233–244.

¹² Alberta Agriculture and Forestry (2016) Triticale crop production. Revised. Alberta Agriculture and Forestry, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/fcd10571](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571)

¹³ Alberta Agriculture and Forestry (2016) Triticale crop production. Revised. Alberta Agriculture and Forestry, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/fcd10571](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571)

¹⁴ G Butler, W Manning, L Serafin (2003) Population density studies in sorghum and wheat. GRDC Update Paper. GRDC, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2003/09/Population-density-studies-in-sorghum-and-wheat>

SECTION 3 TRITICALE

TABLE OF CONTENTS

FEEDBACK

determined for each seed lot, as results vary depending on how old the seed is and conditions it has been grown under.¹⁵



Photo 2: *Triticale paddock sown according to targeted plant population.*

Source: Midwest Cover Crops Council

The range of sowing rates varies with variety and end use (Table 2).

Triticale sown for grazing should be sown at a seeding rate to obtain 150 plants/m² (100–120 kg/ha), which is the same as grazing wheat. Grain-only triticale target population can be reduced to 100–120 plants/m² (60–100 kg/ha), as for main-season grain-only wheat.

When sowing triticale as a cover crop (i.e. under-sown with pasture) reduce seeding rate to approximately 10–20% of normal, targeting 15–30 kg/ha.¹⁶

Table 2: *Recommended plant populations for different uses of triticale.*

Purpose or growing conditions	Best sowing rate (kg/ha)
Grain only	60–100
Grain and grazing	100–120
Under-sowing pastures	15–30
Irrigation, high rainfall	100–120

Source: NSW DPI

The target plant population for triticale will also vary according to rainfall (Table 3).¹⁷ Aim to achieve the same plant populations as for wheat; i.e. set the seeder 25–40% above the setting recommended for wheat as triticale grain is larger than wheat grain (23,000 seeds/kg).¹⁸

Average graded seed sizes are:

- large, 24,000 seeds/kg

¹⁵ K Condon (2003) Targeting optimum plant numbers. Agnote DPI-431. NSW DPI, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/168523/targeting-optimum-plant-numbers.pdf

¹⁶ Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

¹⁷ N Poole (2005) Cereal growth stages. GRDC, <https://www.researchgate.net/file/PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798>

¹⁸ Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, <http://www.farmtrials.com.au/trial/13801>

- medium, 27,500 seeds/kg
- small, 30,000 seeds/kg

Target plant numbers to account for differences in tillering capacity. Triticale does not tiller well. The desired plant density for triticale is 150 plants/m², and up to 200 plants/m² in high rainfall zones. Depending on seed size this equates to a seeding rate of 60–100 kg/ha. If sowing is delayed, or when sowing on light sandy soils, plant at the higher plant density.¹⁹

Lower seeding rates may be suitable for dry conditions. Triticale has greater difficulty in compensating for low stand establishment. Use grower experience and local agronomist feedback to adjust plant density targets to local conditions.²⁰

Table 3: *Plant-establishment densities for triticale.*

Average rainfall (mm)	250–350	350–450	450–550
Planting populations (plants/m ²)	160–180	180–200	200–220

Source: GRDC

Despite the ability to compensate, targeting a variety’s optimum plant density at sowing makes the most efficient use of water and nutrients. To reach a target plant population for the environment and seasonal conditions, adjust sowing rates to allow for:

- sowing date—higher rates with later sowings
- seed germination percentage
- seed size
- seedbed conditions
- type of tillage, e.g. no-till
- soil fertility
- soil type
- soil moisture and seasonal outlook
- weed-seed burden—higher sowing rates for increased plant competition, e.g. if combatting herbicide-resistant ryegrass populations.²¹
- whether the crop is going to be undersown or not.

3.4 Calculating seed requirements

- Key points:
- Choose and manage seeding rates to achieve target plant stand densities in the field.
- Alter sowing rates to account for target population, seed size and germination.²²
- Rates are usually adjusted upwards for forage crops and downwards when undersowing triticale

It is best to calculate the seeding rate using target plant population, germination percentage and seed count per kilogram, which are available on the seed analysis certificate that is available when you purchase the seed.²³

For information on seed quality testing, see [Section 2: Pre-planting](#).

19 Agriculture Victoria (2012) Growing triticale. Note AG0497. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>

20 Alberta Agriculture and Forestry (2016) Triticale crop production. Revised. Alberta Agriculture and Forestry, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/fcd10571](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571)

21 NSW DPI District Agronomists (2007) Wheat growth and development. Procrop Series. NSW DPI, https://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

22 K Condon (2003) Targeting optimum plant numbers. Agnote DPI-431. NSW DPI, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0007/168523/targeting-optimum-plant-numbers.pdf

23 Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcrrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

SECTION 3 TRITICALE

TABLE OF CONTENTS

FEEDBACK

The following formula (Figure 1) can be used to calculate sowing rates, taking into account:

- target plant density
- germination percentage
- seed size
- establishment, usually 80%, unless sowing into adverse conditions.

To calculate 1,000-seed weight:

- count out 200 seeds
- weigh to at least the nearest 0.1 g
- multiply weight (g) by 5²⁴

Example

1000 seed weight (grams) 35	X	target plant population (/m ²) 140	X 100	÷	establishment % X germination % 80 X 90
= Your seedling rate 68 kg/ha					

Your calculation

1000 seed weight (grams) -----	X	target plant population (/m ²) -----	X 100	÷	establishment % X germination % -----
= Your seedling rate ----- kg/ha					

Figure 1: Seeding-rate calculator.

3.5 Sowing depth

Optimum planting depth varies with planting moisture, soil type, seasonal conditions, climatic conditions, and the rate at which the seedbed dries. The general rule is to plant as shallow as possible, provided the seed is placed in the moisture zone, but deep enough that the drying front will not reach the seedling roots before leaf emergence, or to separate the seed from any pre-emergent herbicides used.²⁵

Recommended sowing depth for triticale is 2–5 cm.²⁶

Because triticale seed is generally bigger than other small-grain cereals, it can be seeded deeper than them. This allows to take advantage of moisture stored in the soil, which allows better crop establishment early in the season, particularly in drought-prone areas

Seed placement during sowing is very important when dealing with triticale cultivars. Triticale varieties equal and in many cases exceed the winter hardiness of the best wheats if planted early during autumn. At this depth crops should see

²⁴ P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI, <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>
²⁵ NSW DPI Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries 2007, https://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf
²⁶ DAFWA (2015) Monitoring sowing depth. DAFWA, <https://www.agric.wa.gov.au/mycrop/monitoring-sowing-depth>

uniform seedling emergence and early weed competition.²⁷ Shallow seeding also encourages early vigour.

Planting too deep is equivalent to sowing later. It usually results in decreased emergence, less plant vigour,²⁸ fewer tillers (Photo 3),²⁹ and greater susceptibility to diseases.



Photo 3: *Reduced vigour comes with increased sowing depth.*

Source: DAFWA

Crop emergence is reduced with deeper sowing because the coleoptile may stop growing before it reaches the soil surface, with the first leaf emerging from the coleoptile while it is still below the soil surface. As it is not adapted to pushing through soil (and does not know which way is up), the leaf usually buckles and crumples, failing to emerge and eventually dying.³⁰

For more information, see [Section 4: Plant growth and physiology](#).

3.6 Sowing equipment

As much as 60% of the final yield potential for a cereal crop is determined at planting. Seeding too thinly, using poor quality seed, and uneven stands result in end-of-season yield losses that cannot usually be overcome.

Choosing a seeding system suited to growers' specific needs can have significant benefits in crop performance. Getting the seeder set-up right is critical for rapid seed

27 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

28 Alberta Agriculture and Forestry (2016). Triticale crop production. Revised. Alberta Agriculture and Forestry, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/fcd10571](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571)

29 DAFWA (2015) Monitoring sowing depth. DAFWA, <https://www.agric.wa.gov.au/mycrop/monitoring-sowing-depth>

30 NSW DPI Agronomists (2007) Wheat growth and development. Procrop Series. NSW DPI, https://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

SECTION 3 TRITICALE

TABLE OF CONTENTS

FEEDBACK

germination, uniform crop emergence and good early vigour. Due to the diverse nature of soils and climatic conditions there is no one-size-fits-all solution.

As part of the GRDC stubble initiative, Mallee Sustainable Farming and Dr Desbiolles have compiled dedicated guidelines on seeder technologies including a simple table to assist grain growers in selecting the right seeding configuration for their situation (Table 4).

Table 4: Seeder set up guide.

Seeder options	Stony soils	Non-wetting gutless sands	Rhizoctonia pressure	Marginal moisture	High residue	Pre-emergent herbicide (IBS)	Notes	
Seeder operation	Deep-till sowing	xx	✓ If backfill is not diluted	✓✓	✓ If backfill is not diluted	o	o	For sub-seed disturbance, moisture seeking. Note: tillage depth to suit seed row spacing
	High speed sowing (TINES)	xx	✓	✓	✓	✓	✓	High speed tine sowing possible with controlled soil throw not affecting adjacent seed rows
	High speed sowing (DISCS)	xx	✓ If clearing of top soil improved	✓ If disc penetration maintained	✓ If seed placed in moisture	✓ If hair-pinning not an issue	✓✓ To improve incorporation	Maximum speed to suit paddock conditions and seeder technology
	Inter-row sowing	o	x In non-wetting sand	✓✓	✓✓	✓✓	✓✓	RTK required with good seeder tracking capability and straight stubble rows
	On-row or near-row sowing	✓	✓✓ In non-wetting sand	xx	✓	xx	x	High risk for crop damage
Furrow opener	Narrow point	x Esp. for paddock roughness	✓✓	✓✓	✓ If seeking moisture delving	✓ If good residue management	✓✓	Tine seeders remain the mainstream technology in the Mallee
	Single disc	✓✓	✓ If high soil disturbance	x Esp. with low soil disturbance	✓ If moisture seeking capable	✓✓	x	Best practice paddock management improves the potential of disc seeders
	Triple disc	✓✓	✓✓	✓ With best management	✓	✓✓	✓	With higher disturbance

SECTION 3 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

	Seeder options	Stony soils	Non-wetting gutless sands	Rhizoctonia pressure	Marginal moisture	High residue	Pre-emergent herbicide (IBS)	Notes
Seed placement	Centre row banding	✓✓	✓✓ Esp. with seeding at tillage depth	✓✓ Esp. with deep till furrows	✓ If seeds are placed into moisture	✓✓ Esp. if inter-row sowing	✓✓	Easiest to match with low soil disturbance and water harvesting furrows
	Paired row banding or band seeding	✓ If contact and extra disturbance is minimised	✓ Esp. with seeding at tillage depth	✓ If coupled with best rhizoctonia management	✓✓ If seeds placed on undisturbed soil	✓ If good residue management	✓✓	Improved soil/seed contact on undisturbed soil base
	Side banding	✓ If tillage depth is minimised	✓ If seeds are placed into moisture	✓ If coupled with best rhizoctonia management	✓✓	✓ If good residue management	✓✓	Improved soil/seed contact on undisturbed side ledge
Fertiliser placement	With seeds	✓ Subject to SBU threshold for toxicity	✗ Unless wetting is sufficient	○	✗✗	○	○	Note: Increased fertiliser toxicity risks in low moisture environment
	Deep or split banded	✓ If tillage depth is minimised	✓✓	✓✓	✓✓	○	○	Deep banding often requires deep-tilled furrows
Furrow closing	Press wheels	✓ If hard rubber tyres	✓✓ Esp. if very wide tyre and wetting agent	○	✓✓	✓✓	○	Soil to seed contact and water harvesting furrow benefits
	Rotary harrows	✗	✗✗	○	✓ Esp. Following press wheels	✓ For spreading clumps	✗ Unless safe to do so	Equalising soil throw and residue clumps
	Seed pressing & loose cover	✓ Subject to durability	✓	○	✓✓	○	✓ If control over row contamination of herbicide	Insulation of furrow moisture under loose cover. This option preferred for compaction sensitive, weak textured soils

Key: ✗✗ not recommended at all; ✗ avoid if possible; ✓ possible under conditions; ✓✓ recommended; ○ no direct issue either way
Source: [Mallee Sustainable Farming](#).

3.6.1 Air seeders

An air seeder is a planter which has planting tynes mounted on a heavy duty frame, a central pneumatic seed and fertiliser delivery system, and a ground opener for seed and/or fertiliser placement (Photo 4). In most cases the sowing tyne will be followed by a press wheel that This method drags a tyne or knife-point through the soil and drop seeds in behind it with a press wheel at the back closing it up. The press wheel helps to cover the seed and aid with seed-soil contact.

SECTION 3 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [GCTV19: Different seeders, different yields. Local R&D—valuable solutions for the HRZ grain growers](#)



This system offers many options and adaptations to meet a variety of conditions. The planter's main frame is carried on and controlled by wheels inside the frame. The attitude (fore - aft) levelling is controlled by caster wheels in front of the frame (floating hitch type).

This method of depth control is superior on land with sharp hills or gullies. When the ground opener type is chosen, the appropriate seed row finishing equipment must be installed on the rear of the air seeder.



Photo 4: A New Holland T9 tractor with a Case Flexicoil PTX 600 airseeder bar towing a Flexi-Coil 3850 air cart bin used to sow cereal seed.

Source: GRDC.

3.6.2 Disc seeder

No-till farming has brought new thinking to cropping and figuring out ways to sow into the stubble left from the previous crop has seen farmers turn to disc seeders.

In disc seeding, a metal disc rolls along the ground, cutting open a furrow like a pizza cutter, with a press wheel following behind to press soil back into the slot (Photo 5).



Photo 5: A John Deere Disc seeder.

Source: GRDC.

SECTION 3 TRITICALE

TABLE OF CONTENTS

FEEDBACK

i MORE INFORMATION

[Disc seeders under the microscope](#)

[Bentleg opener seeding research](#)

Unlike air seeders, where straw and chaff are moved to the side as the openers and shanks pass through, the openers on disc drills must cut through crop residue. This allows disc seeders to handle much greater stubble loads than air seeders, which is a major advantage. Disc seeders leave the soil undisturbed and the soil surface relatively flat and free from deep furrows.

Disc drills cut through straw and anchored stubble does not usually cause plugging problems. Therefore, excessive crop residues create problems for disc drills by interfering with disc penetration into the soil and causing ‘hairpinning’ (forcing of uncut straw or chaff into the opener furrow). When hairpinning occurs, the straw and chaff ‘pop-up’ after the drill passes leaving the seed on the soil surface. Cutting coulters in front of the openers, residue manager or row cleaner attachments, down pressure on the discs, opener design, and sharpness of the discs all influence soil penetration and the ability of disc drills to cut through crop residues.

While Disc seeders can handle greater quantities of stubble, they can experience issues with pre-emergent chemicals and subsequent crop damage.

3.6.3 Disc seeders versus tyne seeders

In most cases, discs are better able to handle stubble, but tynes still have a strong following for a variety of reasons. The upshot is that no two farms are the same. Soil conditions, prevailing weather and farming preferences mean there are literally hundreds of different seeder setups, but there are some general rules of thumb (Table 5).³¹

Table 5: Comparisons between Disc and tyne seeders.

Factor	Disc seeders	Tyne seeders
Seeding	In ideal conditions, where the ground is firm but not compacted, a disc machine will achieve more consistent seed depth thanks to better contour following with the close vicinity of a depth gauge wheel. The disc cuts open a narrow slot and the seed is placed at the bottom against the wall, helping it achieve better germination. In less-than-perfect conditions, such as sticky mud and soft, sandy soils, discs are not so effective.	In less-than-ideal soil conditions a tyned seeder is capable of achieving consistent results. There is a much greater margin for error and in no-till seeding, tyned machines are widely used. Advancing tyne seeder technology is achieving similar results to discs in seed placement. Tynes are also better at incorporating pre-emergent herbicides and controlling grass weeds.
Sowing in stubble	Zero-till farming is the main driver behind disc seeder technology with a disc able to either cut through the stubble and trash or avoid it altogether as it creates a furrow. The challenge for discs is that they need to penetrate the soil and trash so the seed isn't just dropped on top, so the seeders can be much heavier and discs need to be kept sharp. They also don't work so well in soft, sandy soils or wet conditions where stubble stems can fold around the disc and be pushed into the furrow, an occurrence known as hairpinning, which restricts seed germination.	Tynes are not as good at getting through heavy stubble where length and quantity can cause it to clump up on the tyne, which leads to blockages. The operator then has to stop and lift the seeder to clear the blockage, then turn around to try to pass through that section again which can mean uneven seeding. Some areas will not be sown and full of weeds while another will be overseeded which leads to clumps of straw.

³¹ J Law (2016) Disc seeders versus tyne seeders. The Weekly Times, <http://www.weeklytimesnow.com.au/machine/crop-gear/disc-seeders-versus-tyne-seeders/news-story/773acc05475aa4d6bbb5a3622d23f444>

SECTION 3 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Factor	Disc seeders	Tyne seeders
Soil Disturbance	Generally speaking, discs have less soil disturbance because the channel they cut through the soil can be as narrow as the thickness of the metal, so in situations where low disturbance is desirable, better results will be achieved. Less soil disturbance also means closer row spacings because there is little impact on neighbouring rows. However, discs can also be configured to achieve more disturbance, if that's what's desired, by setting them at an angle or doubling them up.	Dragging what is effectively a metal stake through the ground will disturb the soil and on average a tyne will throw more out each side meaning you can't have your rows too close together. However, tyne design is also advancing to reduce the amount of soil throw. They are also effective at cutting through compacted soil making them good for farmers who don't use controlled traffic farming. Tynes don't require as heavy a frame as a disc seeder to get through compacted ground.
Wear and damage	A disc is mounted on bearings that can wear quickly in rougher ground and the disc itself will lose its edge. A disc seeder module is also more complex than a tyne setup, so there is more that needs monitoring. However, on rocky ground, the disc rolls over the stone rather than dig it up, which reduces impact and will achieve better seeding.	The knife point on a tyne also wears, but not as quickly and will still work effectively even when it's worn. They're also easier to replace. Breakout systems, which cause the tyne to flick up when a rock is hit, also help to reduce damage, although this can cause the seed to be scattered out the back. Hydraulic breakouts reduce this effect.
Cost	A disc seeder will be more expensive to purchase than a comparable tyned machine. The frames are heavier, the seeder modules more complex with rollers, gauge wheels and other contour-following technology. These costs are offset by the reduced amount of power (about 2hp per row less than a tyned seeder) needed to haul a disc seeder and the speed at which it can operate.	There is less complexity in a tyned machine so they are by nature much cheaper. They are easier to maintain, wearing parts such as knife points are cheaper to replace and manufacturers are happier to provide warranty on their machines. Some tyned machine makers also offer disc kits so a farmer can swap systems depending on conditions to make it a cost-effective best of both worlds.

MORE INFORMATION

[Disc v tyne seeder demonstration Illabo 2013](#)

Source: [The Weekly Times](#).

Making the change from tyne to disc

The following tips have been developed to support growers making the transition:

- Sow dry/early to overcome stickiness in clay soils: the more residue the less this will be a problem.
- Harvest management is critical: residues need to be spread uniformly so discs cut through an even layer of chaff.
- Harvest cereals short, before using the disc for the first time to help with residue flow.
- In the first year using a disc system, sow deep, as the gauge wheel could ride high on the old tyne furrow.
- Row cleaners may be needed to level the ridges and furrows for your disc and gauge wheel. Consider a once-off harrowing or prickle chain to level paddocks to ease the transition from tyne to disc. Level paddocks are critical for good seed placement.
- If wet, wait until conditions dry a little for disc sowing.

- Consult your agronomist regarding pre-emergent herbicides. Also note that you cannot band urea when using discs.
- Standing stubble is better. Once you have mastered using discs, aim to cut stubble as high as possible (consider a stripper front).³²

3.6.4 Setting up and calibrating the seeder

Seeder levelling

To ensure that all tynes are sowing at the same depth, adjust the machine on a level surface.

Coulter alignment

Pull the machine into the ground to check alignment. If alignment is out, raise the machine, slightly loosen the nuts on the coulter assembly and reposition using a straight-edge and a heavy hammer. Recheck in the ground. The next four adjustments must be made in the paddock after you have run the machine at the speed at which you propose to sow.

Tyne tension

Correct tension allows the tyne to vibrate, creating loose soil (tilth) while maintaining the correct point angle. Tyne tension should be in the range 260–400N. Use lower tensions on sandy friable soils. Too much tension results in excessive point wear. Depth Sowing depth is not as critical as the amount of loose soil over the seed. Check the depth to the bottom of the furrow after travelling at least 200m. The rule of thumb for depth is: 'to the first knuckle of your index finger'. For early autumn or spring sowings, when warm, dry conditions after sowing are likely, this depth is necessary. In cold, wet winter conditions, sow more shallowly.

Tilth and speed

The amount of loose soil covering the seed is critical, regardless of the depth of the furrows. Aim for only 5–10 mm of loose soil over the seed. It is important to note that more seed fails to emerge by being buried under too much soil than by any other cause. There is too much tilth if less than 5% of the seed and fertiliser is visible in the furrow. Speed must be increased (up to 12 km/h) to throw more loose soil out of the furrow.

There is too little tilth if a high percentage of seed and fertiliser is visible in the bottom of the furrow. A single loop of heavy chain attached at either side of the seeder can be used to sweep soil from the edges into the furrow. Whatever device you use must follow the contour of the ground and not bulldoze loose soil on top of the seed.

In conventional seedbeds, deep seed burial is also likely, especially where the seedbed is loose and fluffy.

- Rolling to firm the seedbed before sowing is recommended for loose seedbeds.
- If using harrows, try to direct the seed tubes back so the seed lands in the last row of the harrows.
- When direct-drilling, a good rule of thumb is that 5% of the seed and fertiliser should be visible in the furrow.

Soil types and moisture

Often both soil type and moisture will vary within a paddock and as sowing proceeds. Try to sow different soil types in separate blocks and check the soil cover over the seed with changes in soil type.³³

32 T Somes (2017) Sowing into stubble—why seeder calibration and set up is critical. GRDC. <https://grdc.com.au/Media-Centre/Media-News/North/2017/03/Sowing-into-stubble-Why-seeder-calibration-and-set-up-is-critical>

33 H Allan, E Havilah, H Kemp (1997) Establishing Pastures—Machinery. NSW DPI. Dairy Link. http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0016/163123/establishing-pastures-1-10.pdf

VIDEOS

WATCH: [Over the Fence North: Conditions are key to accurate seed placement](#)



Calibration

A frequently neglected but essential part of any cropping program is accurate calibration of machinery. Seeder calibration is important for precise seed placement, and seeders need to be checked regularly during sowing. All seeders should be carefully calibrated before sowing starts. This should be done every season because seed size varies and machinery wear can alter rates.

The simplest method of calibration is as follows:

1. Place some of the seed to be sown in the planter box.
2. Unhook the seeding tubes and tie bags over the outlets in order to collect any seed which would normally go down the tube.
3. With the sowing mechanism engaged, drive the planter over a measured distance (D, metres) with a minimum distance of 100 m.
4. Remove the bags of seed and weigh them on accurate scales (W, kg).
5. Measure the width of the planter in metres (P).

The formula for sowing rate is: = kg/seed per ha.

For example, if 0.61 kg of seed was collected from a 6-m wide planter over a distance of 100 m, the sowing rate would be:

$$\frac{100 \times 0.61}{6} = 10.17 \text{ kg seed/ha}$$

If there are a large number of sowing outlets, seed may be collected from a minimum of a quarter of them. In such cases do not forget to multiply the weight of seed collected from each outlet by the actual number of outlets. Sowing is the most critical operation in the cropping program. Too much seed leads to waste and a probable yield reduction, while too little leads to probable yield reduction. Make sure to take the time to calibrate accurately.³⁴

Point maintenance

Seed placement and furrow profile can be adversely affected using worn points. Attention to point wear is essential, particularly when you are direct-drilling with narrow points that have to carve a channel through undisturbed soil. Expensive steel points can quickly become irretrievably ruined if they are not regularly hard-faced and maintained. An alternative in abrasive soils are cast points.³⁵

3.6.5 Sowing into stubble

Key points:

- Bar clearance and tyne layout influence a machine's ability to cope with heavy stubble loads.
- Select a seeder based on your farming system, cropping environment and financial position.
- Stubble management starts at harvest: height and residue spread will impact sowing.

When it comes to optimising winter crop establishment there are vital steps grain growers can take to improve planting outcomes, particularly when sowing into stubble.

Seeder blockages

One of the major challenges when working in a stubble retained system is blockages in sowing implements, particularly in irrigated and high rainfall zones, where yields and stubble loads are generally high. Blockages become an increasing issue when

34 T Price, B Beumer, P Graham, P Hausler, M Bennett (2008) Agnote: Machinery calibration: Boom-sprays, seeders and fertiliser applicators. DPIR NT https://dpir.nt.gov.au/_data/assets/pdf_file/0011/232967/711.pdf

35 H Allan, E Havilah, H Kemp (1997) Establishing Pastures—Machinery. NSW DPI, Dairy Link. http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0016/163123/establishing-pastures-1-10.pdf

stubble loads are above three tonne per hectare (3 t/ha), or if chaff and straw hasn't been chopped and spread evenly at harvest.

Using seeding equipment designed for retained stubble systems will minimise blockages, but does require a significant capital investment. This research has also found modification to the profile and tyne layout of the seeder bar can reduce stubble clumping and blockages, and improve the machine's ability to cope with heavy stubble loads (ranging from 5–7 t/ha). Utilising inter-row sowing and wider row spacings has also helped growers sow through retained stubbles with greater ease. Disc seeders will cope with sowing into paddocks with much higher stubble loadings.

Seeder set-up and modifications

It is possible for simple modifications to be made to the seeder that will enable it to better cope with stubble. Seeder modifications that will enable sowing into stubble include:

- A straight rather than a curved shank will avoid residue building up.
- Shanks with a rounded cross section have improved residue flow, compared to square shanks.
- Vertical or slightly backward leaning shanks promote a constant off-balancing effect on residue, reducing build up.
- Sudden changes of shape in shank profile inhibits residue flow and promotes clumping. High 'C' shapes, where the upper part of the 'C' is above the stubble flow work well.
- 'Stream-lined' designs with recessed bolt heads for point mounts also reduce residue catching.
- Existing curved shank tynes can be improved by retrofitting stubble tubes to make the face of the shank round and more vertical.
- Long knife-point openers can increase the effective vertical clearance of short tynes, but their break out rating needs to sustain the greater lever arm effect.
- Tyne shank add-ons (Pig Tails or other plastic/metal guards) improve trash flow around the tyne.
- Tread wheel residue manager's hold down the stubble beside the shank as it moves through.
- Row cleaners move stubble away from the disc to prevent hair pinning and assist in crop establishment.
- Residue pinning wheels (Morris Never-Pin wheels) hold the stubble on either side of the disc to assist in cutting ability.

Selecting a seeder when sowing into stubble

As part of the GRDC stubble initiative, Southern Farming Systems (SFS) has conducted extensive trial work on seeding system performance in relation to stubble retention. Key findings from this work include:

- Real time kinematic (RTK) guidance is a critical component to inter-row sowing
- Each seeder has varying capacity to handle retained stubble
- As a rule, discs handle higher loads than tyne and press wheel machines
- Wider tyne spacing across and along the bar will improve stubble handling
- Changing the angle of sowing direction slightly can minimise blockages
- Guidance auto steer on seeder bars will improve inter-row sowing
- Tynes and discs have varying degrees of soil throw and crop safety for pre-emergent herbicides
- Isolation of fertiliser from seed will limit seed burn.³⁶

MORE INFORMATION

[Sowing into stubble—why seeder calibration and set up is critical](#)

[Profitable stubble retention systems for the high rainfall zone](#)

³⁶ T Somes (2017) Sowing into stubble—why seeder calibration and set up is critical. GRDC. <https://grdc.com.au/Media-Centre/Media-News/North/2017/03/Sowing-into-stubble-Why-seeder-calibration-and-set-up-is-critical>

3.6.6 Sandy soil systems

Sandy soils present the highest risk of the soil drying out quickly and reducing germination.

Recent research work suggests the following strategies should be considered for more reliable crop establishment in sandy soils, where marginal moisture conditions are encountered:

- Place seed in contact with undisturbed soil moisture. This requires side banding or paired row banding able to place seeds on undisturbed ledges, or single shoot systems able to band seeds at furrow tilling depth. Deep furrow sowing capabilities may be required to reach moisture, or else growers can use low rake angle openers, low speed and compact seed banding systems to delve deeper.
- Minimise the fertiliser applied with seeds to control fertiliser toxicity, and use a double shoot system, with side or side plus vertical separation.

It is important to note that a lack of sub-seed disturbance may increase the severity of rhizoctonia damage on young seedlings, and the use of liquid banding technology to combine in-furrow trace element application and fungicide protection at sowing may be necessary as part of a mitigating strategy.

Seed-fertiliser separation is particularly important in small seeded crops like canola for successful germination on sandy soils.

Obtaining high Seed Bed Utilisation (SBU) is important to manage fertiliser toxicity risks. In marginal moisture conditions, including non-wetting soils, it may be necessary to have full separation between seed and basal fertiliser, preferably banded at depth to maintain the maximum crop establishment potential.

Successful use of high SBU systems requires careful selection of equipment to suit growers' conditions.

When selecting for a higher SBU system, there are many factors to consider including single or double shoot, distinct split-rows or a wide band sowing, integrated opener design or wing attachment for an existing opener, and fertiliser placement relative to the seed zone.

In order to better establish crops in marginal soil moisture, it is important to select a design able to place seeds on undisturbed soil moisture, being aware that some systems will instead place seeds into furrow backfill, at greater risk of diluted moisture and potentially pre-emergent herbicide damage.

For more information about Fertiliser toxicity and optimising SBU, see [Section 2: Pre-planting](#).

3.6.7 Managing herbicide toxicity

During the shift from conventional farming systems to no-till farming systems, the effective use of herbicides has become increasingly important. A well-planned herbicide strategy can mean the difference between making no-till work, or not. Recently it has become apparent that the rapid change in farming systems has overtaken farmer knowledge on how to use many herbicides in conservation farming systems.

Older, more traditional herbicides that were designed for use in cultivated systems can still be used effectively in no-till systems; however, they are usually used in a different manner. In addition, many herbicide labels (especially older type or generic herbicides) have the same content today as they did 10–15 years ago. Some products with generic counterparts have different label claims for the same active ingredient.

This creates problems for farmers and agronomists wanting to use these herbicides in our modern, no-till farming systems. Residual herbicides at sowing are very effective for controlling a wide range of weeds both in-crop and into the following summer. Some residual herbicides also have valuable knockdown properties. This is very useful, because knockdown herbicide options prior to sowing are limited for

SECTION 3 TRITICALE

TABLE OF CONTENTS

FEEDBACK

hard-to-kill weeds. Knowing the chemistry and mode of action of each herbicide is paramount to enable the best combination of crop safety and weed control. Heavy rainfall just after sowing when combined with certain soils can lead to crop damage. Some herbicides are mobile with soil water, while others are less mobile. Mobility can also change with time for particular herbicides.

The incorporation by sowing (IBS) application technique seems the safest way of using most residual herbicides, as the seed furrow is left free of high concentrations of herbicide. The soil from that furrow is thrown on the inter-row, where it is needed the most. In-furrow weed control is generally achieved by crop competition and/or small amounts of water-soluble herbicides washing into the seed furrow. For this reason, best results in IBS application occur when water-soluble herbicides are used either solely or in conjunction with a less-soluble herbicide.

Because of the furrow created by most no-till seeders, post-sowing pre-emergence (PSPE) applications of many herbicides are not ideal and are usually not supported by labels, as the herbicides can concentrate within the seed furrow if washed in by water and/or herbicide treated soil. Obviously, for volatile herbicides that need incorporation following application, PSPE is not a viable option. Tyne seeders vary greatly in their ability to incorporate herbicides. There are many tyne shapes, angles of entry into the soil, breakout pressures, row spacings, and soil surface conditions. Each of these factors causes variability in soil throw, especially when combined with faster sowing speeds (>8 km/h). Consequently, residual herbicide incorporation is variable between each seeder. There are, therefore, no rules of thumb for sowing speed, row spacing and soil throw.

It is important to check each machine in each paddock. Disc machines show similar variability in their ability to incorporate herbicides. Disc angle, number of discs, disc size, disc shape, sowing speed, closer plates and press wheels all have an impact on soil throw and on herbicide-treated soil returning into the seed furrow. In all cases with tynes and discs, crop safety is usually enhanced by IBS rather than PSPE application of herbicides.³⁷

Tyne seeders are reliably safest at ensuring crop safety, as long as the following guidelines are adhered to:

- Control speed to ensure no soil throw reaches adjacent furrows and the majority of herbicide is concentrated over the inter-row zone
- Ensure seeds are placed at sufficient depth with clean backfill to achieve adequate physical separation between crop seed and herbicide (known as 'positional selectivity').
- Create stable furrows to limit the risk of contaminated soils backfilling over time, and leaching of soluble herbicides into the seed zone.

Care must be taken with disc seeders when using pre-emergent herbicides. Trials in SA lower-north in 2012/13 showed that trifluralin significantly reduced wheat emergence with single discs, by up to 50%. However, using triple discs or applying Sakura® caused no damage.

The greater safety with triple disc systems is explained by their soil throw features being akin to a knife point system. Further, the inclusion of residue managers fitted ahead of the single disc openers significantly reduced crop damage. Growers should always follow herbicide labels to assess suitability for disc seeders.³⁸

VIDEOS

WATCH: [Study sows the seed for best-practice with disc seeders](#)

University of Adelaide research: Dr. Tim Beermann talks disc seeders and pre-emergent herbicides

MORE INFORMATION

[Seeding systems and pre-emergence herbicides](#)

³⁷ B Haskins (2010) Residual herbicides at sowing using disc and tyne no-till seeding equipment. Industry & Investment NSW. <https://riverineplains.org.au/wp-content/uploads/2016/12/ResidualHerbicides.pdf>

³⁸ J Desbiolles, R Barr (2016) Selecting a seeding system for your soil. GRDC. <https://grdc.com.au/Media-Centre/Media-News/South/2016/03/Select-a-seeding-system-for-your-soil>

Plant growth and physiology

Key messages

- Triticale is quite similar to wheat, except it has spreading growth until stem elongation, when the stems extend in the normal erect growth form of wheat.
- Triticale tillers less than wheat.
- The optimum temperature for germination is 20°C.
- The optimum temperature range for growth is 10–24°C.
- The maximum temperature for survival is 33°C.
- Though triticale is generally considered tolerant to salt stress, studies have found that cultivars are slightly less salt tolerant at germination.
- Since the early development of triticale, its tolerance to drought stress has increased compared to other cereals.

4.1 Characteristics of triticale

Triticale is quite similar to wheat, except it has spreading growth until stem elongation, when the stems extend in the normal erect growth form of wheat. The key characteristics of triticale are (Table 1):

- Emerging leaves are rolled in the shoot.
- The leaf blade is flat with a clockwise twist.
- It has a short, membranous ligule.
- It has auricles.
- The seed is a grain similar to that of wheat.¹
- It grows to a height of about 1–1.5 m.
- The leaves are like those of wheat, but larger and thicker. The spikes are also larger.²

¹ HerbiGuide (n.d.) Triticale. HerbiGuide, http://www.herbiGuide.com.au/Descriptions/hg_Triticale.htm; see also HerbiGuide, www.herbiGuide.com.au

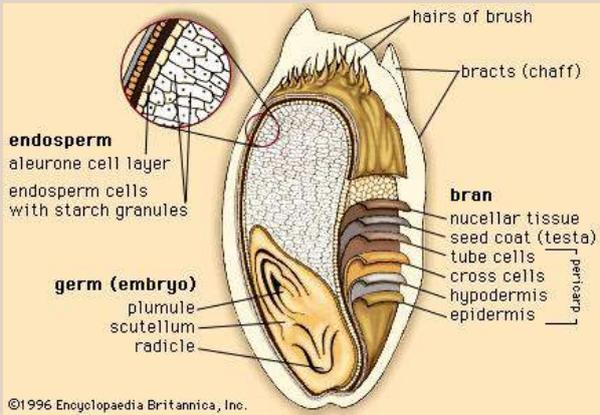
² Infoagro (n.d.) Triticale growing. Infoagro Systems, <http://agriculture.infoagro.com/crops/triticale-growing/>

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Table 1: Main characteristics of triticale.

Plant part	Description
Cotyledons	One
First leaves	Single, and similar to later leaves
Leaves	Emerging leaves rolled in the shoot Blade: parallel sided, flat, clockwise twist when viewed from above, 30–300 mm long, 10–20 mm wide Ligule: short membrane Auricles: present, occasionally with hairs on the shoulders Sheath: rolled, prominent veins, often bluish-green at the base
Stems	Many, unbranched stems arise from base, erect, up to 1,500 mm tall, hollow with solid nodes
Flower head	Compact spike, squarish in cross-section, awned (Figure 1) ³
	 <p>Figure 1: A comparison of flower heads. A: Bread wheat, B: Cereal rye and C: Triticale.</p> <p>Source: Palomar College</p>
Fruit	Grain
Seeds	Pale brown, dull, elongated oval, wrinkled grain, 8–12 mm long × 2.5–4 mm wide, 23–36 grains per gram; easily rubbed from the husks (Figure 2)
	 <p>Figure 2: Cross-section of cereal grain seed. This is rye, but triticale is similar.</p> <p>Source: Encyclopaedia Britannica</p>
Roots	Fibrous ⁴

³ Photos of some important cereal grains. Wayne's World. Palomar College, <http://waynesword.palomar.edu/ecoph12.htm>

⁴ HerbiGuide. Triticale. HerbiGuide, http://www.herbiguide.com.au/Descriptions/hg_Triticale.htm; see also HerbiGuide, www.herbiguide.com.au

Wheat and triticale are difficult to distinguish, since their vegetative characteristics are similar. Removal of the seedling from the soil and observation of the grain shell is a means of distinguishing wheat from triticale. Wheat grain shells tend to be lighter in colour than in triticale. Wheat shells are oval; triticale grain shells are oblong.⁵ In both, the auricles are blunt and hairy, and the leaf sheath and blade hairy too. The ligule is of medium length. Leaf blades twist clockwise.

4.2 Germination and emergence

Germination begins when the seed absorbs water and ends with the appearance of the radicle. Germination has three phases:

- water absorption (imbibition)
- activation
- visible germination

The growth stages of cereals are numbered according to the Zadoks scale (see [section 4.4.1](#)).

Phase 1: Water absorption

Phase 1 starts when the seed begins to absorb moisture. This is growth stage 1 (GS01) in the Zadoks scale. Generally, a seed needs to reach a moisture content of around 35–45% of its dry weight to begin to germinate. Water vapour can trigger germination as rapidly as liquid water can.

Seeds begin to germinate at a relative humidity of 97.7%. Soil so dry that roots cannot extract water from it still has a relative humidity of 99%, which is much higher than that of a dry seed. So even in dry conditions there can be enough moisture for the seed to absorb it and begin Phase 1, although it takes longer than in moist conditions.

Phase 2: Activation

Once the embryo has swollen, it produces hormones that stimulate enzyme activity (GS03). This is Phase 2. The enzymes break starch and protein stored in the seed into sugars and amino acids, which provide energy to the embryo. The larger the seed, the more starch, and therefore energy reserves, it will have stored. If the seed dries out before the embryo starts to grow, it remains viable. Phase 2 continues until the rupture of the seed coat, the first visible sign of germination.

Phase 3: Visible germination

In Phase 3 (GS05–GS09), the embryo starts to grow visibly. The radicle emerges, followed soon after by other primary roots and the coleoptile. The enzymes produced in Phase 2 mobilise sugars and amino acids stored in the seed, and enable their transfer to the growing embryo.⁶

4.2.1 Conditions of germination

Triticale cultivation can be carried out in subtropical, moderately mild and moderately cold climates. Optimal temperatures are:

- for germination, 20°C
- for growth, 10–24°C

The minimum temperature at which triticale can survive is –10°C, and the maximum is 33°C.⁷

In a study comparing the tolerance of cereal seeds to a range of temperatures, triticale was found to be more sensitive than wheat and barley to germination

5 Agriculture Victoria (2012) Identification of cereal seedlings. Note AG0102. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/identification-of-cereal-seedlings>

6 NSW DPI District Agronomists (2007) Wheat growth and development. Procrop Series. NSW DPI, <http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat-barley-and-other-winter-cereals/growth-and-development>

7 Infoagro (n.d.) Triticale growing. Infoagro Systems, <http://agriculture.infoagro.com/crops/triticale-growing/>

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK

temperature.⁸ Very low temperatures can damage triticale seedling during germination and emergence (Photo 1).⁹ For triticale, the thermal time to the emergence of the first seedling has been recorded at 113–119 degree-days, and 127–130 degree-days for 95% emergence.



Photo 1: Cold-temperature damage in emerging triticale.

Source: Alberta Agriculture and Forestry

Though triticale is generally considered to be tolerant to salt stress, studies have shown that cultivars are slightly less salt tolerant at germination than they became after the three-leaf stage of growth.¹⁰ Early researchers found that saline soils could impair triticale emergence, although the application of calcium sulfate (CaSO₄) (Gypsum) helped to increase emergence in these conditions.¹¹

In one study researchers found that decreases in osmotic potential caused a reduction in germination percentage and seedling growth. Drought conditions had more negative effects on germination and seedling growth than did sodium chloride (NaCl). Germination and seedling growth were higher in large seeds than in small seeds in control solution and under osmotic stress. In addition, it was observed that seedlings obtained from larger seeds survived even at the low osmotic potential, whereas seedlings obtained from small seeds did not survive under intensive stress conditions.¹²

Herbicide treatments may also limit germination in triticale, as in other cereals. The successive effect of four herbicides (isoxaben, chlorsulfuron, isoproturon and chlortoluron) and a control on the germination and plant growth of triticale cultivars has been explored. Germination rate of winter triticale seeds obtained from plants treated with herbicide were generally lower, in particular for the isoproturon and chlorsulfuron variants.¹³

As the first primary roots appear, the coleoptile (Photo 2) bursts through the seed coat and begins pushing towards the surface. Emergence is when the coleoptile or the first leaf becomes visible above the soil surface. The coleoptile is well developed in the embryo, where it forms a thimble-shaped structure covering the seedling tube leaf and the shoot. Once the coleoptile emerges from the seed, it increases in length until it breaks through the soil surface. Fully elongated, it is a tubular structure about 50 mm long and 2 mm in diameter. It is white, except for two strands of tissue that contain chlorophyll. The end of the coleoptile is bullet-shaped and is closed except for a small pore, 0.25 mm long, a short distance behind the tip.

8 T Buraas, H Skjenes (1985) Development of seed dormancy in barley, wheat and triticale under controlled conditions. *Acta Agriculturae Scandinavica*, 35 (3), 233–244.

9 Alberta Agriculture and Forestry (2016) Triticale crop production. Revised. Alberta Agriculture and Forestry, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/fcd10571](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571)

10 LE Francois, TJ Donovan, EV Maas, GL Rubenthaler (1988) Effect of salinity on grain yield and quality, vegetative growth, and germination of triticale. *Agronomy Journal*, 80 (4), 642–647. See also Hill Laboratories (n.d.) Crop guide: Triticale. KB item 28750v1. Hill Laboratories, https://www.researchgate.net/publication/250102346_Effect_of_Salinity_on_Grain_Yield_and_Quality_Vegetative_Growth_and_Germination_of_Triticale

11 JD Norlyn, E Epstein (1984) Variability in salt tolerance of four triticale lines at germination and emergence. *Crop Science*, 24(6), 1090–1092.

12 D Kaydan, M Yagmur (2008) Germination, seedling growth and relative water content of shoot in different seed sizes of triticale under osmotic stress of water and NaCl. *African Journal of Biotechnology*, 7 (16), 2862–2868.

13 S Slawomir, M Robert (1996) Successive effect of herbicides on triticale seed germination and plant growth. In H Guedes-Pinto, N Darvey, V Carnide (eds) *Triticale: Today and Tomorrow*. Springer Netherlands, pp. 743–747.

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 2: Cereal seed germination showing the coleoptile (green) emerging to reach soil surface.

Source: [Crop Gene Bank](#)

When the coleoptile senses light it stops growing and the first true leaf pushes through the pore at the tip. ¹⁴ Up to this point, the plant has been living on reserves within the seed. ¹⁴ A difference between the coleoptile and the first true leaf is that the coleoptile knows which way the soil surface is. If it does not reach the surface, the first leaf, which can't sense which way is up, may emerge under the soil and grow in any direction, resulting in crinkled leaves beneath the surface. This is one reason that planting depth is so important.

Optimum planting depth varies with planting moisture, soil type, seasonal conditions, climatic conditions, and the rate at which the seedbed dries. The general rule is to plant as shallow as possible, provided the seed is placed in the moisture zone, but deep enough that the drying front will not reach the seedling roots before leaf emergence (Photo 3), and to separate the seed from any pre-emergent herbicides used. ¹⁵

¹⁴ NSW DPI District Agronomists (2007) Wheat growth and development. Procrop Series. NSW DPI, <http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat-barley-and-other-winter-cereals/growth-and-development>

¹⁵ NSW DPI Agronomists (2007) Wheat growth and development. Procrop Series. NSW DPI, <http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat-barley-and-other-winter-cereals/growth-and-development>

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 3: Emerged triticale seedlings.

Source: Midwest Cover Crops Council

Sowing depth also influences the rate of emergence and the percentage of seedlings that emerge. Deeper seed placement slows emergence; this is equivalent to sowing later. Seedlings emerging from greater depth are also weaker, more prone to seedling diseases, and tiller poorly (Photo 4).¹⁶ Crop emergence is reduced with deeper sowing because the coleoptile may stop growing before it reaches the soil surface, with the first leaf emerging from the coleoptile while it is still below the soil surface. As it is not adapted to pushing through soil (i.e. does not 'know' which way is up), the leaf usually buckles and crumples, failing to emerge and eventually dying.¹⁷ Soil bulk density can also influence crop emergence at different sowing depths. Research has confirmed the importance of avoiding smaller-sized seed when deep sowing.



Photo 4: By the stage of the first unfolded leaf, GS11, there is a noticeable difference in vigour between a seedling sown too deep (left) and correctly sown seedling (right).

Source: GRDC

¹⁶ N Poole (2005) Cereal growth stages. GRDC, <https://www.researchgate.net/file/PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798>

¹⁷ NSW DPI Agronomists (2007) Wheat growth and development. Procrop Series, NSW DPI, <http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat-barley-and-other-winter-cereals/growth-and-development>

4.2.2 Soil moisture

Soil moisture influences the speed of germination. Germination is rapid if the soil is moist and warm. When the soil dries to near the permanent wilting point, the speed of germination slows. Instead of taking five days at 7°C, the germination speed with adequate moisture, at the point of permanent wilt, the seed will take 10 days at 7°C to germinate.

Germination in a seed may stop and start in response to available moisture. Therefore, seeds that have taken up water and entered Phase 2, but not reached Phase 3, remain viable if the soil dries out. This can happen when dry sowing is followed by a small amount of rain that keeps the soil moist for a few days before drying out. When the next rain comes, the seed resumes germinating, taking up water and moving quickly through Phase 2, so that germination is rapid. This ability to start and stop the germination process before the roots and coleoptile have emerged is an important consideration when dry sowing. If the seedbed dries out before the coleoptile has emerged, the crop needs to be monitored to determine whether it will emerge, so the critical decision to re-sow can be made.

Sowing into hard-setting or crusting soils that dry out after sowing may result in poor emergence. Hard soil makes it difficult for the coleoptile to push through to the surface, particularly in varieties with short coleoptiles. In some crusting soils, gypsum and/or lime may improve soil structure and assist seedling emergence.

Stubble reduces the impact of raindrops on the soil surface and helps to prevent formation of soil crusts. Stubble retention also encourages biological activity and increases the amount of organic matter, which improves the stability of the soil by binding the soil particles together.¹⁸

4.3 Effects of temperature, photoperiod, climate and environment

4.3.1 Temperature

Temperature, photoperiod, environment and climate affect plant growth and physiology.

One study explored the effect of high temperatures at different growth stages on triticale. Thermal treatments consistently reduced grain yield ($P < 0.05$), the magnitude of the effect ranging between 5% and 52%. The greatest effect (46% yield decrease) was found when temperature increased during stem elongation, and the least (15%) when treatments were imposed during heading–anthesis; an intermediate effect (27%) was found when treatments were imposed during booting–anthesis. Greatest yield losses were seen when plants were exposed to high temperatures in the booting–anthesis stage.¹⁹

Temperature can also affect the photosynthesis and respiration rates of triticale, leading to changes in growth.²⁰

High temperatures (e.g. above 33°C) are known to induce rapid growth which diminishes the cell pool of metabolites (e.g. amino acids, nitrates and carbohydrates) and therefore nutritional quality.²¹

¹⁸ NSW DPI District Agronomists (2007) Wheat growth and development. Procrop Series. NSW DPI, <http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat-barley-and-other-winter-cereals/growth-and-development>

¹⁹ C Ugarte, DF Calderini, GA Slafer (2007) Grain weight and grain number responsiveness to pre-anthesis temperature in wheat, barley and triticale. *Field Crops Research*, 100 (2), 240–248.

²⁰ M Winzeler, DE McCullough, LA Hunt (1989) Leaf gas exchange and plant growth of winter rye, triticale, and wheat under contrasting temperature regimes. *Crop Science*, 29 (5), 1256–1260.

²¹ CM McGovern, F Snyders, N Muller, W Botes, G Fox, M Manley (2011) A review of triticale uses and the effect of growth environment on grain quality. *Journal of the Science of Food and Agriculture*, 91 (7), 1155–1165.

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK

4.3.2 Photoperiod

There is limited research into the effects of photoperiod on triticale growth, and results vary between studies.

The developmental responses to temperature and photoperiod of five triticale cultivars and one wheat cultivar were examined in the field at Werribee, Victoria, in 1974. Researchers created a range of photoperiod and temperature treatments by using six times of sowing and supplemental illumination to provide an 18-hour day length at one of the two sites. The order in which the varieties reached the various developmental stages changed very little with the successive times of sowing, but differed when the natural day length was compared with the 18-hour regime. When the duration of each phase was shortened by a longer mean daily photoperiod or a higher mean daily temperature, they observed that the photoperiod had a greater effect than the temperature.²²

4.3.3 Salinity

In Australia, data is limited on the salt tolerance of triticale. However, it can be inferred that triticale has similar high salt tolerance as wheat and cereal rye (Table 2). Crops in this high salinity tolerance rating can grow in saline soils up to 10 dS/m (Saturated extract ECe).

Table 2: Tolerance of some common crops to salinity.

High tolerance	Moderate tolerance	Low tolerance
Wheat	Lucerne	Maize
Barley	Peas	Sugar cane
Canola	Sweetcorn	Red clover
Cotton		Sub. clover
Ryegrass		
Sorghum		
Soybeans		

Source: Australian Soil Fertility manual, JS Glendinning 1999

Trials conducted in the Northern region between 2002–2007 explored various options to manage subsoil constraints including; plant adaptation through breeding of tolerant cultivars, agronomic decisions, and chemical, mechanical and biological treatments. Triticale was found to have high tolerance to saline soils. The trial found that different crop species showed differences in sensitivity to increasing subsoil Chlorine (Cl) concentration (a measure of salinity). Grain yield of most species declined with increasing subsoil Cl. Barley and triticale yielded better than bread wheat at sites high in subsoil Cl.²³

Research in Europe suggests that triticale is a fairly salt-tolerant crop, and recommends its cultivation in saline soils instead of crops that are salt-sensitive.²⁴

Studies in the US found that relative grain yield for triticale cultivars was unaffected by soil salinity up to 7.3 dS/m (electrical conductivity of the saturated-soil extracts in the root zone). Each unit increase in salinity above this reduced grain yield by 2.8%. These results place triticale in the salt-tolerant category. Yield reduction results primarily from a reduction in spike number rather than from lower weight per spike or

²² JB Brouwer (1977) Developmental responses of different hexaploid triticales to temperature and photoperiod. *Animal Production Science*, 17 (88), 826–831.

²³ R Dalal (2007) GRDC Final reports: DNR00004–SIP08 (north) Combating subsoil constraints. <http://finalreports.grdc.com.au/DNR00004>

²⁴ RM Koebner, PK Martin (1996) High levels of salt tolerance revealed in triticale. In H Guedes-Pinto, N Darvey, V Carnide (eds) *Triticale: Today and Tomorrow*. Springer Netherlands, pp. 429–436.

lower weight per individual seed. Cultivars are slightly less salt tolerant at germination than they are after the three-leaf stage of growth.²⁵

IN FOCUS

The effect of salt stress on photosynthesis and growth of triticale

Researchers treated six triticale cultivars with sodium chloride (NaCl) in concentrations of 0.5, 100, 200, 300 mmol/L. After 15 days, they measured the photosynthetic rate, transpiration rate, stomatal conductance, intercellular carbon dioxide (CO₂) concentration, root length, seedling height and fresh weight. They found that the 50 mmol/L NaCl process promoted the photosynthetic rate and the growth of the seedlings. However, as the concentration of NaCl increased, the net photosynthetic rate, transpiration rate and stomatal conductance of the seedlings decreased, the intercellular CO₂ concentration showed regular changes, and the growth of seedlings was impeded.²⁶

4.3.4 Drought

Since the early development of triticale, its tolerance to drought stress has increased compared to other cereals.²⁷

A wide range of genotypic variability exists within triticale strains and cultivars show a wide range of tolerances to drought. In addition, the usefulness of other parameters, e.g. leaf gaseous exchange and chlorophyll content, for measuring drought tolerance have been assessed.

Stomatal conductance has proven to be important in determining the amount of water used and how efficiently it is used by cereal crops; it therefore affects productivity. Stomatal conductance is a measure of the rate at which carbon dioxide enters the stomata and water vapour exits. One study explored stomatal conductance in durum wheat and triticale in different environments. It was found that the greater stomatal conductance of triticale confers an advantage to this crop in both water- and radiation-use efficiency.²⁸

Water stress

Water availability in semi-arid regions is becoming increasingly threatened as rains become more erratic and droughts more frequent. Improving crop Water Use Efficiency (WUE) has become a priority. One study found that moisture level significantly influences grain yield and intrinsic WUE in triticale. Well-watered conditions increased grain yield, which ranged from 3.5–0.8 t/ha⁻¹ in 2013 and 4.9–1.8 t/ha⁻¹ in 2014. Intrinsic WUE increased with decreasing moisture level. Flag-leaf photosynthesis and pre-anthesis assimilates contribute much less carbon to grainfilling under water stress than previously thought.²⁹

25 LE Francois, TJ Donovan, EV Maas, GL Rubenthaler (1988) Effect of salinity on grain yield and quality, vegetative growth, and germination of triticale. *Agronomy Journal*, 80 (4), 642–647.

26 LR Shi, XG Cui, YX Zhu (2009) The effect of salt stress on photosynthetic characteristics and growth of various triticale. *Journal of Hengshui University* 2009–04, http://en.cnki.com.cn/Article_en/CJFDTOTAL-HSSZ200904022.htm

27 RS Jessop (1996) Stress tolerance in newer triticales compared to other cereals. In H Guedes-Pinto, N Darvey, V Carnide (eds) *Triticale: Today and Tomorrow*. Springer Netherlands, pp. 419–427.

28 R Motzo, G Pruneddu, F Giunta (2013) The role of stomatal conductance for water and radiation use efficiency of durum wheat and triticale in a Mediterranean environment. *European Journal of Agronomy*, 44, 87–97.

29 L Munjonji, KK Ayisi, B Vandewalle, G Haesaert, P Boeckx (2016) Combining carbon-13 and oxygen-18 to unravel triticale grain yield and physiological response to water stress. *Field Crops Research*, 195, 36–49.

4.4 Plant growth stages

Plant development is divided into five general stages: germination and early seedling growth, tillering and vegetative growth, elongation and heading, flowering, and kernel development. Numerical scales have been developed for quantifying growth stages of small-grain crops. A growth stage key provides farmers, advisers and researchers with a common reference for describing the crop's development. Management by growth stage is critical to optimising returns from inputs such as nitrogen (N), herbicides, plant-growth regulators and fungicides.

4.4.1 Zadoks scale of cereal growth stages

The Zadoks scale marks the growth stages of cereals according to 10 distinct developmental phases (Figure 3).³⁰ Table 2 relates the main features of the earlier stages of growth with the Zadoks scale.³¹

The Zadoks system uses a two-digit code to refer to the principal stages of growth from germination (stage 0) through kernel ripening (stage 9). The second digit represents a subdivision of the principal growth stages. For instance, 13 indicates that in principal stage 1 (seedling growth) subdivision 3, when leaves are at least 50% emerged from the main stem; 75 indicates that in principal stage 7 (kernel development), the plant has reached subdivision 5, where the grain is at the medium milk stage. The Zadoks system is often differentiated from other similar systems by the use of the letter Z before the number of the growth stage; in GrowNotes and other GRDC publications, the Z is converted to GS, for growth stage.

The principal Zadoks growth stages used in relation to disease control and N management are those from the start of stem elongation through to early flowering, GS30–GS61.

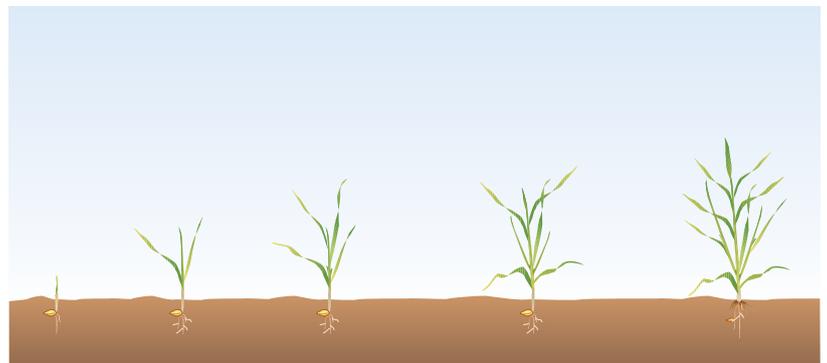
³⁰ N Poole (2005) Cereal growth stages. GRDC, <https://www.researchgate.net/file/PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798>

³¹ P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI, <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>

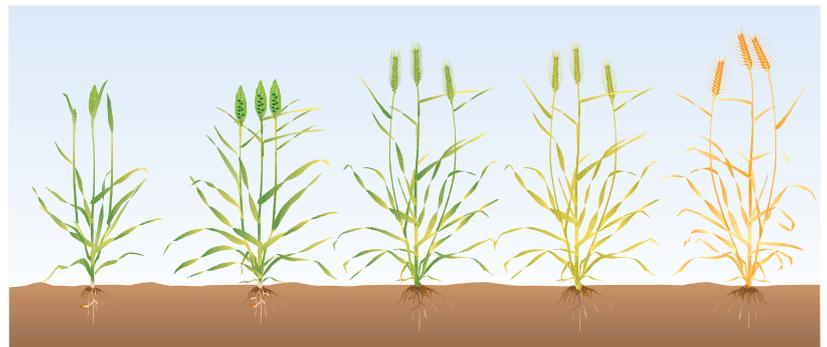
SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Zadoks Growth Stage	GS 00-09	GS10-19	GS20-29	GS30-39	GS40-49
Development phase	Germination	Seedling growth	Tillering	Stem elongation	Booting



Zadoks Growth Stage	GS 50-59	GS60-69	GS70-79	GS80-89	GS90-99
Development phase	Ear emergence	Flowering	Milk development (grain fill period)	Dough development (grain fill period)	Ripening

Figure 3: The Zadoks cereal-growth stages.

Source: GRDC

SECTION 4 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 3: Cereal growth stages.

Crop growth stage					
2-leaf stage	Start of tillering	Tillering stage	Fully tillered stage	Start of jointing	Early boot stage
Two leaves (L) have unfolded; third leaf present, yet to fully expand	First tiller (T1) appears from between a lower leaf and the main shoot. Usually 3 or 4 leaves on the main tiller.	Tillers come from the base where leaves join the stem and continue forming, usually until there are 5 leaves on the main shoot. Secondary roots developing.	Usually no more tillers form after the very young head starts forming in the main tiller. Tillering completed when first node detected at base of main stem.	Jointing or node formation starts at the end of tillering. Small swellings (joints) form at the bottom of the main tiller. Heads continue developing and can be seen by dissecting a stem.	The last leaf to form, the flag leaf, appears on top of the extended stem. The developing head can be felt as a swelling in the stem.
Zadoks decimal code					
2 leaves unfolded (Z12)	4 leaves unfolded (Z14)	5 leaves on main shoot or stem (Z15)	6 leaves on the main shoot or stem (Z16)	First node formed at base of main tiller (Z31)	Z35–Z45
	Main shoot and 1 tiller (Z21)	Main shoot and 1 tiller (Z21)	Main shoot and three tillers (Z23)		

Source: NSW DPI

Reading the Zadoks growth key

The main points to understanding the use of the Zadoks scale are:

- The Zadoks growth stage (GS) key does not run chronologically from GS00 to GS99. For example, when the crop reaches the stage of three fully unfolded leaves (GS13) it begins to tiller (GS20)—before it has completed the stages of four, five or six fully unfolded leaves (GS14, GS15, GS16).
- During tillering, it is easier to assess the main stem and the number of tillers than it is the number of leaves (due to leaf senescence). The growth stage is determined by the main stem and number of tillers per plant, e.g. GS22 is main stem plus two tillers up to GS29, the main stem plus nine or more tillers.
- In Australian cereal crops, plants usually reach GS29 before the main stem starts to stem elongate (GS30), dependent on variety and plant available nitrogen.
- As a consequence of growth stages overlapping it is possible to describe a plant with several growth stages at the same time. For example, a cereal plant at GS32 (second node on the main stem) with three tillers and seven leaves on the main stem would be at GS32, GS23 and GS17 at the same time, yet for practical purposes would be regarded as at GS32, since this describes the most advanced stage of development.
- After stem elongation (GS30) the growth stage describes the stage of the main stem, not an average of all the tillers. This is particularly important when timing the application of fungicides, e.g. GS39 is full flag leaf on the main stem, meaning that not all flag leaves in the crop will be fully emerged.³²

4.4.2 Germination and early seedling growth

The kernel (seed, or caryopsis), consists of a seed coat surrounding an embryo and endosperm. The embryo contains the seedling root (radicle), stem, and growing points of the new grain plant. The endosperm provides nutrients for growth until the first true leaves emerge and the root system is established. When moisture conditions are favourable, the seed germinates with the emergence of the radicle and the coleoptile, the first shoot, which forms a protective sheath around the first four leaves.

The primary root system includes the radicle and roots that develop from stem tissue near the kernel. It may penetrate the soil up to 30 cm, and provides the developing

³² N Poole (2005) Cereal growth stages. GRDC, <https://www.researchgate.net/file/PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798>

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK

seedling with water and nutrients. The primary root system supports plant growth until tillering, when the secondary root system becomes the main root system of the plant. The primary roots may persist for the life of the plant and can support some plant growth through the heading stage. The first secondary roots appear at the tillering node about 2.5 cm below the soil line at the two- or three-leaf stage. These roots are always produced at about the same distance below the soil's surface, regardless of the depth at which the seed is planted. The secondary root system makes up the major part of the fully developed plant's root system.

Root development approaches its maximum at about the boot stage. The 'boot' is the swollen flag-leaf sheath, within which the developing spike is located after being pushed up as the stem has elongated.

As the seedling's root system is forming, the coleoptile grows upward and ruptures, allowing the first leaf to begin unfolding as soon as the coleoptile tip breaks the soil surface. Emergence usually occurs six to 20 days after sowing, depending on temperature and moisture (Figure 4). Emergence may be later than 20 days after sowing under prolonged cold or dry conditions. Initial formation of leaves and stems occurs at the shoot apex, which is located just below the soil surface.

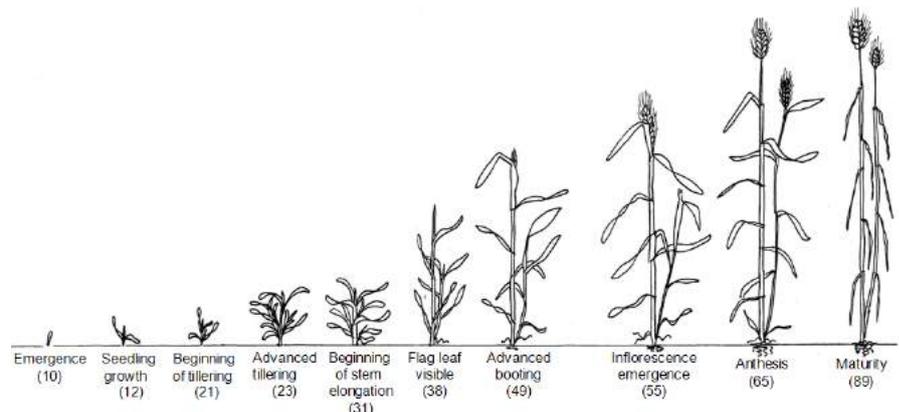


Figure 4: Growth stages of small-grain cereals. Numbers correspond to the Zadoks growth key.

Source: Royo and Villegas 2011

4.4.3 Tillering and vegetative growth

Branching in small-grain cereals is called tillering (or stooling). Individual branches are called tillers, and the mass of tillers is the stool. Two to four primary tillers develop from buds in the crown area of the main stem. Secondary tillers develop from buds in the axils of leaves at the base of the primary tillers. Tertiary tillers may develop from buds in the axils of leaves at the base of the secondary tillers.

The number of tillers that form is influenced by plant density (more with low plant density), soil moisture and nutrient supply (more with high supply), sowing date (more with early sowing), temperature (more under cooler temperatures), and cultivar. Water stress, nutrient deficiency, low temperatures, weed competition, and pest damage during early development reduce the number of tillers.

The emergence of primary tillers is synchronous with the emergence of leaves on the main stem of the plant (Photo 5).³³ The first primary tiller begins developing as leaf four of the main stem emerges; the second primary tiller begins developing as leaf five emerges. Subsequent primary tillers begin developing when subsequent leaves emerge.

Successive tillers develop fewer leaves; flowering and grain development is delayed, but only slightly, on later-developing tillers. Before the main stem and tillers begin to

³³ University of Wisconsin (2013) Wheat growth and development. University of Wisconsin, <http://corn.agronomy.wisc.edu/Crops/Wheat/L007.aspx>

elongate, the spikes differentiate. The precursors (primordia) of all florets (flowers with lemma and palea, the outer bracts) or spikelets (units consisting of several florets on a thin axis, subtended at the base by two bracts, or glumes) develop at this time.

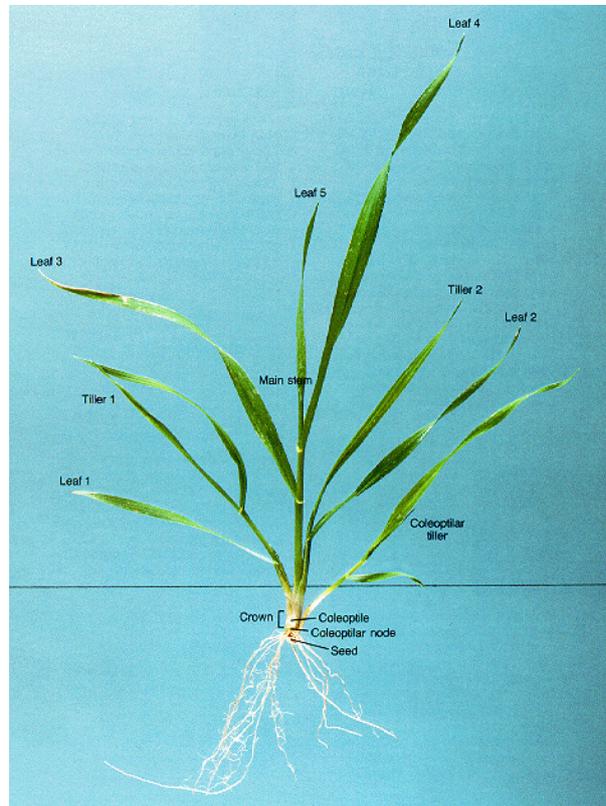


Photo 5: Plant parts in relation to growth stage.

Source: University of Wisconsin

4.4.4 Stem elongation and heading

Stem elongation, or jointing, occurs when stem internodes increase in length and bring the nodes above ground. The uppermost five or six internodes elongate, the lowest ones beginning first. The appearance of the first node above ground marks the beginning of jointing. Jointing begins about the time all spikelet primordia have formed. The flowering structure (inflorescence) of wheat, triticale, and barley is called a spike. Inflorescences are composed of spikelets, each consisting of one or more flowers, called florets, at nodes along the spike or panicle.

During stem elongation, the spike increases in length from about 3 mm to its final size, and individual florets mature. All stages of spikelet development in wheat, triticale, and barley begin near the middle of the spike and proceed toward the base and tip.

The last leaf of the small-grain plant to emerge is called the flag leaf. When the flag leaf blade has completely emerged, the appearance of its ligule (a short membrane on the inside of the leaf at the junction of the blade and sheath) marks the beginning of the boot stage. During this stage, the enlarging spike swells and splits the sheath of the flag leaf. Heading begins when the spike begins emerging through the collar of the flag leaf and is complete when the base of the spike is visible.

4.4.5 Flowering and grainfilling

Anthesis generally occurs 14 days after apical spikelet emergence for triticale.³⁴

The flowers of wheat, triticale, barley, and oat are self-pollinated; most of the pollen is shed before the anthers emerge from the florets. Flowering (anthesis, or pollen shed) usually occurs within two to four days of the spikes completely emerging from the boot. If emergence occurs during hot weather, flowering may occur while the spikes are still in the boot. Most cells of the grain endosperm are formed during a period of rapid cell division following pollination. These cells enlarge and accumulate starch during grain filling. Most of the carbohydrate used for grain filling comes from the photosynthetic output of the flag leaf. Developing spikelets compete for limited supplies of photosynthate and nitrogen. The smallest, slowest-growing florets, which occur at the tip of the spikelet, are often unable to obtain enough nutrients to keep growing. Some spikelets at the base of the wheat or barley spike also may fail to develop.

The stages of grain ripening are called milk, soft dough, hard dough, hard kernel, and harvest ripe (Photo 6). Dry matter begins accumulating in the kernel during the milk stage. During the early milk stage, a clear fluid can be squeezed from the kernel. By the time the grains reach the late milk stage, the fluid has turned milky (and can still be squeezed from the kernel). Most of the dry matter accumulates during the soft-dough stage. Loss of water gives the kernel a doughy or mealy consistency. At the end of the hard-dough stage, the kernel reaches physiological maturity, water content drops to about 30%, and the plant loses most of its green colour. The kernel contents can be divided with a thumbnail. At the hard-kernel stage, the plant is completely yellow and water content of the kernel is 20–25%. The contents of the kernel are difficult to divide with a thumbnail, but its surface can be dented. When kernel moisture content has dropped to 13–14%, the grain is harvest ripe. The surface cannot be dented with a thumbnail.³⁵

34 S Tshewang (2011) Frost tolerance in Triticale and other winter cereals at flowering. Master's thesis. University of New England, <https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm-contributor%3A%22Birchall+C%22>

35 L Jackson, J Williams (2006) Small grain production part 2: Growth and developments of small grains. University of California, <http://anrcatalog.ucanr.edu/pdf/8165.pdf>

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 6: Stages of cereal-grain ripening from the milk stage (top) to the harvest-ripe stage (bottom).

Source: Jackson and Williams 2006

4.4.6 Growth of triticale compared to other cereals

One of the advantages of triticale over wheat and barley is its early vigour, which enables fast crop growth during the first stages of development and a rapid cover of the soil by the canopy (Photo 7).

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK

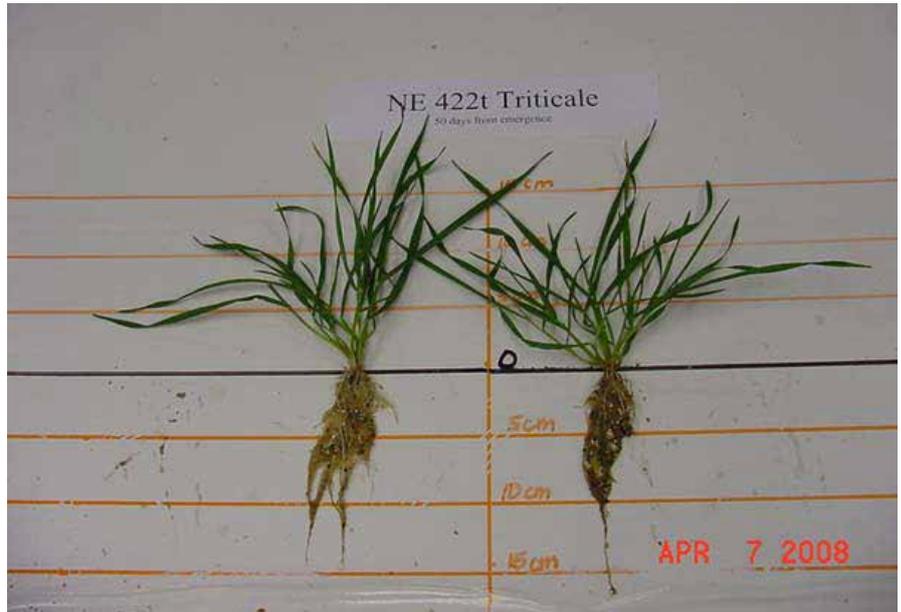


Photo 7: *Triticale 50 days after emergence.*

Source: Midwest Cover Crops Council

Trials in the UK were used to compare triticale and wheat growth. Researchers found a noticeable difference between the species in the length of key growth phases. The growth phase from sowing to GS31 (first node detectable) was, on average, 8.5 days shorter for the triticale, and from GS31 to GS61 (flowering) 1.75 days shorter for triticale than for wheat. However, from GS61 (grainfilling) to harvest was considerably longer—10.6 days—in the triticale (Figure 5).³⁶ The longer grainfilling phase did not confer a greater 1,000-grain weight (TGW) to the triticale varieties. Instead, this extra time was needed to fill the greater number of grains per ear that triticale has.

Despite the shorter duration to flowering, triticale formed more biomass during this phase than wheat. This was associated with both a greater number of stems and greater biomass per stem. The relative differences between the biomass of the different species at GS61 translated into differences at harvest, where triticale produced a greater yield. It can be seen that the yield advantages of triticale come from a combination of a greater number of heads per square metre and more grains per head that are filled during a longer grainfilling period. These are supported by greater biomass that is evident throughout the season.³⁷

³⁶ S Clarke, S Roques, R Weightman, D Kindred (2016) Understanding triticale. AHDB, <https://cereals.ahdb.org.uk/media/897536/pr556-understanding-triticale.pdf>

³⁷ S Clarke, S Roques, R Weightman, D Kindred (2016) Understanding triticale. AHDB, <https://cereals.ahdb.org.uk/media/897536/pr556-understanding-triticale.pdf>

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK

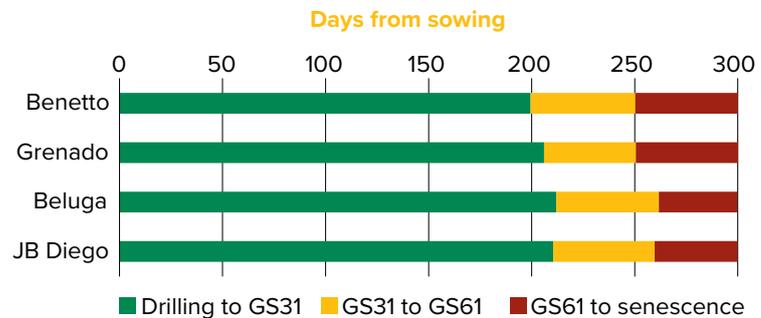


Figure 5: Length of key growth phases of two triticale varieties (Benetto and Grenado) and two wheat varieties (Beluga and JB Diego). Results are an average of two experiments. Plots grown at 180 kg N/ha.

Triticale cultivars tiller less profusely than wheat cultivars of similar maturity.³⁸ Significant differences in tillering abilities between triticale and wheat influences management practices. Triticale can compensate for having fewer tillers by producing more spikelets per head and setting more grains per spikelet, thereby producing more grains per pot than the other two cereals. The average kernel weights of triticale were also greater than those of wheat and rye. In one trial, total Water Use Efficiency (WUE) of triticale was less than that of the other cereals, particularly at the higher rates of N. The experiment showed that the yield of triticale was not restricted by less profuse tillering, and that it was able to compensate for this by producing more grains per ear and heavier kernels.³⁹

IN FOCUS

Variation in temperate cereals in rain-fed environments

Barley yields more grain and total biomass than does triticale, which in turn yields more biomass than do bread wheat, durum wheat and oats when sown at the same time in rain-fed environments in southern Australia. Researchers wanted to determine reasons for these differences. They grew cultivars of each species at five field sites, and measured variation in their phenology and both pre- and post-anthesis growth.

Barley achieved a higher yield of grain and biomass in a shorter time than the other species. It reached physiological maturity about 10 days (180 thermal units) before the other species, and also reached double ridge and anthesis earlier. Triticale was also earlier to reach double ridge and terminal spikelet than the mean for the other species, although it had a similar physiological maturity to the wheats. Barley and triticale developed a greater leaf area and dry mass faster than the wheats and oats. The differences in leaf area was established from the time the first leaf had fully expanded. Barley also developed main-stem leaves and tillers faster than the other species, whereas triticale was slower in this respect. The rate of crop growth was greatest in barley and triticale up to anthesis, but no differences between species were found in their relative growth rates. The growth rate of individual grains and of total grain per unit of ground

³⁸ GK McDonald, BG Sutton, FW Ellison (1983) The effect of time of sowing on the grain yield of irrigated wheat in the Namoi Valley, New South Wales. *Australian Journal of Experimental Agriculture and Animal Husbandry*, 24, 236–243.

³⁹ JB Golding (1989) Restricted tillering in triticale cv. currency: an impediment to grain yield? 5th Australian Agronomy Conference, <http://www.regional.org.au/au/asa/1989/contributed/crop/pt-20.htm>

SECTION 4 TRITICALE

TABLE OF CONTENTS

FEEDBACK

area were substantially greater in barley than the other species; oats and durum wheat were the slowest. Grain growth rate per unit of ground area was significantly associated with grain yield at one site where this was examined. The change in stem mass between anthesis and physiological maturity, which was determined to assess the possible contribution of stem reserves to grain, was also positively associated with grain yield at the two sites where it was determined, and more so at the drier site. The change in stem mass averaged 76 g/m² at the two sites, and this represented 25% of the total grain yield. However, the range varied from 13–39% of grain yield (corrected for husk mass in barley and oats). The loss in leaf sheath mass averaged 68 g/m² at both sites; this was not associated with grain yield.⁴⁰

In dry springs, triticale yields are 10–15% below wheat, due to triticale’s longer grainfilling period. Because of this, grain size may suffer in a hot, dry finish (Photo 8).⁴¹



Photo 8: *Triticale flowering (left) before grainfill (right).*

Sources: left, [KT Farmlife](#); right, [Living Crop Museum](#)

40 C López-Castañeda, RA Richards (1994) Variation in temperate cereals in rainfed environments II. Phasic development and growth. *Field Crops Research*, 37 (1), 63–75.

41 Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, <http://www.farmtrials.com.au/trial/13801>

Nutrition and fertiliser

Key messages

- In nutrient-deficient soils, triticale appears to respond better to applied fertilisers than other cereals do: it can survive by utilising trace elements in soils which would be considered deficient for any other type of crop. However, the growth and yield of triticale are very responsive to phosphorus and nitrogen.
- Triticale has a higher nutrient-uptake efficiency than other crops.
- The nutrition requirements of triticale are similar to those of wheat. Triticale is very responsive to high inputs of seed and fertiliser. Adequate fertiliser is needed to achieve protein levels above 10%.
- Triticale grows productively on alkaline soils where certain trace elements are deficient for other cereals. It can also grow better than most other cereals on acidic soils.
- In the northern grain-growing region, soils are generally very fertile, although there is increasing evidence that fertility has been run down over time.
- Triticale is tolerant of acidic soils and those high in Aluminium.

High yields in any crop are strongly dependent on adequate nutrients being available during growth. Triticale has a very extensive root system (see Photo 1) and can mine the soil more efficiently than other cereals where fertility is poor.¹ In general, triticale will respond favourably to cultural practices commonly used for the parental species wheat. However, it has been found that grain biomass and yield response of triticale are substantially higher than wheat when given larger amounts of nitrogen and phosphorus inputs.²

1 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

2 S Tshewang (2011) Frost tolerance in triticale and other winter cereals at flowering. Master's thesis. University of New England, https://e-publications.uned.edu.au/vital/access/manager/Repository/uned:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 1: Above- and below-ground growth of triticale plant, showing the extensive root system.

Photo: [Osborne Seed Company Variety Trials](#)

This section covers several aspects of the availability of nutrients to plants: the fertility of soils, crop removal rates, tests to determine nutrient levels and imbalances, and fertilisation. To help identify nutritional deficiencies, also refer to the GRDC's [Winter Cereal Nutrition: the Ute Guide](#), which has been made available as an app for mobile devices.

5.1.1 Declining soil fertility

In some areas of the Northern region, the natural fertility of cropped agricultural soils is declining over time.³ This decline has not been seen in the central NSW region where N and P fertility is increasing. Grain growers must continually review their soil-management programs to ensure the long-term sustainability of high-quality grain production. Pasture leys, legume rotations and fertilisers all play an important role in maintaining the chemical, biological and physical fertility of soils.

Paddock records that include yield and protein levels, results of fertiliser test strips, crop monitoring information, and the results of soil and plant tissue tests all help the grower to formulate an efficient and effective cropping program. Although crop rotations with grain legumes and ley pastures help maintain and improve soil fertility, fertilisers remain the major source of nutrients to replace those removed by grain production. Fertiliser programs must supply a balance of the required nutrients in amounts needed to achieve a crop's yield potential. The higher yielding the crop, the greater the amount of nutrient removed.

³ J Carson (2017) Biological inputs, northern grain-growing region. Soilquality.org, <http://www.soilquality.org.au/factsheets/biological-inputs-northern-grain-growing-region>

Balancing sources of nutrition

The yield of a crop will be limited by any nutrient the soil cannot adequately supply. Poor crop response to one nutrient is often linked to a deficiency in another nutrient. Sometimes, poor crop response can also be linked to acidity, sodicity or salinity, pathogens, or a lack of beneficial soil microorganisms.⁴

To obtain the maximum benefit from investment, fertiliser programs must provide a balance of required nutrients. For example, there is little point in applying enough nitrogen (N) if phosphorous (P) or zinc (Zn) deficiency is limiting yield. To make better crop-nutrition decisions, growers need to consider the use of paddock records, soil tests and test strips. This helps to build an understanding of which nutrients the crop removes at a range of yield and protein levels.

Monitoring of crop growth or even conducting tissue tests during the season will assist in identifying factors such as water stress, P or Zn deficiency, disease, or other management practices responsible for reducing yield.⁵

5.1.2 Fertilisers

Successful fertiliser decisions require robust information about a crop's likely yield response to that nutrient in a specific soil type, also taking into account the paddock history and season. As with most crops, rates of fertiliser application for triticale should be based on soil testing and other historical response information, as well as anticipated costs and returns. It is therefore also valuable to know the anticipated market for the grain and whether price gradients may reward higher protein levels. This may warrant extra nitrogen usage.⁶

Triticale has similar phosphorus and nitrogen requirements to wheat and responds well to most compound fertilisers. Zinc has also been found to be a valuable added nutrient for many soils found in the Northern region.⁷

In trials in Armidale, Geroogery and Narrabri, NSW, researchers tested the response of triticale varieties to N and P application. Soil tests indicated marked differences between the years in N and P status. In 2002, the site had a very low soil N level (2 µg/g nitrate) and a low/medium level of P (16 µg/g available P). The data from the 2004 site indicated much higher levels of nutrients, 64 µg/g nitrate and 46 µg/g phosphorus. Although this experiment was conducted in 2004 and used varieties that have now been largely superseded, the major findings remain relevant: that, in a high-rainfall region with yield potential above average, the yield responses to N fertiliser of a range of triticale varieties is at least equal to those for wheat (Table 1). With high yield potential (up to 8 t/ha) triticale varieties showed up to four times the yield response of the wheat variety Janz. At lower yields levels (2 t/ha) there were no differences in response between wheat and triticale varieties.

4 DAF Qld (2010) Overview [of nutrition management]. DAF Queensland, <https://www.dafqld.gov.au/business-priorities/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview>

5 DAF Qld (2010) Overview [of nutrition management]. DAF Queensland, <https://www.dafqld.gov.au/business-priorities/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview>

6 Agriculture Victoria (2012) Growing triticale. Note AG0497. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>

7 Agriculture Victoria (2012) Growing triticale. Note AG0497. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Table 1: Response of triticale (t/ha) to nitrogen fertiliser.

Variety	0 nitrogen	50 kg/ha nitrogen	100 kg/ha nitrogen	Response 100 kg/ha nitrogen
Everest	6.85	7.96	7.98	1.13
Kosciusko	7.37	7.48	8.34	0.97
Tahara	7.96	8.22	8.52	0.56
Janz wheat	6.73	6.99	7.00	0.27

Source: Jessop and Fittler 2009

These results indicated that, with low–medium yield expectations, wheat and triticale appear to show similar responses to additional N fertiliser. In locations with greater yield potential there is a suggestion that N requirements of triticale varieties exceed those of bread wheat varieties. The exact amounts of additional N fertiliser applied will depend on expected grain yields, soil N status, availability of water to the crop, and the current ratio of N fertiliser prices and crop returns.

Growers need to aim for sufficient soil N to obtain 11.5% protein in triticale, as below this level both grain yield and protein will be reduced. This aspect of triticale has been overlooked in the past and often triticale yields have been severely reduced compared with those in wheat as a result of inadequate N fertiliser application.⁸

A productive triticale will require P and N at sowing. Additional nitrogen is likely to be required for maximum dry-matter production for grazing and grain yield, particularly if the crop has been grazed. Consider applying 15–20 kg P/ha at sowing. This is equivalent to 75–100 kg monoammonium phosphate (MAP) per ha which will also include 7.5–10 kg N/ha. A triticale used for grazing as well as grain production will require significant N. If targeting 3 t/ha (when grazing triticale) then a minimum of 69 kg N/ha should be applied just to cover removal. If grazing is also included or soil nitrogen levels are low, additional N should be applied. Application can be split between sowing and top-dressing after grazing or during the stem-elongation stage (soon after the Zadoks growth stage 31, Figure 1).

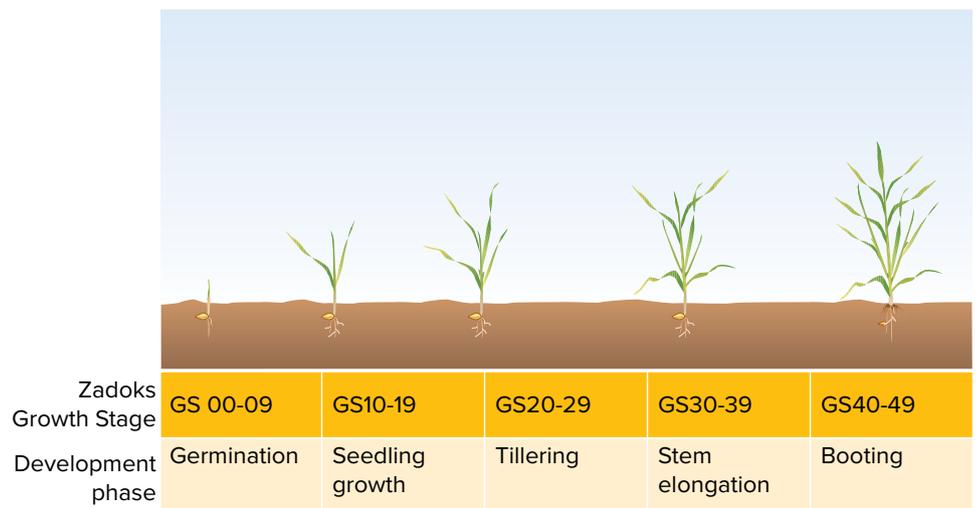


Figure 1: The Zadoks cereal-growth stages.

Source: GRDC

⁸ RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy, Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report.pdf

SECTION 5 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

MORE INFORMATION

[Crop nutrition: region by region](#)

GRDC factsheet, [Targeted nutrition at sowing](#)

VIDEOS

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Paddocks with a history of legume-dominant pasture or a pulse crop (e.g. lupins, field peas) tend to have a higher N status than those with a history of grassy pasture or cereal and canola crops and will not need as much applied N.⁹

Table 2¹⁰ lists the concentrations of nitrogen and phosphorous in common fertilisers. Use this to calculate total quantity of fertiliser to apply. In the example with a requirement of 69 kg N/ha this could be achieved by applying:

- 100 kg MAP per ha or 10 kg N per ha, plus
- 130 kg urea per ha or 59.8 kg N per ha supplying a total of 69 kg N per ha for the season.

Table 2: Nitrogen and phosphorous content of common high-analysis fertilisers.

Product	Phosphorus		Nitrogen	
	Kg/kg product	Kg/100 kg product	Kg/kg product	Kg/100 kg product
MAP	2.2	22	1.0	10
DAP	2.0	20	1.8	18
Urea	0	0	4.6	46

MAP = monoammonium phosphate, DAP = diammonium phosphate
Source: Waratah Seed Company

In a field experiment conducted in India, nine combinations of N and P were factorially randomised with four triticales and one check each of wheat and rye, to investigate the effect of progressive rates of application (180–300 kg N + P/ha⁻¹) of combined N + P fertiliser on grain yield and quality. Grain yield, protein content, and values for yield components significantly increased with increasing combined N + P fertiliser rates up to 240 kg N + P/ha⁻¹ (comprising 200 kg N + 40 kg P). The response of further increases in N + P rates gradually diminished thereafter, despite increasing N and/or P in the fertiliser combinations.¹¹

5.1.3 Fungi and soil health

Arbuscular mycorrhiza (AMF, previously known as VAM) is a fungus that penetrates the roots of a vascular plant in order to help them to capture nutrients from the soil. These fungi are scientifically well known for their ability to take up and transport mineral nutrients from the soil directly into host plant roots. Approximately 80% of known plant species, including most economically important crops, have a known symbiosis with them. Triticale has a low dependence on VAM (see table 3, below).

The microscopic fungal fibres vastly extend the root system. They extract water and nutrients from a large volume of surrounding soil, and bring them to the plant, improving nutrition intake and, hence, plant growth. A plant's root system, however big, can never be as extensive as the network of fungal fibres.

In cropping systems, most plants depend, to varying degrees, on mycorrhizal fungi to supply them with nutrients such as phosphorus and zinc. (By comparison, saprobic soil fungi, which colonise and break down organic matter, and do not require a host plant to complete their lifecycle.) In return, the plant hosts the fungus and supplies it with carbohydrates. AMF is therefore known as an obligate symbiont. It produces spores as a means of survival in soil during the absence of a host (e.g. during a clean fallow) and then germinates and colonise host roots once plants grow again.

This mutually beneficial partnership has existed as long as there have been plants growing in soil.

⁹ Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkrcr.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

¹⁰ Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkrcr.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

¹¹ S Moinuddin, MMRK Afridi (1997) Grain yield and quality of triticale as affected by progressive application rates of nitrogen and phosphorus fertiliser. *Journal of Plant Nutrition*, 20 (4–5), 593–600.

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

AMF levels can be severely reduced by long periods of fallow, such as those induced by drought. The longer the fallow, the less chance of survival of these spores and this is the cause of the syndrome that is called long fallow disorder (LFD). Hyphae in soil or in roots in the soil may also grow to new roots; however, they survive for less time in the soil than the spores. AMF levels can also be reduced by the growth of non-host crops.

Primarily, LFD is a phosphorus or zinc deficiency of the plant; it can be overcome by the application of P and/or Zn fertilisers. Having adequate populations of mycorrhizal fungi present in soils therefore can be beneficial; and in some cases it is essential for crop growth. Without mycorrhizae, much higher amounts of P and/or Zn fertiliser are required to attain the same level of productivity as when plants are supported by AMF.

When reintroduced to the soil, the arbuscular mycorrhiza colonizes the root system, forming a vast network of filaments. This fungal system retains moisture while producing powerful enzymes that naturally unlock mineral nutrients in the soil for natural root absorption.

Maintaining high mycorrhizal populations promotes good crop growth and the efficient use of P and Zn fertilisers. Many crop species require only half the phosphate concentration in soil when they are colonised by AMF.¹²

The colonisation of rye roots with arbuscular mycorrhizal fungi was investigated at two sites, cultivated using conventional or biological-dynamic farming methods. The AMF infection rate and infected root length were significantly higher at the biologically-dynamic cultivated site. It is suggested that these differences are due to several factors, such as the use of fertilisers and agro-chemicals, and the influence of crop rotation.¹³

Management to optimise mycorrhizae

There are two important and distinct concepts to understand when considering the management of crops for optimising mycorrhizal levels. These are a crops' dependency on mycorrhizae (important for the growth of that particular crop) (Table 3) and that crops' ability to produce mycorrhizal inoculum (important for the growth of the following crop). A crop with a low dependency may still produce suitable levels of inoculum for the next crop.

AM dependency, the extent to which a crop relies on AM to achieve maximum growth, varies with the crop species and variety, and with the P and Zn status of the soil.

Table 3: Mycorrhizal dependency rankings of summer and winter crops.

Mycorrhizal dependency	Winter Crops	Summer Crops
Very High	Linseed Fababean	Cotton Maize Pigeonpea Lablab
High		Sunflower Soybean Navybean Mungbean Sorghum
Low	Fieldpea Oats Wheat Triticale	
Very Low	Barley	
Independent	Canola Lupins	

¹² N B (2009) Mycorrhizae and their influence on P nutrition. GRDC Update Paper, GRDC, <https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2009/09/mycorrhizae-and-their-influence-on-p-nutrition>

¹³ B Sattelmacher, S Reinhard, A Pomikalko (1991) Differences in Mycorrhizal colonization of rye (*Secale cereale* L.) grown in conventional or organic (biological-dynamic) farming systems. Journal of Agronomy and Crop Science, 167 (5), 350–355.

If you suspect low numbers of AMF in your paddock:

- Grow crops with low or very low mycorrhizal dependency, e.g. triticale, wheat or barley, as they won't suffer much yield loss but will still increase the AMF inoculum for following crops.
- Avoid non-mycorrhizal crops, as they will not increase AMF inoculum status.
- If you wish to grow a crop that is highly dependent on AMF (e.g. to get a good price for your grain), apply high rates of P and Zn fertilisers.
- Adopt zero- or reduced-tillage practices during fallow periods, as this is less harmful to AMF than frequent tillage.¹⁴

5.2 Crop removal rates

Each tonne of triticale harvested will remove approximately 23 kg N/ha from the paddock (Table 4).¹⁵ So, if targeting 3 t/ha of grain then a minimum of 69 kg N/ha should be applied just to cover grain removal. If grazing is also included or soil nitrogen levels are low, additional N should be applied.

Table 4: *Nutrients removed (kg) per tonne of grain produced.*

Crop type	Nitrogen	Phosphorus	Potassium	Sulfur
Wheat	21	3.0	5	1.5
Triticale	21	3.0	5	1.5
Barley	20	2.7	5	1.5
Oats	17	2.5	4	1.5

Source: Agriculture Victoria

5.3 Soil testing

Key points:

- The range of soil test values used to determine if a nutrient is deficient or adequate is termed a critical range.
- Revised critical soil test values and ranges have been established for nutrients, crops and soil class.
- A soil test value indicates if there is sufficient nutrient supply to meet the crop's demand.
- A value above the critical range indicates there is not likely to be a crop yield response to added nutrients.
- A value below the critical range indicates there is likely to be a crop yield response to added nutrients.
- Fertiliser decisions are based in part on where the result of the soil test falls along the critical range.
- Critical ranges for combinations of nutrient, crop and soil types are still being established.
- Critical ranges are being established for topsoils (0–10 cm) and subsoils (10–30 cm in some cases, and to the depth of the crop root-zone in others), depending on the nutrient.
- Deeper sampling is considered to be essential for understanding soil nutritional status and fertiliser requirements in northern cropping systems.
- Soil sampling to greater depth (0–60 cm) is considered important for more mobile nutrients (N, K and S) as well as for pH, salinity and sodicity.

¹⁴ N Seymour (2009) Mycorrhizae and their influence on P nutrition. GRDC Update Paper. GRDC, <https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2009/09/mycorrhizae-and-their-influence-on-p-nutrition>

¹⁵ Agriculture Victoria (2008) Establishing forage cereals. Note AG1269. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/forage-cereals/establishing-forage-cereals>

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- Use local data and support services to help integrate soil test data into making profitable fertiliser decisions.

Recent research has highlighted that nitrogen applications can be wasted, even on cropping soils that have low N availability, if the levels of other nutrients such as potassium (K), P and sulfur (S) are not adequate.

Fertiliser is a major cost for grain growers, so making careful selections of crop nutrients is a major determinant of profit. Both under-fertilisation and over-fertilisation can lead to economic losses, due to unrealised crop potential or wasted inputs.

Before deciding on how much fertiliser to apply, it is important to understand the quantities of available nutrients in the soil, where they are located in the soil profile and the likely demand for nutrients in that season.

The values from appropriate soil tests can be compared against critical nutrient values and ranges; these indicate which nutrients are limiting and which are adequate.

Soil test critical values advise growers if a crop is likely to respond to added fertiliser, but without further information, they do not predict optimum fertiliser rates. When considered in combination with information about target yield, available soil moisture, last year's nutrient removal and soil type, soil tests can help in making fertiliser decisions.

There has recently been a lot of research conducted on the importance of subsoil layers for nutrients such as P and K in the Northern region.

5.3.1 Why test soil?

Soils are tested for several reasons, but the principal ones are to:

- Estimate how much water can be stored.
- Monitor soil fertility levels.
- Estimate which nutrients are likely to limit yield.
- Measure properties such as pH, sodium (sodicity) and salinity, acidity, or high levels of boron or aluminium which affect the crop demand as well as the ability to access nutrients.
- Measure the occurrence of soil-borne diseases.
- Zone paddocks for variable application rates.
- Diagnose the reasons for poor plant performance—soil-test results are part of the information that support decisions about fertiliser rate, timing and placement.
- To quantify and physical problems e.g. compaction.¹⁶

5.3.2 Basic requirements

There are three basic steps that must be followed if meaningful results are to be obtained from soil testing. These are to:

1. Use a representative sample of soil.
2. Analyse the soil using the accepted procedures that have been calibrated against fertiliser experiments in that region.
3. Interpret the results using criteria derived from those calibration experiments.

As each of these steps may be under the control of a different person or entity, it is important to use standardised procedures to that results are accurate. For example, the sample may be taken by the farmer manager or by a consultant agronomist; it is then sent to an analytical laboratory; and finally the soil test results are interpreted by an agronomist to develop recommendations for the farmer.¹⁷

¹⁶ GRDC (2014) Soil testing for crop nutrition (Southern Region). Factsheet. GRDC, www.grdc.com.au/GRDC-FS-SoilTestingS

¹⁷ D Loch (n.d.) Soil nutrient testing: how to get meaningful results. DAF Queensland, https://www.daf.qld.gov.au/_data/assets/pdf_file/0006/65985/Soil-Nutrient-Testing.pdf

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5.3.3 Types of test

Appropriate soil tests for measuring soil extractable or plant available nutrients are:

- bicarbonate extractable P (Colwell-P);
- acid extractable P (BSES-P), to assess slower release soil P reserves and the build-up of fertiliser residues (not required annually);
- bicarbonate extractable K (Colwell-K);
- KCl-40 extractable S; and
- 2M KCl extractable inorganic N, which provides measurement of nitrate-N and ammonium-N.

Other measurements that aid the interpretation of soil nutrient tests include soil pH, percentage of gravel in the soil, soil carbon/organic matter content, P sorption capacity (currently measured as phosphorus buffering index, or PBI), electrical conductivity (EC), and chloride and exchangeable cations (CEC) including aluminium.¹⁸

5.4 Plant-tissue testing for nutrition levels

Plant-tissue testing can be limited in its usefulness in monitoring crop health, because by the time noticeable symptoms appear in a crop the yield potential can be markedly reduced. Plant-tissue testing can also be used to diagnose a deficiency or monitor the general health of the crop.

To determine micronutrient status, plant tissue testing is usually more reliable than soil testing.¹⁹

The only way to know whether a crop is adequately nourished before visual symptoms indicate imbalances is to have plant tissue analysed during the growing season.

5.4.1 What plant-tissue analysis shows

Plant-tissue analysis shows the nutrient status of plants at the time of sampling. This, in turn, shows whether soil nutrient supplies are adequate. In addition, plant-tissue analysis will detect unseen deficiencies and may confirm visual symptoms of deficiencies. Toxic levels of nutrients may also be detected.

When sampling:

- Sample the correct plant part at the specified time or growth stage.
- Use clean plastic disposable gloves to sample to avoid contamination.
- Sample tissue (e.g. entire leaves) from vigorously growing plants unless otherwise specified in the sampling strategy.
- Take a sufficiently large sample quantity (adhere to guidelines for each species provided).
- When troubleshooting, take separate samples from good and poor growth areas.
- When necessary, wash samples while fresh to remove dust and foliar sprays.
- Keep samples cool after collection.
- Refrigerate or dry if samples can't be despatched to the laboratory immediately, to arrive before the weekend.
- Generally sample in the morning while plants are actively transpiring.

Things to avoid when sampling:

- Avoid spoiled, damaged, dead or dying plant tissue.
- Don't sample plants stressed by environmental conditions.

¹⁸ GRDC (2014) Soil testing for crop nutrition, Northern region. Factsheet. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/01/soil-testing-for-crop-nutrition-south>

¹⁹ GRDC (2014) Soil testing for crop nutrition, Northern Region. Factsheet. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/01/soil-testing-for-crop-nutrition-south>

- Don't sample plants affected by disease, insects or other organisms.
- Don't sample soon after applying fertiliser to the soil or foliage.
- Avoid sample contamination by dust, fertilisers, chemical sprays, perspiration and sunscreen.
- Avoid atypical areas of the paddock, e.g. poorly drained areas.
- Do not sample plants of different vigour, size and age.
- Do not collect from different cultivars (varieties) to make one sample.
- Don't collect samples into plastic bags as this will cause the sample to sweat and hasten its decomposition.
- Don't sample in the heat of the day, i.e. when plants are moisture stressed.
- Don't mix leaves of different ages.²⁰

The successful use of plant tissue analysis depends on sampling the correct plant part at the appropriate growth stage (Table 5).

Table 5: *Plant tissue requirements for nutrient testing of triticale.*

Growth stage to sample	Plant part	Number required
Seedling to early tillering (GS 14–21)	Whole tops cut off 1 cm above ground	40
Early tillering to 1st node (GS 21–31)	Youngest expanded blade (YEB) plus next 2 lower blades	25
Flag leaf ligule just visible to boots swollen (GS 39–45)	Youngest expanded blade (YEB) plus next 2 lower blades	25

Source: Back Paddock Company

5.5 Nitrogen

Key points:

- Nitrogen (N) is needed for crop growth in larger quantities than any other nutrient.
- Nitrate (NO_3^-) is the highly mobile form of inorganic nitrogen in both the soil and the plant.
- Sandy soils in high-rainfall areas are most susceptible to nitrate loss through leaching.
- Soil testing and nitrogen models will help determine seasonal nitrogen requirements.²¹

The two forms of soil mineral N absorbed by most plants are nitrate (NO_3^-) and ammonium (NH_4^+) (see Figure 2).²² In well-aerated soils during the growing season NO_3^- becomes the main form of N available for crops as microbial activity quickly transforms NH_4^+ into NO_3^- . It is crucial to keep NO_3^- at an adequate level because, on one hand, if they are too low crop production will be limited and, on the other hand, if they are too high environmental pollution can result. The levels of soil NO_3^- vary across space and over time. Proper agricultural management needs to consider both site-specific variations as well as temporal patterns in soil NO_3^- to supply optimum amounts from both organic and mineral sources.²³

20 Back Paddock Company (n.d.) Back Paddock SoilMate: Guidelines for sampling plant tissue for annual cereal, oilseed and grain legume crops. Back Paddock Company. <http://www.backpaddock.com.au/assets/Product-Information/Back-Paddock-Sampling-Plant-Tissue-Broadacre-V2.pdf?phpMyAdmin=c59206580c88b2776783fdb796fb36f3>

21 GRDC (2006) Triticale. Ground Cover. Issue 59, 1 January 2006. GRDC. <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-59/Triticale>

22 Soilquality.org. Nitrogen, NSW. Factsheet. Soilquality.org. <http://www.soilquality.org.au/factsheets/nitrogen-nsw>

23 M Ladoni, AN Kravchenko, GP Robertson (2015) Topography mediates the influence of cover crops on soil nitrate levels in row crop agricultural systems. PLOS ONE, 10 (11), DOI 10.1371/journal.pone.0143358

SECTION 5 TRITICALE

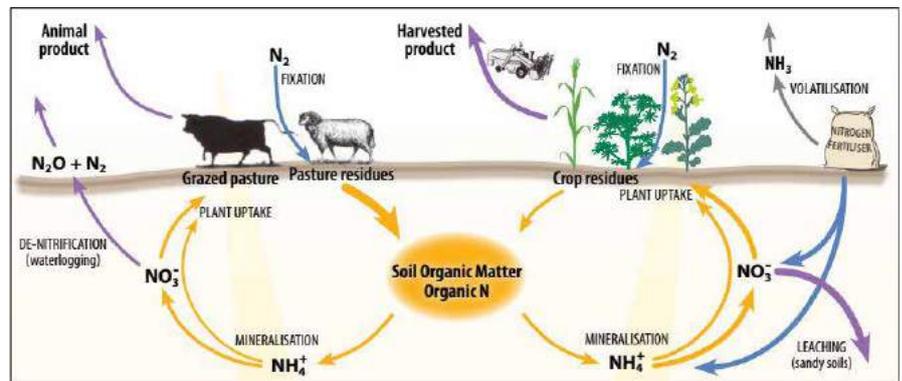
[TABLE OF CONTENTS](#)
[FEEDBACK](#)


Figure 2: How the two forms of soil mineral nitrogen fit into the principle nitrogen cycling pathways in mixed cropping–pasture systems.

Source: Soilquality.org

The results of trials outside Canberra to explore crop management of dual-purpose cereals indicated that N should be applied at sowing to ensure good early plant growth and to build up Dry Matter production. Post-sowing nitrogen application should be left until after grazing: it should not be applied just before grazing due to the risk of high forage nitrate levels. High nitrate in forage can lead to nitrite toxicity in grazing livestock, especially under cool, cloudy conditions. Immediately after grazing finishes, growers may safely apply 50 kg of nitrogen (in the form of urea) per hectare immediately after grazing finishes to boost plant recovery, if N budgeting indicates the crop may require this treatment.²⁴

For more information on N budgeting, see [Section 5.5.2 Managing nitrogen–N Budgeting](#), below.

IN FOCUS

Responses of triticale, wheat, rye and barley to nitrogen fertiliser

Researchers conducted a field experiment at Mintaro, South Australia, on triticale and three other grains to learn more about how they respond to N fertiliser. They planted a hexaploid triticale from Mexico and local cultivars of wheat, rye and barley. To each they applied five levels of fertiliser nitrogen (0, 35, 70, 105 and 140 kg/ha) with four replications. Note that starting levels of nitrogen in the trials were not reported.

There was a visually discernible response to nitrogen fertiliser by all four genotypes from an early stage, and this confirmed by quantitative sampling at the stages of tillering, anthesis and maturity. Responses in plant dry weight to 105 kg N/ha were maintained until anthesis, but grain yield only improved at 35 kg N/ha. Total dry-matter production responses at maturity to more than 35 kg N/ha were small. The numbers of tillers and heads were increased by adding nitrogen up to 140 kg/ha for tillering, and 105 kg/ha for heads. Plant height increased with the application of up to 70 kg/ha, but greater amounts of N than this resulted in significant lodging in both and triticale. For all genotypes, thousand-grain weight decreased with increasing level of nitrogen supply, while grain and straw nitrogen increased up to levels of 140 and 105 kg /ha, respectively. Nitrogen supply had little effect on maturity: plants at 0 kg/ha and 140 kg/ha of N reached anthesis less than a day apart. The lack of a significant nitrogen × genotype interaction in nearly all the data suggests that the triticale is the same as the traditional cereals in it nitrogen needs. Triticale consistently out-

²⁴ D Lush (2014) Rules of thumb for grazing cereals. Ground Cover. Issue 109, March–April 2014. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-109-Mar-Apr-2014/Rules-of-thumb-for-grazing-cereals>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

yielded the other cereals in total dry-matter production, followed by the rye, wheat and barley in that order. Grain yield was highest in the wheat and lowest in the rye, the latter also being the least responsive to nitrogen. The advantage of the triticale lay in its high grain protein, combined with good yield.²⁵

IN FOCUS

Nitrogen timing for boot-stage triticale forage yield and phosphorus uptake

The optimal time to apply N for boot-stage winter triticale forage production and P removal is not well established. In a US experiment that took place in 2006 and 2007, irrigated winter triticale was grown on soils that were either low and relatively high in P (having been tested using the Olsen P test). The triticale was treated with six rates of autumn pre-plant N and two rates of late-winter N. The researchers measured triticale boot-stage biomass, protein, nitrate-N, P concentrations, and P uptake. The N applied in autumn increased forage production and frequently produced more boot-stage triticale biomass. It also tended to increase P uptake, but reduced P and forage-protein concentrations, probably due to plant dilution. In the high-P soil, higher N increased forage P concentrations in one of the two years. Forage protein in the range of 10.5–11.0% was needed to maximise forage production.²⁶

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Lodging risk

The main commercial triticale varieties are relatively tall compared with newer wheat varieties, increasing the likelihood of lodging. However, breeding efforts have created varieties with a lower risk of lodging. The likelihood of lodging is increased by high rates of nitrogen fertiliser and under irrigated conditions.²⁷

For example, in a field experiment at Mintaro, South Australia, researchers found that plant height increased with the application of up to 70 kg/ha, but greater amounts of N than this resulted in significant lodging in both wheat and triticale.²⁸

For more information on how to manage a lodged crop, see [Section 12.2.1—Lodging](#).

5.5.1 Symptoms of Nitrogen deficiency

Nutrient deficiency symptoms in triticale are similar to those in wheat and other cereals.

25 RD Graham, PE Geytenbeek, BC Radcliffe (1983) Responses of triticale, wheat, rye and barley to nitrogen fertiliser. *Animal Production Science*, 23 (120), 73–79.

26 B Brown (2009) Nitrogen timing for boot stage triticale forage yield and phosphorus uptake. Western Nutrient Management Conference. [http://www.extension.uidaho.edu/nutrient/pdf/smallgrain/New/Nitrogen timing for boot stage triticale forage yield and phosphorus uptake.pdf](http://www.extension.uidaho.edu/nutrient/pdf/smallgrain/New/Nitrogen%20timing%20for%20boot%20stage%20triticale%20forage%20yield%20and%20phosphorus%20uptake.pdf)

27 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC. http://www.apri.com.au/1A-102_Final_Research_Report.pdf

28 RD Graham, PE Geytenbeek, BC Radcliffe (1983) Responses of triticale, wheat, rye and barley to nitrogen fertiliser. *Animal Production Science*, 23 (120), 73–79.

What to look for in the paddock

Light green to yellow plants particularly on sandy soils or unburnt header or swathe rows (Photo 2).²⁹

- Double-sown areas have less symptoms if nitrogen fertiliser was applied at seeding.
- Nitrogen deficiency can occur in waterlogged areas of the paddock.

What to look for in the plant

- Plants are pale green with reduced bulk, shorter stature and fewer tillers.
- Symptoms first occur on the oldest leaf, which becomes paler than the others and shows marked yellowing starting at the tip and gradually merging into light green (Photo 3).
- Other leaves start to yellow, and the oldest leaves change from yellow to almost white.
- Leaves may not die for some time.
- Stems may be pale pink.
- Plants develop more slowly than healthy plants, but maturity is not greatly delayed.
- Reduced grain yield and protein levels.



Photo 2: Nitrogen deficiency on unburnt header row.

Source: DAFWA

²⁹ DAFWA (2015) Diagnosing nitrogen deficiency in wheat. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogen-deficiency-wheat>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 3: Deficient plants are smaller with yellow leaves and fewer tillers.

Source: DAFWA

What else it could be

Before assuming nitrogen deficiency, eliminate other possible causes of symptoms (Table 6).

Table 6: Other problems of triticale that could be confused for nitrogen deficiency.

Condition	Similarities	Differences
<u>Waterlogging</u>	Pale plants with oldest leaves most affected	Root browning or lack of feeder roots and wet soil
<u>Potassium deficiency</u>	Pale plants with oldest leaves most affected	Differences include more marked leaf-tip death and contrast between yellow and green sections in potassium-deficient plants. Tillering is less affected.
<u>Molybdenum deficiency</u>	Pale, poorly tillered plants	Molybdenum deficiency affects the middle leaves first and causes white heads, shrivelled grain and delayed maturity

Source: DAFWA

5.5.2 Managing nitrogen

Key points:

- The first step to managing N is having a N budget for each paddock for each year.

VIDEOS

WATCH: [GCTV14: Nitrogen deficiency](#)



- Nitrogen is very mobile in the soil, it can move half the wetting front following a watering/rainfall event. This is both a benefit and in some cases a disadvantage.
- The amount of N that can be applied with the seed is limited.
- There is no consistent difference in the response to N between different forms of N fertiliser.
- In general, increases in grain protein concentration are greater with N applications between flag-leaf emergence and flowering.
- Volatilisation losses can be significant in some cases: the greatest risk is with urea, and lower, but still significant, with a solution of urea and ammonium nitrate (UAN) and ammonium sulphate.³⁰
- Trials in NSW found that triticale requires 80 kg/ha to maximise yield.³¹

Deficiency symptoms can be treated with N fertiliser or foliar spray or with urea etc. spread in front of rainfall or an irrigation event. Note that, when topdressing on dry, alkaline soils in dewy conditions, there is a risk of volatilisation loss from urea or ammonium sources of nitrogen. Losses rarely exceed 3% per day.³²

There are four main sources of nitrogen available to crops: stable organic nitrogen, rotational nitrogen, ammonium and nitrate. To optimise plants' ability to use soil nitrogen, growers should first be aware of how much of each source there is. The best method of measuring these nitrogen sources is soil testing.

N Budgeting

Matching plant demand with fertiliser N supply is important for a number of environmental and economic reasons. Nitrogen is lost through volatilisation, leaching and denitrification. By ensuring that the plant N use matches the fertiliser N you are minimising the chances of excess N reducing water quality and contributing to acidification.

More efficient use of nitrogen fertiliser reduces both greenhouse gas emissions and on-farm costs. Nitrous oxide, which can be emitted from N fertiliser applied to agricultural soils, is a potent greenhouse gas, having a global warming potential 310 times that of carbon dioxide. Using monitoring tools such as N budgeting will ensure that fertiliser applied to pasture and crops will provide maximum production benefit with minimal environmental impact.

Steps

- Step 1: Record paddock name
- Step 2: Calculate target yield: One good way to calculate a target yield is to use the French-Schultz approach:

Where growing season rainfall is the total received between April–October:

Triticale potential yield = 18 x (growing season rainfall in mm–90)

Wheat potential yield = 20 x (growing season rainfall in mm–110)

Barley potential yield = 18 x (growing season rainfall in mm–90)

Oats potential yield = 22 x (growing season rainfall in mm–90)

Grain legumes potential yield = 12 x (growing season rainfall in mm–130)

- Step 3: Calculate N budget: Using Table 7 (and Table 8 to correct for the extra N that becomes available over the growing season).
- Step 4: Apply correct amount of fertiliser: Urea contains 46% N, ammonium nitrate 34% N, di-ammonium phosphate (DAP) 18% N, mono-ammonium phosphate (MAP) 11.3% N, and sulphate of ammonia 21% N. But note that sulphate

30 G McDonald, P Hooper (2013) Nitrogen decision: Guidelines and rules of thumb. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Nitrogen-decision-Guidelines-and-rules-of-thumb>

31 J Sykes (2005) Triticale maximum yield experiment. Riverine Plains. Online Farm Trials. http://www.farmtrials.com.au/trial/16484?search_num=3

32 DAFWA (2015) Diagnosing nitrogen deficiency in wheat. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogen-deficiency-wheat>

SECTION 5 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

of ammonia is highly acidifying and needs between 4–7 kg lime per kg N applied to balance the acidity; see Acidity Tools for further details.

Table 7: Nitrogen budget based on an autumn-winter deep soil N test to 60 cm depth

		Example	Growers' calculation
Crop demand			
	Target yield	4.0 t/ha	
Multiplied by	Target protein	X 13%	
Multiplied by	Correction factor	X 2.34	
Equals	N-demand	122 kg N/ha	
Soil supply			
	Measured soil mineral N in the top 60 cm at sowing–autumn - winter deep-soil-N test.	100 kg N/ha	
Add	Estimated production of mineral N (mineralisation*) during crop production—see Table 8.	80 kg N/ha if low fertility soil	
Equals	Gross N supply	180 kg N/ha	
Less	Assume 50% is not taken up by the crop**	- 90 kg N/ha	
	Net N-supply	90 kg N/ha	
Fertiliser needed			
Subtract soil supply from crop demand	Net extra N required	122 - 90 = 32 kg N/ha	
Crop demand: multiply "Net extra N required" by 2	Fertiliser N needed (assuming 50% efficiency of N recovery)***	32 x 2 = 64 kg N/ha	

Mineralisation of N (marked as * in Table 7, above), that is N made available to plants by the breakdown of plant residues and organic matter, is fastest in warm, moist conditions. Most rapid mineralisation occurs after summer and autumn storms and is slowest in dry summers and also in mid-winter. Mineralisation continues during crop growth but is difficult to measure because the N is taken up by roots as fast as it is formed. It occurs at rates of up to 1 kg N/ha/day in moist, warm ($\approx 16^{\circ}\text{C}$) topsoil in spring, and at about 0.2 kg N/ha/day in cold, wet soils in winter. Mineralisation rates in soils with retained stubbles can be 1–1.5 kg N/ha/day following rain while the soil remains wet, dropping to zero once the soil has dried out.

The 50% efficiency of N recovery by plants (marked as *** in Table 7, above) is based on many studies which show that plant tops on average take up at least half of the applied N. This does not necessarily mean that the remaining 50% is all lost. Roots can take up about 30% of the N, and thus some of this residual N will eventually become available to the next generation of plants once the roots decay. True losses of N occur from:

- Volatilisation (gaseous losses of N) can be high in warm conditions, particularly from top-dressed urea with no follow-up rainfall to wash in the urea granules, and on alkaline soils).
- Denitrification (commonly less than 5–10 kg N/ha) is only likely if soils are warm and waterlogged and have a high amount of nitrate present and a source of

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

carbon for microbes. Denitrification is the conversion of nitrate-N to gaseous N, and so is a loss of N which would have been available to plants.

- Leaching (loss of N in water—below the root-zone or laterally) as nitrate-N in wet years.

The amount of N fixed in different environments is determined by legume content and herbage yield. As a rule-of-thumb, 20–25 kg N in plant tops can be expected to be fixed on average for every tonne of legume dry matter produced. Assuming legume dry matter is not measured, Table 8 can be used to estimate N availability during the growing season.

Table 8: *Estimated within-growing-season mineralisation rates in southern NSW cropping soils (based on estimates of Mark Peoples, CSIRO Canberra).*

Fertility status of soil	Nitrogen (kg N/ha) which becomes available during the growing season
Low e.g. continuously cropped, low use of N fertilisers, N deficiency common in crops, < 0.08% topsoil total N.	60
Medium e.g. crop-pasture rotation, 2nd or 3rd crop into the rotation, moderate use of N fertilisers, 0.08–0.12% topsoil total N.	80
Moderate-high e.g. 1st crop after pasture, moderate clover pasture contained at least 20–30% clover, moderate use of N fertiliser, > 0.12% topsoil total N.	100
High fertility e.g. 1st or 2nd crop after winter-cleaned pasture of high legume content (>50% legume content), > 0.12% topsoil total N.	160

Source: [Agriculture Victoria](#).

The N benefits from subterranean clover or annual medic pastures rarely last beyond two years. Nitrogen benefits from lucerne can occur 2–3 years after lucerne removal (due to slower breakdown of lucerne residues than for annual legumes). However, if lucerne is removed only shortly before cropping, N fertiliser may be required for the first crop because it can take several weeks for the N in legume residues to break down and become available to other plants. N deficiency is unlikely to be a problem for spring-removed lucerne.³³

For example, triticale used for grazing and grain could use up to 100 kg N/ha. Consider applying 60–100 kg N/ha as a topdressing if soil nitrogen levels are low, however this depends on N in the paddock, N removed, Dry Matter production and other variables. This is where working out an N budget is important. Long fallow paddocks following good legume pastures generally have satisfactory nitrogen levels. The contribution of crops and pastures to soil nitrogen depends on the amount of plant material produced and/or the subsequent grain yield. The actual amount of soil nitrogen accumulated is highly variable.³⁴

Timing of application

The two main questions with N management are how much N is needed, and when it should be applied.

Grain-yield improvements are mainly caused by increased tiller numbers and grains per head, both of which are determined early in the life of a triticale plant. A sufficient supply of nitrogen during crop emergence and establishment is critical. Nitrogen-use

³³ Agriculture Victoria (2017) Nitrogen monitoring tools. <http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/nitrogen-n>

³⁴ P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI. <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

efficiency can be improved by delaying fertiliser application until the crop's roots system is adequately developed, 3–4 weeks after germination.

Later nitrogen applications can also have yield benefits by aiding increased tiller survival, leaf duration and photosynthetic area. However, delaying application reduces the chance that economic gain from the response to nitrogen will be achieved. An advantage of late applications (once the first node is visible) is that growers have a better idea of seasonal conditions and what the yield potential might be before applying the nitrogen.³⁵

The critical factor in budgeting the amount of N to apply is the target crop yield and protein yield, as crop yield potential is the major driver of N requirement. As a guide, Table 9 shows the N required for different yield and protein combinations at maturity and anthesis.³⁶

Clearly predicting yield during the growing season is crucial to allow growers to make tactical decisions on N management. Recent experience has shown that Yield Prophet® can predict yields accurately in mid-August and can assist with N decisions.³⁷

Table 9: Nitrogen requirements for cereal crops at different combinations of yield and grain protein at maturity, and the corresponding N required at anthesis.

Grain yield (t/ha)	Growth stage	Grain protein (%)				
		9	10	11	12	13
kg N/ha						
1	Maturity	21	23	26	28	30
	Anthesis	17	19	21	22	24
2	Maturity	42	47	51	56	61
	Anthesis	34	37	41	45	49
3	Maturity	63	70	77	84	91
	Anthesis	51	56	62	67	73
4	Maturity	84	94	103	112	122
	Anthesis	67	75	82	90	97
5	Maturity	105	117	129	140	152
	Anthesis	84	94	103	112	122
6	Maturity	126	140	154	168	182
	Anthesis	101	112	124	135	146

The estimates are based on the assumption that 75% of the total crop N is in the grain at maturity and that 80% of the total N is taken up by anthesis.

Source: GRDC

Optimising nitrogen-use efficiency

The three main stores in the soil of nitrogen that can feed crops is nitrogen in soil organic matter, nitrogen in plant residues, and mineral nitrogen (ammonium and nitrate). To optimise plants' ability to use soil nitrogen, growers should first be aware of how much of each source there is. The best method of measuring these is soil testing.

The release of nitrogen during the decomposition of organic matter in the soil is a significant supply of N to crops during the growing season. Most N models

³⁵ R Quinlan, A Wherrett (2013) Nitrogen, NSW. Soilquality.org.au

³⁶ G McDonald, P Hooper (2013) Nitrogen decision: Guidelines and rules of thumb. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Nitrogen-decision-Guidelines-and-rules-of-thumb>

³⁷ G McDonald, P Hooper (2013) Nitrogen decision: Guidelines and rules of thumb. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Nitrogen-decision-Guidelines-and-rules-of-thumb>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

estimate the amount of organic nitrogen in the soil from the amount of total organic carbon present.

Mineralisation is the main process by which soil organic matter is converted by microorganisms into plant-available forms of N (Figure 3). The amount of N mineralisation depends on three factors—the soil’s total N content, its temperature and water content.

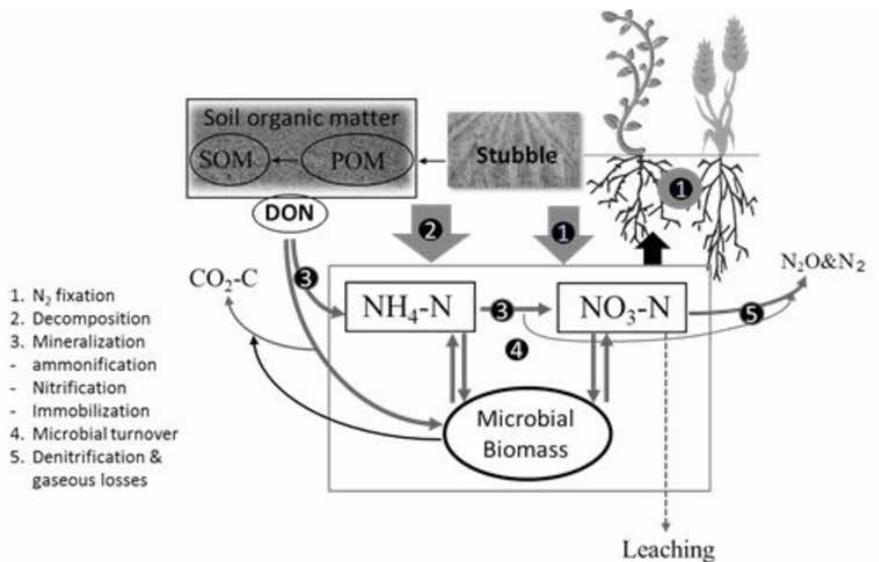


Figure 3: Biological processes involved in nitrogen cycling that influence plant available nitrogen levels in soil. SOM—soil organic matter, DON—dissolved organic nitrogen, POM—particulate organic matter.

Source: GRDC.

During the growing season, the amount of mineralisation is reasonably predictable and models are available that will estimate mineralisation over time periods ranging from days to years.

In the year after a legume crop or legume-based pasture, there is an additional burst of mineralisation from legume residues. In the first year after a legume, this can be one quarter of the legume’s biologically-fixed N.

A rule of thumb for mineralisation, based on measurements in southern NSW in a continuously-cropped chromosol, is where there is 0.1% N in the top 10 cm, it mineralises about 0.3 kg N/ha/mm of summer rain and 0.5 kg N/ha/mm of summer rain after a legume.

Growers can include an estimate of in-crop mineralisation in a nitrogen budget when calculating fertiliser requirement for the 2015 growing season.

The amount of N mineralised between harvest and sowing of the next crop can be measured by soil sampling before sowing. But after sowing, the amount of N mineralised is more difficult to measure because there is simultaneous mineralisation of nitrogen in the soil and uptake by the growing crop. Models provide the best estimates of in-crop mineralisation.³⁸

To work out the amount of N mineralisation over summer, estimate:

Organic carbon (OC%) x summer rainfall 0.15 = kg/N mineralised

The decomposition of plant residues, particularly those of legumes, can supply significant amounts of N to cereal crops. Generally the amount of N fixed by legume crops is proportional to the amount of vegetative growth and the amount of grain

³⁸ A Lawson (2015) Understanding the factors that affect mineralisation. GRDC. <https://grdc.com.au/Media-Centre/Media-News/South/2015/01/Understand-the-factors-that-affect-mineralisation>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

i MORE INFORMATION

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[Factors influencing nitrogen supply from soils and stubbles](#)

removed (i.e. the harvest index). In loam or clay soils, legumes in rotation will have slightly higher levels of available nitrogen than sandy soils due to less leaching.

To accurately estimating how much nitrogen (and other nutrients) cereal crops require the grower needs an effective method of estimating yield potential: the basic assumption is that for every tonne of grain produced, a cereal crop requires 45 kg N.³⁹

For more information on estimating yield potential, see [Section 1: Planning and Paddock Preparation](#).

5.6 Phosphorus

Key points:

- Phosphorus is one of the most critical and limiting nutrients in agriculture in the Northern Region.
- Phosphorus cycling in soils is complex.
- Only 5–30% of phosphorus applied as fertiliser is taken up by the plant in the year of application.
- Phosphorus fertiliser is best applied at seeding.
- Compared with bread wheats, triticale and rye have been found to be more efficient in using P at low levels of P supply. However, phosphorus fertiliser for triticale is recommended in the same amounts as those recommended for wheat, 10–15 kg/ha at sowing.
- Triticale has been classified as phosphorus-efficient; i.e., it is higher yielding than other cultivars under low P supply. Triticale has also been classified as phosphorus-responsive; i.e. it is higher yielding than other cultivars under high P supply.⁴⁰

After nitrogen stress, phosphorus is the second most widely occurring nutrient deficiency in cereal systems around the world.⁴¹ Phosphorus is essential for plant growth, but few Australian soils have enough P for sustained crop and pasture production. Many soils have large reserves of total phosphorus, but low levels of available phosphorus. Complex soil processes influence the availability of P applied to the soil, with many soils able to adsorb or 'fix' phosphorus, making it less available to plants (Figure 4).⁴² A soil's ability to fix phosphorus must be measured when determining requirements for crops and pastures.⁴³

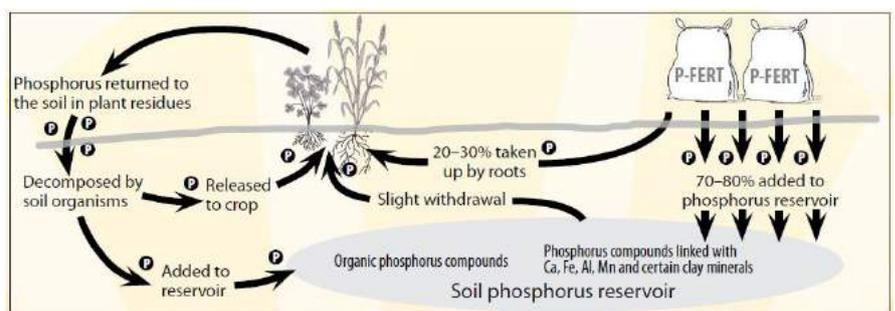


Figure 4: The phosphorus cycle in a typical cropping system is particularly complex, because movement through the soil is minimal and availability to crops is severely limited.

Source: Soilquality.org

39 Soilquality.org (2017) Optimising soil nutrition, Queensland. Soilquality.org, <http://www.soilquality.org.au/factsheets/optimising-soil-nutrition-queensland>

40 JI Ortiz-Monasterio, RJ Pena, WH Pfeiffer, AH Hede (2002) Phosphorus use efficiency, grain yield, and quality of triticale and durum wheat under irrigated conditions. In Proceedings of the 5th International Triticale Symposium, Annex, 30 June–5 July. Vol. 30.

41 JI Ortiz-Monasterio, RJ Pena, WH Pfeiffer, AH Hede (2002) Phosphorus use efficiency, grain yield, and quality of triticale and durum wheat under irrigated conditions. In Proceedings of the 5th International Triticale Symposium, Annex, 30 June–5 July. Vol. 30.

42 Soilquality.org, Phosphorus, Queensland. Factsheet. Soilquality.org, <http://www.soilquality.org.au/factsheets/phosphorus-queensland>

43 R Quinlan, A Wherrett, S Alt (2017) Phosphorus, NSW. Factsheet. Soilquality.org.au, <http://www.soilquality.org.au/factsheets/phosphorus-nsw>

IN FOCUS

Cereal types, soil types and phosphorus use

Crop growth on the flats is typically thicker than on sand hills, but in most years grain yields are less. Researchers wanted to test the concept of reducing rates where the crop is likely to yield lower, and possibly increasing them where the crop is likely to yield more, and GRDC funded a project to investigate this.

It was already known that soil P levels in the topsoil (0–10 cm) do not vary markedly across different soil types in the Mallee: 19 ppm for soil in the flats, 17 ppm on the slopes and 11 ppm in the sand hills. In 2005 and 2006, the researchers applied different P treatments to crops on these soils. As well, in 2005, they also tested the value of growing a different cereal crop on the flats (triticale) compared with the sand hill (barley).

In 2005, grain yield responses to applied P were greater in the lighter soil zone (the sand hills) than in the heavier soil zone (the flats). The most economic rate for both zones was 3 kg/ha. A higher rate of P (11 kg/ha) increased grain yield on the lighter soil more than on the heavier shallow soil. This is consistent with lower levels of leaf-tissue P from the crop on the sand hill (3,000 mg/kg) than on the flat (3,700 mg/kg).

In this trial the grain yield of triticale was the same on the flats (1.3 t/ha) as on the sand hill, while the barley grain yield was similar on the flats (1.47 t/ha) and the sand hill (1.48 t/ha).

In 2006, grain-yield responses of barley and triticale to different rates of P and N fertiliser were compared for the three different zones (flat, slope and hill) in this paddock. In each zone, two rates were compared, one rate for an average year and a lower rate.

As in 2005, grain yields were lower on the flats than on the sand hills. However, in these lower-yielding crops grain yield responses to P and N were relatively small. In only two cases for triticale (on the flats and in the hills) did yield increases cover the cost of the extra fertiliser (0.07 t/ha) within a zone, and in one case (on the slopes) for the barley (0.06 t/ha).⁴⁴

While there has been substantial improvement (e.g. through genetic gains) in terms of P responsiveness in triticale since its breeding in Australia, there has been little improvement in terms of phosphorus-use efficiency; i.e. performance in low-phosphorus conditions.

Triticale responds well to P application. A field experiment in Brazil found that triticale presented higher dry matter production and grain yield response to P than seven wheat cultivars did.⁴⁵

Triticale also responds well to phosphorus application under drought conditions.⁴⁶

The presence of other elements influences the availability of P. For instance, phosphorus deficiency is thought to be responsible for biomass reduction of triticale in nutrient solution with aluminium, an issue on acidic soils. One study suggests that

⁴⁴ A Mayfield (n.d.) SPA00003: Improvement of nutrient management through effective use of precision agriculture technologies in the southern Australian grains industry. Final reports. GRDC, <https://grdc.com.au/research/reports/report?id=986>

⁴⁵ JR Ben (1991) Response of triticale, wheat, rapeseed and lupine to phosphorus in soil. In 2. Proceedings of the International Triticale Symposium. Passo Fundo, Brazil, 1–5 October 1990.

⁴⁶ M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

in previous experiments, P deficiency was probably the most important limiting factor in acid nutrient solutions with aluminium.⁴⁷

In sandy soils P has a tendency to leach out of the soil. Soils with sufficient levels of 'reactive' iron (Fe) and aluminium (Al) will tend to resist phosphorus leaching. If growers have sandy soils with low 'reactive' levels of Fe and Al then they should test P levels and apply less phosphorus more often, so that phosphorus isn't lost to leaching. In soils with high free lime (10–20%), phosphorus will react with calcium carbonate in the soil to create insoluble calcium phosphates. Lock-up of phosphorus occurs on these soils at high pH and more sophisticated methods of applying phosphorus may be needed.⁴⁸

5.6.1 Symptoms of Phosphorus deficiency

What to look for in the paddock

- Smaller, lighter green plants with necrotic leaf tips, generally on sandier parts of the paddock or between header or swathe rows.
- Plants look unusually water-stressed despite adequate environmental conditions (Photo 4).⁴⁹
- Affected areas are more susceptible to leaf diseases.
- Lines in the crop where there is a missed strip of fertiliser.

What to look for in the plant

- In early development, usually in cases of induced phosphorus deficiency, seedlings appear to be pale olive green and wilted (Photos 5 and 6).
- On older leaves, chlorosis starts at the tip and moves down the leaf on a front, while the base of the leaf and the rest of the plant remains dark green. Unlike with nitrogen deficiency, necrosis (death) of these chlorotic (pale) areas is fairly rapid, with the tip becoming orange to dark brown and shrivelling, while the remainder turns yellow. By this stage, the second leaf has taken on the early symptoms of phosphorus deficiency.
- By tillering, uncommon symptoms of severe deficiency are dull, dark green leaves with slight mottling of the oldest leaf.
- Plant maturity is delayed.



Photo 4: Stunted early growth with reduced tillers in P deficient crop on the left.

Source: DAFWA

47 VL Quartin, HG Azinheira, MA Nunes (2001) Phosphorus deficiency is responsible for biomass reduction of triticale in nutrient solution with aluminium. *Journal of Plant Nutrition*, 24 (12), 1901–1911.

48 G Bailey, T Brooksby (2016) Phosphorus in the south east soils. Download on web page South East soil issues, Natural Resources South East. <http://www.naturalresources.sa.gov.au/southeast/land/soil-management/South-East-Soil-Issues>

49 DAFWA (2015) Diagnosing phosphorus deficiency in wheat. DAFWA. <https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-wheat>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 5: *P*-deficient plants on the left are later maturing with fewer and smaller heads.

Source: DAFWA



Photo 6: *Dark leaves with necrosis moving down from the tip of the oldest leaf is symptom of P deficiency.*

Source: DAFWA

What else it could be

The symptoms above may also be due to other causes (Table 10).

Table 10: Other problems of triticale that could be confused for phosphorous deficiency.

Condition	Similarities	Differences
<u>Nitrogen deficiency</u>	Small, less tillered and light green plants	Phosphorus-deficient plants are thinner with darker leaves and older leaf tip death without leaf yellowing
<u>Molybdenum deficiency</u>	Small, less tillered and light green plants	Phosphorus-deficient plants are thinner with darker leaves and older leaf tip death without leaf yellowing
<u>Potassium deficiency</u>	Small, less tillered and light green plants	Phosphorus-deficient plants are thinner with darker leaves and older leaf tip death without leaf yellowing

Source: DAFWA

Plants have a high requirement for P during early growth. As P is relatively immobile in the soil, topdressed or sprayed fertiliser cannot supply enough to correct a deficiency.

Phosphorus does leach on sands with a very low phosphorus buffer index (PBI, a measure of phosphorus retention), particularly on coastal plains. Topdressing is effective on these soils.⁵⁰

Soil testing

Testing the phosphorus levels in your soil is important and will help in the budgeting of your phosphorus dollar. The release of phosphorus is related to:

- The total amount of phosphorus in the soil.
- The abundance of iron and aluminium oxides.
- Organic carbon content.
- Free lime or soluble calcium carbonate.
- Phosphorus buffer index (PBI).

Available phosphorus tests like the Colwell and Olsen's phosphorus test don't measure available phosphorus. Rather they express an indication of the rate at which P may be extracted from the soils. This rate is calibrated with field trials. There is a relationship between total soil phosphorus and Colwell phosphorus, and this can enable you to predict when a given level of phosphorus input (fertiliser) or output (product removal) will result in a risk of phosphorus rate of supply becoming a limiting factor.⁵¹

5.6.2 Managing phosphorus

Key points:

- P reserves can be run down over several decades of cropping. However, after decades of consistent P application, many soils in Australia now have adequate P status.
- Before deciding on a fertiliser strategy, use soil testing to gain a thorough understanding of the nutrient status across the farm.
- If the soil P status is sufficient, there may be an opportunity for growers to save money on P fertiliser by cutting back to a maintenance rate.

50 DAFWA (2015) Diagnosing phosphorus deficiency in wheat. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-wheat>

51 G Bailey, T Brooksby (2016) Phosphorus in the south east soils. Download on web page South East soil issues, Natural Resources South East, <http://www.naturalresources.sa.gov.au/southeast/land/soil-management/South-East-Soil-Issues>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

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WATCH: [Improving phosphate use efficiency](#)



WATCH: [Over the Fence North: Deep P placement delivers yield return on Darling Downs](#)



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[Crop nutrition: Phosphorus management—Northern Region](#)

- Consider other factors: if pH (CaCl_2) is less than 4.5, the soil is water repellent or root-disease levels are high, then the availability of soil P is reduced and a yield increase to fertiliser P can occur even when the soil test P results show that levels are adequate.
- Work with an adviser to refine your fertiliser strategy.
- Adding fertiliser to the topsoil in systems that rely on stored moisture does not always place nutrients where crop needs them.
- Testing subsoil (10–30 cm) P levels using both Colwell-P and BSES-P soil tests is important in developing a fertiliser strategy.
- Applying P at depth (15–20 cm deep on 50 cm bands) can improve yields over a number of cropping seasons (if other nutrients are not limiting).
- Addressing low P levels will usually increase potential crop yields, so match the application of other essential nutrients, particularly N, to this adjusted yield potential.⁵²

Place phosphorous with or near the seed at seeding time, or band prior to seeding. High application rates can lead to both salt burning of the seedlings and a thin plant stand, and potentially reduce yield.⁵³

Phosphorus fertiliser and, where necessary, nitrogen fertiliser are recommended in the same amounts as those recommended for wheat. The current recommendations are:

- Phosphorus at 10–15 kg/ha and 10–20 kg/ha of nitrogen applied at sowing.

Arbuscular mycorrhizae fungi play an important role in plant uptake of P. The uptake of this nutrient by wheat, rye, and triticale was, respectively, 10%, 64%, and 35% higher with AMF infection than without. Triticale followed wheat, with similar mycorrhizal dependency.⁵⁴

5.7 Sulfur

Sulfur is an essential plant nutrient that (along with N) is required for the production of amino acids, which make up proteins. In cereals, lower sulfur levels lead to lower protein and because this affects the quality of the flour, the price received for this grain will be reduced. A lack of sulfur will also affect the oil content and hence the price received for canola.

Yield losses also occur in low-sulfur situations, especially with canola. Ideally, plants will take up sulfur at the same levels as phosphorus.

Sulfur is present to varying degrees in nearly all soils. Soils with clay and gravel have generally more sulfur present than sandier soils from high-rainfall areas. This is due in part to the composition of the original parent rock. Organic sulfur, which is mineralised into plant-available sulfate sulfur, is more prevalent in soils with high clay and gravel content. The sandier soils from higher-rainfall areas do not have any ability to restrict the leaching of water-soluble sulfate sulfur. Sulfur remaining in plant residues is readily recycled into the soil.⁵⁵

Historically, adequate S has been supplied by mineralisation from organic matter, from being applied as a nutrient in N and P fertilisers (sulfate of ammonia and superphosphate), or via the presence of calcium sulfate layers in the subsoil that are accessible to the roots. However, with the increased use of high-analysis N and P fertilisers that are low in S, deficiency in crops is increasing, especially in wet years, due to leaching. S deficiency appears to occur because of a complex interaction between seasonal conditions, crop species and plant availability of subsoil S, which

52 GRDC (2012) Phosphorus management, southern region. Factsheet. GRDC, www.grdc.com.au/GRDC-FS-PhosphorusManagement

53 Alberta Agriculture and Forestry (2016) Fall rye production. Agdex 117/20-1. Revised. Alberta Government, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/agdex1269/\\$file/117_20-1.pdf](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf)

54 R Pandey, B Singh, TVR Nair (2005) Impact of arbuscular-mycorrhizal fungi on phosphorus efficiency of wheat, rye, and triticale. *Journal of Plant Nutrition*, 28 (10), 1867–1876.

55 Summit Fertilizers (n.d.) Sulfur (S). Summit Fertilizers, <http://www.summitfert.com.au/research-and-agronomy/sulphur.html>

impact on the ability of the soil S test to predict plant-available S. Deficiencies may be more evident in wet years due to S leaching.⁵⁶

Triticale and sulfur

The forage production of triticale and wheat is essential to many livestock producers. Very little data is available concerning the effects of sulfur fertilisation on production and quality of triticale or wheat forage. However, research conducted in a greenhouse may give clues to the use of S in the paddock.

Early research was conducted to evaluate the addition of S as either ammonium thiosulfate (ATS) or ammonium sulfate (AS) on production and quality of triticale and wheat forage on four different soils (note that starter S levels were not stated). Sulfur fertilisation increased forage yields and S concentrations of both crops on all soils, and in many cases, resulted in higher N concentrations in the forage. Sulfur fertilisation also increased the in vitro digestibility of wheat, but had little effect on triticale digestibility. Both S sources performed similarly. Application of S after the first clipping was effective in increasing second-clipping forage production on three of the four soils, and forage S concentrations were dramatically increased for both crops on all soils. Although the magnitude of response varied, S fertilisation was effective in increasing production and quality of triticale and wheat forage grown in the greenhouse.⁵⁷

Treatments of nitrogen and phosphorous fertilisers have also been found to significantly increase the dry matter, sulfur concentrations and sulfur uptake of triticale compared to unfertilised treatments.⁵⁸

It should be noted that these trials are based primarily on greenhouse trials, and not in the paddock.

Whilst greenhouse data is helpful, paddock trials are important, and unfortunately these are limited in triticale. Growers should be aware of S levels and budget accordingly, but in my experience, there is often no dry matter increases in cereals due to S application in central-western NSW over many years of S use.

Agronomist's view

5.7.1 Symptoms of Sulfur deficiency

What to look for in the paddock

- Areas of pale plants (Photo 7).⁵⁹
- Areas of acidic soils.
- Soils low in organic matter.

What to look for in the plant

- Plants grow poorly and lack vigour, and have reduced tillering, delayed maturity and lower yields and protein levels.
- The youngest leaves are affected first and most severely.
- The leaves on deficient plants turn pale with no stripes or green veins, but generally do not die although growth is retarded and maturity delayed (Photo 8).
- With extended deficiency the entire plant becomes lemon yellow and stems may become red usually on the northern, sunny side.

⁵⁶ GRDC (2014) Soil testing crop nutrition, Northern Region. Factsheet. GRDC, www.grdc.com.au/GRDC-FS-SoilTestingN

⁵⁷ RL Feyh, RE Lamond, DA Whitney, RG Sears (1993) Sulfur fertilisation of wheat and triticale for forage production 1. Communications in Soil Science and Plant Analysis, 24 (5–6), 443–455.

⁵⁸ B Laszity (1993) The variation of sulfur contents and uptakes in triticale during growth. Agrochimica.

⁵⁹ DAFWA (2015) Diagnosing sulfur deficiency in cereals. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-sulfur-deficiency-cereals>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 7: Areas of pale plants characterise sulfur deficiency.

Source: DAFWA



Photo 8: Leaves on sulfur deficient cereal plants become uniformly pale.

Source: DAFWA

What else it could be

The symptoms described above may also be caused by other issues (Table 11).

Table 11: Other problems of triticale that could be confused for sulfur deficiency.

Source: DAFWA

Condition	Similarities	Differences
<u>Iron deficiency</u>	Pale new growth	Iron-deficient plants have interveinal chlorosis
<u>Group B herbicide damage</u>	Seedlings with pale new leaves	Plants generally recover from Group B herbicide damage; and leaves often have interveinal chlorosis.
<u>Waterlogging, or nitrogen, molybdenum or manganese deficiency</u>	Pale growth	The youngest leaves of sulfur-deficient plants are affected first while the middle or older leaves are affected first with waterlogging, and manganese, nitrogen and molybdenum deficiency

5.7.2 Managing sulfur

Top-dressing 10–15 kilograms per hectare of sulfur as gypsum or ammonium sulphate will overcome S deficiency.

Foliar sprays generally cannot supply enough sulfur for plant needs.⁶⁰

Modern high-analysis fertilisers will usually contain enough S to supply sufficient levels to cereal crops.

If a deficiency manifests in an established crop, it can be easily corrected with an application of sulphate of ammonia.

Supplies of sulfur (elemental or sulphate)

Plants take up sulfur in the sulphate (SO₄) form. The sulfate form is water-soluble, and being an anion, readily leaches. The elemental form of sulfur needs to be broken down into the sulfate form before becoming available to the plant. This is achieved by bacteria (*Thiobacillus* spp.) which digest the sulfur and excrete sulfate. All soils contain these bacteria. It takes about a fortnight for elemental sulfur to start breaking down, so it should be used before a plant deficiency can be seen. In waterlogged conditions, where sulfate sulfur will be lost by leaching or run-off, the bacteria will become dormant, so sulfur will not be lost.

Pros and cons of the two sulfur sources

Sulfate sulfur is:

- immediately available to the plant
- water-soluble
- quick acting
- leachable
- easily lost with one heavy fall of rain

Elemental sulfur is:

- released slowly
- not lost by leaching
- more available when maximum plant growth occurs in spring

⁶⁰ DAFWA (2015) Diagnosing sulfur deficiency in cereals. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-sulfur-deficiency-cereals>

i MORE INFORMATION

[Sulfur as a nutrient for agricultural crops in southern and eastern Australia](#)

[Sulfur in Northern Vertosols](#)

- will build up a sulfur ‘bank’
- slow to break down.⁶¹

Local tools help S fertiliser decision making

There are few summaries of information specifically about S nutrition for cereals grown in eastern Australia. This reflects historic rarity of S deficiency in cereals grown in the region as well as grain price being unrelated to S content in the grain. Fact sheets (based on information from Western Australia) highlight the need to consider the soil type as it relates to S adsorption capacity and potential for S leaching. Soils with clay, or iron and aluminium oxides retain S through adsorption and tend to be less prone to S leaching. Conversely, deep sandy soils, particularly subject to high rainfall conditions, are prone to S leaching. Under these conditions or when soil testing, plant testing or historical records show there is a risk of cereal becoming S deficient it is useful to know the amount of S removed by the crop.

The amount of S in wheat in south-eastern Australia is 1.5 kg S/t stubble and 1.7 kg S/t grain. In New South Wales, the amount of S removed by dual purpose wheat (i.e. grazed and harvested for grain) is given as 0.4 kg S/t dry matter grazed and 1.5 kg S/t grain (these figures can be used as a guide for triticale). Calculations for the amount of S fertiliser needed in any crop is based on supplying the crop with enough S to cover immediate nutrient usage or removal. The amount of S required is given as 20 kg S/ha to meet the needs of dual purpose wheat in New South Wales (these figures can be used as a guide for triticale). However, S recommendations tend not to be based on preventing nutrient removal, rather S tends to be recommended when deficiencies are expected.⁶²

5.8 Potassium

Key points:

- Soil testing combined with plant-tissue testing is the most effective means of determining potassium requirements.
- Triticale can be sensitive to potassium deficiency and responses to its application.
- Potassium deficiency is an emerging issue in northern cropping soils.
- It is important to maintain adequate potassium in soil as once symptoms of deficiency emerge, costly fertiliser applications will be required.⁶³
- Banding away from the seed, at sowing or within four weeks of sowing, is the most effective way to apply potassium when the requirement is less than 15 kg/ha.

Potassium (K) is an essential plant nutrient. It has many functions, including the regulation of the opening and closing of the stomata, the breathing holes on plant leaves that control moisture loss from the plant. Potassium increases vigour and disease resistance of plants, and helps them to form and move starches, sugars and oils. Available potassium exists as an exchangeable cation associated with clay particles and humus.⁶⁴

A study in Europe found that triticale is more sensitive to potassium deficiency than to phosphorus deficiency.⁶⁵

Other research showed that the highest rate of grain yield for triticale (6.1 t/ha–1) was obtained by application of 160 kg/ha-1 of nitrogen and 90 kg/ha-1 of potassium. The

61 Summit Fertilizers (n.d.) Sulfur (S). Summit Fertilizers, <http://www.summitfertz.com.au/research-and-agronomy/sulphur.html>

62 CropPro (2013) Sulfur as a nutrient for agricultural crops in southern Australia. <http://www.croppro.com.au/resources/Review%20Sulphur%2026082013.pdf>

63 Soilquality.org (2017) Potassium, Queensland. Soilquality.org, <http://www.soilquality.org.au/factsheets/potassium-queensland>

64 R Quinlan, A Wherrett, S Alt (2017) Potassium, NSW. Soilquality.org, <http://www.soilquality.org.au/factsheets/potassium-nsw>

65 R Gaj (2012) The effect of different phosphorus and potassium fertilisation on plant nutrition in critical stage and yield of winter triticale. Journal of Central European Agriculture, 13 (4), 704–716.

i MORE INFORMATION

Mineral supplements needed when grazing cereals

application of different levels of N affected grain protein of triticale, but using different amounts of K did not.⁶⁶

Generally, in the southern region, cropping soils are unresponsive to additions of K. However, as crops continue to mine K from soils, this may change in the future.

Potassium deficiency is more likely to occur on light soils (soils low in OM) and with high rainfall, especially where hay is cut and removed regularly.

Factors such as soil acidity, soil compaction and waterlogging will modify root growth and the ability of crops to extract subsoil K.⁶⁷

High potassium:sodium (K:Na) ratios in wheat and some triticale varieties can induce magnesium (Mg) deficiency in grazing stock, which may show up as tetany. Surveys in southern Australia showed that all varieties of cereals tested had a K:Na ratio that could cause magnesium deficiency in livestock. One contributing factor to the variation in animal gains is the mineral nutrition provided by cereals to grazing livestock. The Mg content of cereal is typically satisfactory for stock, but the high K content and very low Na content of forage result in a high rumen K:Na ratio, which impedes magnesium absorption in the rumen.⁶⁸

Potassium deficiency in northern soils

Throughout Queensland’s cropping regions there has been a gradual decline in soil potassium levels due to crop removal of K and low application rates of K fertiliser. In particular, grain growers on red Ferrosol soils in the inland Burnett region have increasingly encountered potassium deficiency over the last 10 years or so, due to reserves in these soils running down. The problem is also becoming increasingly evident on medium-heavy cracking clay soils. Cotton, legumes and hay baling–silage systems have had a particularly high impact on potassium reserves in some soils.

Crops may vary in their response to potassium fertiliser application and, in winter cereals, responses are generally low unless large deficiencies are present. However, while significant soil potassium reserves still exist in many Queensland cropping soils, particularly the heavier alluvial and cracking clay soils, it is important to maintain soil reserves by replacing the potassium removed in harvested products. If potassium is allowed to be depleted to such an extent that crop productivity is affected, heavy and very costly fertiliser applications will be required.⁶⁹

5.8.1 Symptoms of Potassium deficiency

What to look for in the paddock

- Smaller, lighter green plants with necrotic leaf tips, generally on sandier parts of the paddock or between header or swathe rows (Photo 9).⁷⁰
- Plants look unusually water-stressed despite adequate environmental conditions.
- Affected areas are more susceptible to leaf disease.
- Sandy areas in the paddock.

What to look for in the plant

- Plants appear paler, and weak and floppy (Photo 10).
- Older leaves are affected first, with leaf tip death and progressive yellowing and death down from the leaf tip and edges. There is a marked contrast in colour between yellow leaf margins and the green centre.
- Yellowing leaf tip and leaf margins sometimes generates a characteristic green 'arrow' shape towards leaf tip.

66 SA Tababtabaei, GH Ranjbar (2012) Effect of different levels of nitrogen and potassium on grain yield and protein of triticale. International Research Journal of Applied and Basic Sciences, 3 (2), 390–393.

67 GRDC (2014) Soil testing for crop nutrition, southern region. Factsheet. GRDC, www.grdc.com.au/GRDC-FS-SoilTestingS

68 L Bell, H Dove (2012) Mineral supplements needed when grazing cereals. Ground Cover. Issue 98, May–June 2012. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-98-May-June-2012/Mineral-supplements-needed-when-grazing-cereals>

69 Soilquality.org (2017) Potassium, Queensland. Soilquality.org, <http://www.soilquality.org.au/factsheets/potassium-queensland>

70 DAFWA (2015) Diagnosing potassium deficiency in wheat. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-wheat>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- Plants are stunted and spindly
- Small seed size.



Photo 9: *There are fewer symptoms of K deficiency in header rows.*

Source: DAFWA

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 10: Potassium-deficient plants may display floppy older leaves and furled flag leaf from water stress.

Source: DAFWA

What else it could be

The symptoms described above may be due to other issues (Table 12).

Table 12: Other problems of triticale that could be confused for potassium deficiency.

Condition	Similarities	Differences
<u>Molybdenum deficiency</u>	Pale plants with leaf tip death	Potassium-deficient plants do not have white or rat-tail heads, and have more marked contrast between yellow and green sections of affected leaves
<u>Nitrogen deficiency</u>	Pale plants with oldest leaves most affected	Potassium-deficient plants have more marked leaf-tip death and contrast between yellow and green sections of affected leaves, and tillering is less affected
<u>Spring drought</u>	Water-stressed plants with older leaves dying back from the tip, yellowing progressing down from tip and edges and often leaf death occurs	The main difference is that potassium deficiency is more marked in high-growth plants in good seasons
<u>Root lesion nematodes</u>	Smaller, water-stressed, pale plants	Root-lesion-nematode affected plants have 'spaghetti' roots with few feeder roots

Source: DAFWA

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

MORE INFORMATION

Potassium responses observed in South Australian cereals

Topdressing potassium will generally correct the deficiency. Foliar sprays generally cannot supply enough potassium to overcome a severe deficiency and can also scorch crops.⁷¹

5.8.2 Managing potassium

Soil and plant-tissue analyses together give insight into the availability of potassium in the soil. Growers should not rely on soil testing alone, as results are subject to many potential sources of error.

Tissue analysis of whole tops of crop plants will determine whether a deficiency exists, but won't define a potassium requirement. These results are generally too late to be useful in the current season, but inform the need to assess K requirements for the next crop.

Potassium available in the soil is measured by the Colwell-K or Exchangeable K soil tests. The amount of potassium needed for plant nutrition depends on the soil's texture (Table 10).

Table 13: Critical (Colwell) soil-test thresholds for potassium (in ppm).

	Deficient	Moderate	Sufficient
Cereals, canola, lupins, etc. (Brennan and Bell 2013)	<50	50–70	>70
Pasture legumes (Gourley et al. 2007)	<100 (sand) <150 (clay loam)	100–140 (sand) 150–180 (clay loam)	>140 (sand) >180 (clay loam)

Source: Soilquality.org

Sandy soils require less potassium to be present, but are more likely to show deficiencies. Clay soils require more potassium to be present, but are more capable of supplying replacement potassium through the weathering of clay minerals.

Potassium lost through product removal should be replaced once paddocks fall below sufficient K levels, rather than waiting for deficiency symptoms to appear. Replacement requirements for each crop differ, and this must be accounted for when budgeting K requirements for the coming season.

Fertiliser types

Sulphate of potash (SOP), or potassium sulphate, is usually recommended if soils are deficient in K. Applying the cheaper muriate of potash (MOP), or potassium chloride, also corrects potassium deficiency, but it also adds chloride to the soil, which contributes to overall salinity and can decrease the establishment of seedlings.

Potassium magnesium sulphate can also be used where magnesium and sulphate are also required. This form is often used in 'complete' fertiliser blends. Potassium nitrate supplies nitrogen and potassium in a highly water-soluble (and available) form, but is rarely used in broadacre farming because of its cost.

Fertiliser placement and timing

Potassium generally stays very close to where it is placed in the soil. Banded potassium has been shown to be twice as accessible to the crop as topdressed potassium. This is thought to be related to improved availability for the emerging crop, and decreased availability for weeds. Seed must be sown within 50 mm of the potassium drill row or seedlings may miss the higher levels of potassium. High band rates (>15 kg/ha) of potassium can inhibit sensitive crops (e.g. lupins, canola). If a paddock is severely deficient then potassium needs to be applied early in the season, at seeding or up to four weeks after.⁷²

⁷¹ DAFWA (2015) Diagnosing potassium deficiency in wheat. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-wheat>

⁷² Soilquality.org (n.d.) Potassium, NSW. Soilquality.org, <http://www.soilquality.org.au/factsheets/potassium-nsw>

5.9 Micronutrients

Key points:

- Trace elements are important in particular situations but are not miracle workers.
- Deficiencies are not uncommon, but when they occur can result in large yield penalties.
- Diagnosis by soil tests and tissue tests is difficult, but in most cases the potential for deficiencies can be assessed by reviewing soil types, crop type and seasonal conditions.
- Products vary in their efficiency and growers should look for evidence of the efficacy of products in their region.

Most growers and agronomists are fully aware of the nitrogen and phosphorus demands of crops, and meeting those demands is a major investment in crop production. Sulfur and potassium are also important in some regions, as are calcium and magnesium. These six nutrients, the macronutrients, are complemented by a set of nutrients required in smaller amounts; the micronutrients or trace elements. Even though needed in tiny quantities, copper (Cu), manganese (Mn), iron (Fe), zinc (Zn), boron (B) and molybdenum (Mo) are all essential for plant growth. Essential trace elements are nutrients which are required by plants and animals to survive, grow, and reproduce, but are needed in only minute amounts. Northern cropping soils are more likely to be deficient in Zn, Cu, and Mn than the other trace elements.

Of these three, Zn deficiency is probably the most important in the Northern region because it occurs over the widest area. Zn deficiency can severely limit annual pasture-legume production and reduce cereal-grain yields by up to 30%. Cu deficiency is also important because it may result in total crop failure.

If Zn, Cu and Mn are not managed well, the drop in productivity of crops and pastures can leave the farmer suffering expensive losses, and further production can also be lost through secondary effects such as increased disease damage and susceptibility to frost.

Adequate trace-element nutrition is just as important for vigorous and profitable crops and pastures as adequate major element (such as nitrogen or phosphorus) nutrition.

Triticale grows productively on alkaline soils where certain trace elements are deficient enough that they will not be suitable for other cereals.⁷³

In early trials, it was reported that triticale commonly expressed the Cu efficiency trait derived from its cereal rye parent (i.e. can perform better than many other crops on small amounts of Cu because it uses the element so efficiently), and had efficiency traits for Zn and Mn. Triticale usually performs remarkably well on highly calcareous soils which are often deficient in Mn and Zn and sometimes in Cu.⁷⁴

5.9.1 Manganese

Manganese helps with photosynthesis. It is freely available in the north-coast NSW acid soils but can be deficient in sandy soils. Manganese deficiency in cereals is widespread. The availability of Mn in soil is strongly related to soil pH. Soils with higher pH have lower Mn availability than soils with lower pH. Mn deficiency is therefore more likely to be a problem on alkaline soils. However, responses to Mn have also been recorded on impoverished, acid to neutral sandy soils.

The availability of Mn is also strongly affected by seasonal conditions and the availability is lowest during a dry spring. Transient Mn deficiency may also appear during cold, wet conditions but affected plants are often seen to recover following rains in spring when soil temperatures are high. Manganese deficiency is

MORE INFORMATION

[Detecting and managing trace element deficiencies in crops](#)

[Trace elements: copper and manganese—their role, requirements and options](#)

[Micronutrients and trace elements](#)

[What is missing? Identifying and managing trace element deficiencies](#)

[Better fertiliser decisions for crop nutrition](#)

⁷³ M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

⁷⁴ D Reuter (2007) Trace element disorders in South Australian agriculture. http://www.pir.sa.gov.au/_data/assets/pdf_file/0011/49619/Trace_Element_disorders_in_SA.pdf

exacerbated by dry soil, high soil pH, alkaline fertilisers and root pruning herbicides (particularly Groups A and B).

Symptoms of Manganese deficiency

What to look for in the paddock

- Manganese deficiency often appears as patches of pale, floppy plants in an otherwise green, healthy crop (Photo 11).⁷⁵
- Areas of the paddock that are strongly alkaline, poorly drained or in areas with strongly acidic sandy soils.

What to look for in the plant

- Plants are frequently stunted and occur in distinct patches.
- The middle leaves are affected first, but it can be difficult to determine which leaves are the most affected as symptoms rapidly spread to other leaves and the growing point (Photo 12).
- Leaves develop interveinal chlorosis and/or white necrotic flecks and blotches.
- Leaves often kink, collapse, and eventually die.
- Tillering is reduced, with extensive leaf and tiller death. With extended deficiency, the plant may die.
- Surviving plants produce fewer and smaller heads.



Photo 11: Patches of pale, floppy plants in otherwise healthy crop.

Source: DAFWA

⁷⁵ DAFWA (2015) Diagnosing manganese deficiency in wheat. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-wheat>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

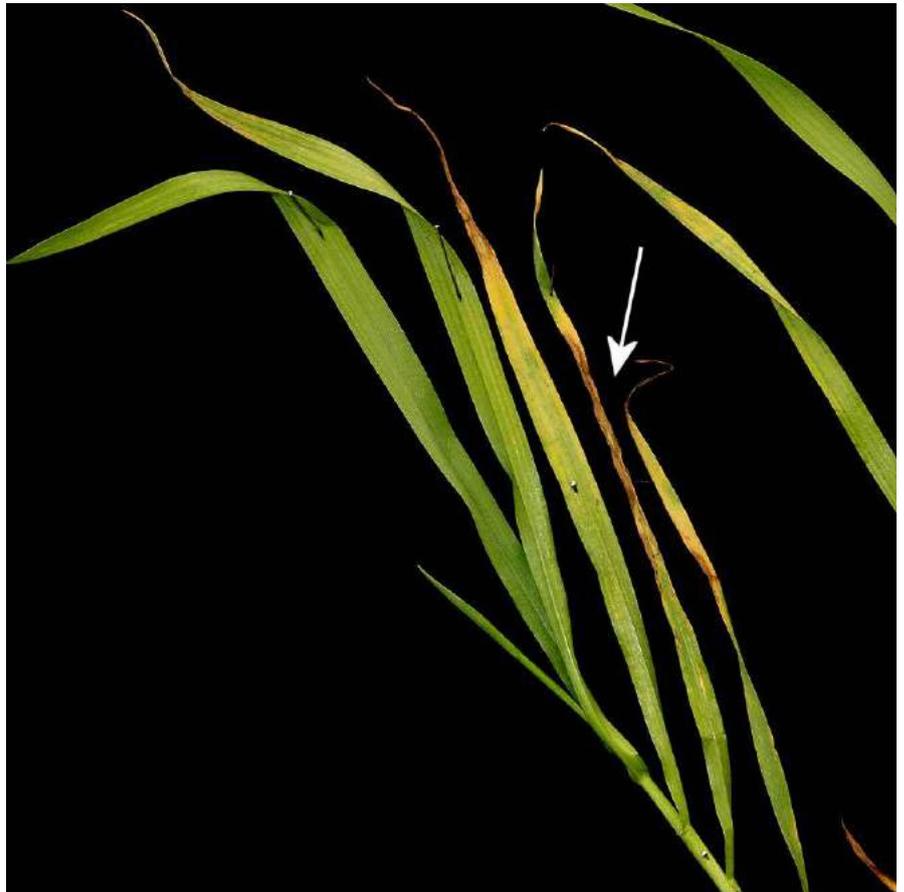


Photo 12: Middle leaves are affected first, and show yellowing and necrosis.

Source: DAFWA

What else it could be

The symptoms described above may also be due to other issues (Table 14).

Table 14: Other problems of triticale that could be confused for manganese deficiency.

Condition	Similarities	Differences
<u>Zinc deficiency</u>	Pale plants with interveinal chlorosis and kinked leaves	Differences include linear 'tramline' necrosis on zinc-deficient plants. Manganese-deficient plants are more yellow and wilted.
<u>Nitrogen deficiency</u>	Pale plants	Nitrogen-deficient plants do not show wilting, interveinal chlorosis, leaf kinking and death
<u>Waterlogging</u>	Pale plants	Waterlogged plants do not show wilting, interveinal chlorosis, leaf kinking and death
<u>Iron deficiency</u>	Pale plants	New leaves are affected first. and plants do not die
<u>Sulfur deficiency</u>	Pale plants	New leaves are affected first. and plants do not die

Source: DAFWA

Managing manganese deficiency

- Seed treatments and foliar sprays are available to treat manganese deficiency.

- Consider using acidifying ammonium nitrogen fertilisers, which can reduce manganese deficiency by lowering pH and making manganese more available to growing crops.
- Consider manganese fertiliser, which is effective but expensive, as high rates and several applications are required to generate residual value.⁷⁶

Due to the detrimental effect of high soil pH on Mn availability, correction of severe Mn deficiency on highly calcareous soils can require the use of Mn-enriched fertilisers banded with the seed (3–5 kg Mn/ha) as well as one to two follow-up foliar sprays (1.1 kg Mn/ha). In the current economic climate, growers on Mn-deficient country have tended not to use Mn-enriched fertilisers due to their cost, and have relied solely on a foliar spray. This is probably not the best or most reliable strategy for long-term management of the problem.

Neither soil nor foliar Mn applications has any residual benefits and must be re-applied every year. Another approach is to coat the seed with Mn. This technique is cheap and will probably be the most effective in conjunction with foliar sprays and/or Mn-enriched fertilisers. The use of acid fertilisers (e.g. nitrogen in the ammonium form) may partially correct Mn deficiency on highly alkaline soils, but will not overcome a severe deficiency.

Mn deficiency in crops can also be corrected by fluid application at seeding.⁷⁷

Where soils are high in manganese (typical of many soils in Australia) many triticale cultivars carry tolerance, and therefore can grow well.⁷⁸ Manganese is freely available in northern coastal NSW acid soils, often in toxic amounts in very acid soils. Toxicity is remedied with lime.

5.9.2 Copper

Copper is necessary for carbohydrate and nitrogen metabolism, with inadequate Cu resulting in stunting. Copper is also required for lignin synthesis which is needed for cell wall strength and the prevention of wilting. Deficiency symptoms of Cu are dieback of stems, yellowing of leaves, stunted growth and pale green leaves that wither easily. Copper deficiencies are mainly reported in sandy soils, which are low in organic matter. Copper uptake decreases as soil pH increases. Increased phosphorus and iron availability in soils decreases copper uptake by plants.⁷⁹

Triticale is tolerant to low concentrations of available copper in soil, a condition widely associated with poor sandy soils in Australia. Such soils may contain enough total copper for tens of thousands of crops but it is relatively unavailable to widely grown cultivars of wheat, oats and barley.⁸⁰

IN FOCUS

Tolerance of triticale, wheat and rye to copper deficiency in low and high soil pH

Researchers investigated the tolerance of triticale to low copper in a soil adjusted to extremes of pH, and compared it with the tolerance of its parent species, wheat and rye. The experiment was conducted using plants in pots of soil in a glasshouse. The wheat plants were extremely sensitive to copper deficiency at all soil pH values and failed to produce heads or grain, whereas rye produced maximum yield irrespective of

⁷⁶ DAFWA (2015) Diagnosing manganese deficiency in wheat. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-wheat>

⁷⁷ N Wilhelm, S Davey (2016) Detecting and managing trace element deficiencies in crops. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Detecting-and-managing-trace-element-deficiencies-in-crops>

⁷⁸ M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

⁷⁹ RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press.

⁸⁰ RD Graham (1978) Tolerance of triticale, wheat and rye to copper deficiency. Letters. Nature, 271, 542–543.

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

copper status or soil pH. Triticale demonstrated intermediate tolerance by virtue of the copper–pH–genotype interaction: it was tolerant (like rye) at pH 5.0, but sensitive (like wheat) at pH 8.4.

Concentrations of copper were highest in rye and lowest in wheat, and decreased with increasing pH. The uptake of copper into grain and shoot was also lowest in wheat, and showed the same pH dependence as concentration. The appearance of symptoms of copper deficiency in all plants that had low yields suggests that the major effect of pH in this system was on copper availability; the change in availability was, however, insufficient to affect the response of wheat (which is highly sensitive) or of rye (highly tolerant). Triticale responded dramatically to the pH treatment and, as predicted, for such a hybrid was generally intermediate in tolerance to copper deficiency.⁸¹

Symptoms of Copper deficiency

What to look for in the paddock

- Before head emergence, deficiency shows as areas of pale, wilted plants with dying new leaves in an otherwise green, healthy crop (Photo 13).⁸²
- After head emergence, mildly affected areas have disorganised, wavy heads. Severe patches have white heads and discoloured late maturing plants.
- Symptoms are often worse on sandy or gravelly soils, acidic soils, organic alkaline soils, where root-pruning herbicides have been applied, and in recently limed paddocks.

What to look for in the plant

- The youngest growth is affected first.
- The first sign of copper deficiency before flowering is growing-point death and tip withering, and/or bleaching and twisting up to half the length of young leaves (Photo 14).
- The base of the leaf can remain green.
- Old leaves remain green, but are paler than normal.
- Tiller production may increase, but tillers die prematurely.
- Mature plants are dull grey–black in colour, with white or stained empty or ‘rat-tail’ heads.
- Grain in less severely affected plants may be shrivelled. Heads with full grain droop due to weak stems.

81 SP Harry, RD Graham (1981) Tolerance of triticale, wheat and rye to copper deficiency and low and high soil pH. *Journal of Plant Nutrition*, 3 (1–4), 721–730.

82 DAFWA (2015) Diagnosing copper deficiency in wheat. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-copper-deficiency-wheat>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 13: *Pale, necrotic flag leaf at head emergence.*

Source: DAFWA

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 14: Partly sterile head and twisted flag leaf.

Source: DAFWA

What else it could be

The symptoms described above may also be caused by other issues (Table 12).

Table 15: Other problems of triticale that could be confused for copper deficiency.

Condition	Similarities	Differences
<u>False black chaff</u>	Discoloration on the upper stem and glumes	False black chaff does not affect yield or grain quality
<u>Molybdenum deficiency</u>	White heads and shrivelled grain	Molybdenum deficiency affects middle leaves first rather than the youngest leaf
<u>Boron deficiency</u>	Youngest leaf death	Boron-deficient plants are dark rather than light green, and affected leaves have marginal notches and split near the base
<u>Stem and head frost damage</u>	White heads, shrivelled grain, late tillers and delayed maturity	Spring frost does not cause death or twisting of the flag leaf, and is location specific (frost-prone areas)
<u>Take-all</u>	White heads and shrivelled grain	Take-all causes blackened roots and crowns and often kills the plant

Source: DAFWA

Managing copper deficiency

- Use foliar spray (only effective in the current season) or drilled soil fertiliser. Where required, copper is normally applied with the fertiliser at 1–2 kg/ha every 3–6 years.
- Copper foliar sprays are not effective after flowering, as sufficient copper is required pre-flowering for pollen development.
- Mixing copper throughout the topsoil improves availability due to more uniform nutrient distribution.
- As copper is immobile in the soil, topdressing is ineffective, being available to the plant only when the topsoil is wet.
- In long-term no-till paddocks, frequent, small applications of copper via drilled or in-furrow application reduces the risk of plant roots not being able to obtain the nutrient in dry seasons.
- Copper drilled in deep increases the chances of roots being able to obtain enough copper when the topsoil is dry.⁸³

Traditionally, Cu deficiency has been corrected by applying Cu-enriched fertilisers and incorporating them into the soil. Most soils require 2 kg Cu/ha to fully correct a deficiency, and this application may be effective for many years. Due to the excellent residual benefits of soil-applied Cu, deficiency of this element in crops and pastures has been largely overcome in most areas following the use of 'blue stone' mixes in the 1950s and 1960s. However, Cu deficiency may be re-surfacing as a problem due to a number of reasons:

- Applications of Cu made 20–40 years ago may be running out.
- The use of nitrogen fertilisers is increasing, and they will increase the severity of Cu deficiency.
- Cu deficiency is affected by seasonal conditions and farming practices (e.g. lupins in a lupin–wheat rotation make Cu deficiency worse in succeeding wheat crops).

Performance of soil applied Cu will improve with increased soil disturbance.

Although Cu deficiency is best corrected with soil applications, foliar sprays will also overcome the problem in the short term. A foliar spray of Cu (75–100 g Cu/ha) is very cheap (approximately 90 c/ha for the ingredient) but a second spray immediately before pollen formation may be necessary in severe situations. This was the case in a trial conducted on lower Eyre Peninsula in 2015, where a late foliar spray was needed to completely eliminate Cu deficiency in an area that was extremely deficient in the trace element and the problem had been exacerbated by a dry spring when wheat was forming pollen and setting grains.⁸⁴

Although plants do need copper, the main reason copper is applied is for the benefit of grazing stock. Copper deficiency is more common on light-textured soils such as sands or sandy loams. Where required, copper is normally applied with the fertiliser at 1–2 kg/ha every 3–6 years. Including copper in the fertiliser will provide a long-term supply to pasture and grazing stock. Where copper deficiency has been diagnosed in stock, more direct supplementation such as copper drenches are recommended.⁸⁵

5.9.3 Zinc

Zinc helps in the production of a plant hormone responsible for stem elongation and leaf expansion. It is readily available in acid soils, but combines easily with iron in the north-coast NSW red soils. This is easily cured with the addition of zinc sulfate or crushed zinc minerals. Deficiencies of zinc (Zn) are well known in all cereals and cereal-growing countries, and deficiency is a nutritional constraint for crop production

⁸³ DAFWA (2015) Diagnosing copper deficiency in wheat. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-copper-deficiency-wheat>

⁸⁴ N Wilhelm, S Davey (2016) Detecting and managing trace element deficiencies in crops. GRDC Update Paper, GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Detecting-and-managing-trace-element-deficiencies-in-crops>

⁸⁵ Agriculture Victoria (2008) Trace elements for dryland pastures. Note AG0265. Revised. Agriculture Victoria, <http://apo.org.au/system/files/57108/apo-nid57108-98416.htm>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

in Australia, being particularly widespread in cereals growing on calcareous soils common in much of the Northern region. Physiological evidence suggests that a critical level of zinc must be present in the soil before roots will either grow into it or function effectively.

Triticale is thought to have a high tolerance to Zn deficiency compared to wheat, and is second only to cereal rye, which is a very resistant crop to Zn deficiency.⁸⁶

In one experiment, Zn deficiency symptoms were either absent or only slightly apparent in triticale and rye, and occurred more rapidly and severely in wheats, particularly in durum wheats. In field experiments at the milk stage, decreases in shoot dry-matter production due to Zn deficiency were absent in rye, and were on average 5% visible in triticale, 34% in bread wheats and 70% in durum wheats. Zinc fertilisation had no effect on grain yield in rye, but enhanced grain yield of the other cereals. Zinc efficiency of cereals, expressed as the ratio of yield (shoot dry matter or grain) produced under Zn deficiency compared to Zn fertilisation were, on average, 99% for rye, 74% for triticale, 59% for bread wheats and 25% for durum wheats.⁸⁷

Zinc-use efficiency is highest in rye, and declines (in descending order) in triticale, bread wheat, and durum wheat (Figure 5). The differences in expression of Zn efficiency are possibly related to a greater capacity of efficient genotypes to acquire Zn from the soil compared to inefficient genotypes.⁸⁸

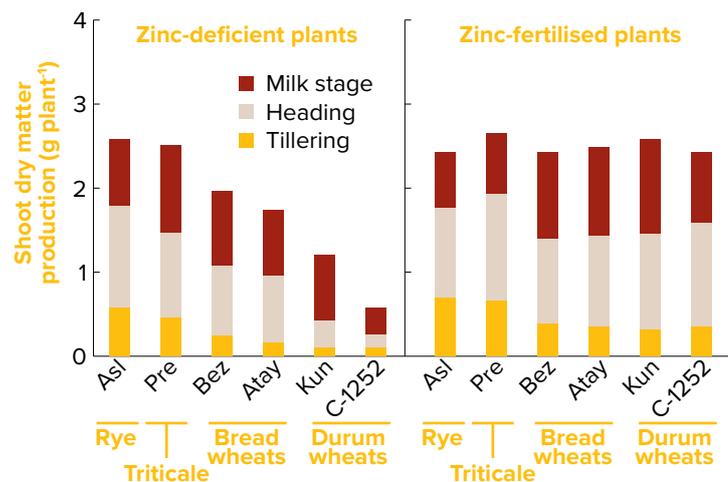


Figure 5: Dry-matter production of different cereals grown in a field experiment without and with Zn fertilisation in a Zn-deficient calcareous soil. (ASL is Aslim, PRE is Presto, BEZ is Bezostaja-1, ATAY is Atay-85, KUN is Kunduru-1149.) Fertiliser was applied at the rate of 23 kg Zn/ha-1. Plants (main tillers) were sampled at the stages of tillering (105 DAJF), heading (144 DAJF) and milk (168 DAJF), where DAJF stands for days after January 1.

Source: Cakmak et al. 1997

Symptoms of Zinc deficiency

What to look for in the paddock

- Patchy growth of stunted plants with short, thin stems and usually pale green leaves.

⁸⁶ M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

⁸⁷ I Cakmak, H Ekiz, A Yilmaz, B Torun, N Köleli, I Gültekin, A Alkan, S Eker (1997) Differential response of rye, triticale, bread and durum wheats to zinc deficiency in calcareous soils. Plant and Soil, 188 (1), 1–10.

⁸⁸ I Cakmak, H Ekiz, A Yilmaz, B Torun, N Köleli, I Gültekin, A Alkan, S Eker (1997) Differential response of rye, triticale, bread and durum wheats to zinc deficiency in calcareous soils. Plant and Soil, 188 (1), 1–10.

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- Heavily limed soils, sands and gravels or alkaline grey clays tend to be most affected.
- Zinc-deficiency symptoms are usually seen on young seedlings early during the growing season.

What to look for in the plant

- Young to middle leaves develop yellow patches between the mid-vein and edge of the leaf and extend lengthways towards the tip and base of the leaf. This stripe may occur only on one side of the mid-vein.
- The areas eventually die turning pale grey or brown
- The leaf changes from green to a muddy greyish-green in the central areas of middle leaves.
- Stunted plants often have 'diesel-soaked' leaves, showing dead areas about halfway along the leaves, causing them to bend and collapse in the middle section (Photo 15).⁸⁹
- Maturity is delayed.⁹⁰



Photo 15: Leaves yellow and die and can have tramline effect on leaves. Necrosis halfway along middle and older leaves causes them to droop.

Source: DAFWA

What else it could be

The symptoms described above may also be due to other issues (Table 16).

⁸⁹ DAFWA (2015) Diagnosing zinc deficiency in wheat. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-wheat>

⁹⁰ DAFWA (2015) Diagnosing zinc deficiency in wheat. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-wheat>

Table 16: Other problems of triticale that could be confused for zinc deficiency.

Condition	Similarities	Differences
<u>Manganese deficiency</u>	Leaf kinking, pale lesions, streaks and wilted plants	Manganese-deficient plants are very pale, are more common as patches of limp, dying plants, and lack the parallel necrotic tramlines adjoining the midrib
<u>Wheat streak mosaic virus</u>	Stunted plants with many tillers and striped leaf lesions	Zinc-deficient plants have pale, linear spots or lesions that can develop into parallel 'tramlines', and lack vivid yellow streaks towards the leaf tip
<u>Yellow dwarf virus</u>	Stunted plants with many tillers and striped leaf lesions	Zinc-deficient plants have pale linear spots or lesions that can develop into parallel 'tramlines', and lack vivid yellow streaks towards the leaf tip

Source: DAFWA

Managing zinc deficiency

- Use a foliar spray (effective only in current season) or starter fertiliser blend.
- Zinc foliar sprays need to be applied as soon as deficiency is detected to avoid irreversible damage.
- As zinc is immobile in the soil topdressing is ineffective, being available to the plant only when the topsoil is wet.
- Mixing zinc through the topsoil improves availability due to more uniform nutrient distribution.
- Zinc drilled in deep increases the chances of roots being able to obtain enough of the element when the topsoil is dry.
- Zinc seed treatment is used to promote early growth as the dressing can provide the seeds full requirement.
- Zinc present in compound fertilisers often meets the current requirements of the crop.⁹¹

Zinc may be required on light-textured soils such as sands or sandy loams, and particularly those that are alkaline, as the more alkaline the soil, the lower the availability of zinc for plant uptake. Zinc responses on pasture are rare, but where required zinc should be applied at about 1–2 kg/ha, every 5–6 years.⁹²

Correction of Zn deficiency in a way that provides benefits after the year of treatment is possible through the use of Zn-enriched fertilisers, or with a pre-sowing spray of Zn onto the soil, which will be incorporated with subsequent cultivation. There is also the option of a Zn-coated MAP products which can be used to supply Zn to the crop, and is most useful when pre-drilling urea before the crop.

Another option that will also provide long-term benefits and has become available recently is the application of liquid zinc at seeding. The advantage of this approach is that it will provide residual benefits for subsequent crops and pastures and has a low up-front application cost (providing you ignore the capital investment in a fluid-delivery system).⁹³

Soil application (pre-plant) - Applying 15–20 kg/ha of zinc sulphate monohydrate 3–4 months before planting should meet the total plant requirement for 5–8 years. Zinc is not mobile in the soil and needs to be evenly distributed over the soil surface, and then thoroughly cultivated into the topsoil. In the first year, a foliar zinc spray may also be required.

91 DAFWA (2015) Diagnosing zinc deficiency in wheat. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-wheat>

92 Agriculture Victoria (2008) Trace elements for dryland pastures. Note AG0265. Revised. Agriculture Victoria, <http://apo.org.au/system/files/57108/apo-nid57108-98416.htm>

93 N Wilhelm, S Davey (2016) Detecting and managing trace element deficiencies in crops. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Detecting-and-managing-trace-element-deficiencies-in-crops>

Soil application (at planting) - Banding zinc with phosphorus at planting is an efficient means of delivering zinc to the plants roots. Water injection with either zinc monohydrate or zinc heptahydrate may also be an option for some growers. If applied as a starter fertiliser component, the amount should be at least 1 kg of zinc/ha (about 40 kg/ha of product) which will only provide enough zinc for that crop.

Seed dressing may provide sufficient Zn to meet crop requirement, but will not build up residual zinc to the soil. May be a cost-effective option where soil P levels are adequate.

Foliar sprays - Two applications are necessary. Apply at three weeks and again at five weeks after emergence. It is important both sprays be applied before the crop is six weeks old. The most economical form of foliar zinc is a tank-mix of 1 kg zinc sulphate heptahydrate/ha plus 1 kg urea/ha in 100 L water/ha plus surfactant at 100 mL of 1000 g/L product/100 L of spray mixture (or 160 mL of 600 g/L product/100 L of spray mixture).

Water high in carbonate will produce insoluble zinc carbonate. Consider having the water analysed for suitability in crop protection programs and using a commercial buffering agent.

Zinc heptahydrate sprays may not be compatible with herbicides. Several chelate forms of zinc are available which are generally more compatible with herbicides. Always read the label to determine compatibility.⁹⁴

5.9.4 Iron

Iron (Fe) is involved in the production of chlorophyll and is a component of many enzymes associated with energy transfer, nitrogen reduction and fixation, and lignin formation. Iron deficiencies are mainly manifested by yellow leaves, which are due to low levels of chlorophyll. Leaf yellowing first appears on the younger upper leaves in interveinal tissues. Severe iron deficiencies cause the leaves to turn completely yellow or almost white, and then brown as leaves die. Iron deficiencies are found mainly in alkaline soils, although some acidic, sandy soils, low in organic matter, may also be iron-deficient. Cool, wet weather enhances iron deficiencies, especially in soils with marginal levels of available iron. Poorly aerated or compacted soils also reduce iron uptake. High levels of available phosphorus, manganese and zinc in soils can also reduce iron uptake.⁹⁵

Symptoms of Iron deficiency

What to look for in the paddock

- Pale plants, particularly in waterlogged or limed areas (Photo 16).⁹⁶
- Where the soil type is alkaline, or acidic soils with excessive levels of soluble manganese.

What to look for in the plant

- The youngest growth is affected first and most severely.
- Symptoms begin with young leaves turning pale green or yellow.
- Interveinal areas become yellow and in severely deficient plants interveinal areas turn almost white (Photo 17).
- New growth remains yellow for some time before leaves start to die.
- Old leaves remain pale green and apparently healthy.
- Severely affected plants are stunted, with thin spindly stems.

94 Queensland Department of Agriculture and Fisheries (2012) Wheat–nutrition. <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition>

95 RHJ Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press.

96 DAFWA (2015) Diagnosing zinc deficiency in cereals. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-iron-deficiency-cereals>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Image courtesy
CSIRO Publishing

Photo 16: *Pale green to yellow plants may indicate an iron deficiency.*

Source: DAFWA

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 17: Pale yellow, iron-deficient leaves, most showing prominent green veins (the three on the right) compared with dark green healthy leaf (left).

Source: DAFWA

What else it could be

The symptoms described above can also be caused by other issues (Table 14).

Table 17: Other problems of triticale that could be confused for iron deficiency.

Condition	Similarities	Differences
<u>Sulfur deficiency</u>	Pale plants with pale new growth	Sulfur-deficient plants do not have interveinal chlorosis
<u>Group B herbicide</u>	Pale seedlings with interveinal chlorosis on new leaves	Herbicide-damaged plants generally recover, and are not restricted to waterlogged areas
<u>Waterlogging, or nitrogen, molybdenum and manganese deficiency</u>	Pale growth	Middle or older leaves are affected first

Source: DAFWA

Managing iron deficiency

- No yield responses to iron to justify soil application.
- Where symptoms occur, particularly in cold and wet conditions, they are frequently eliminated as soil and air temperatures rise.
- Foliar sprays will remove the symptoms where they occur in highly calcareous or limed soils.⁹⁷

5.10 Paddock nutrition

Key points:

- Growers can minimise fertiliser inputs by optimising plants' use of pre-existing reserves of soil nutrients.
- Maximising root abundance and rooting depth means that roots can take advantage of nutrients and water in the subsoil.
- Use of soil reserves of nitrogen can be optimised by testing for the different forms of nitrogen and using these figures conduct a N budget.
- Good yield estimates are critical when estimating nutrient requirements.

One way to optimise plant uptake of nutrient reserves in soil is to maximise root abundance and rooting depth. A bigger root system gives plants access to more soil and ensures they can follow nutrients and water down the soil profile. This is especially important for leachable nutrients such as nitrogen and sulfur, and where there are nutrients with significant reserves in the subsoil. Root abundance and rooting depth can be increased by maintaining optimum soil pH and minimising soil compaction and plant root diseases.

Nutrient availability is optimised in soils with topsoil pH levels are in the optimum range of pH 6.0–7.5 (CaCl₂). Maintaining the pH above 5.2 in the subsurface will prevent aluminium toxicity, which restricts root growth down the soil profile (Photo 18).⁹⁸



Photo 18: Roots of cereal grown in acidic subsurface soil (right) are shortened by aluminium toxicity.

Source: Soilquality.org

⁹⁷ DAFWA (2015) Diagnosing iron deficiency in wheat. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-iron-deficiency-cereals>

⁹⁸ Soilquality.org (2017) Optimising soil nutrition, Queensland. Soilquality.org, <http://www.soilquality.org.au/factsheets/optimising-soil-nutrition-queensland>

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

The application of agricultural lime is an effective way of managing soil acidity and maintaining appropriate soil pH.

Subsoil compaction can reduce the rooting depth of plants by slowing the rate of root penetration. This means roots are unable to access subsoil moisture and leachable nutrients such as nitrogen, and can result in poor nitrogen-use efficiency. Avoiding traffic on the site when soils are moist or wet, restricting traffic to defined wheel tracks (controlled-traffic farming) and minimising the amount of tillage all help to reduce or avoid subsoil compaction.

Plant-root diseases and pathogens can severely decrease root exploration and nutrient uptake. Root lesion nematodes and crown rot are common in Northern cropping regions.

The use of break crops to prevent the build-up of disease and pathogens, growing tolerant crops to maximise yield when nematodes or diseases are present, and practicing good farm hygiene are some of the most effective strategies to manage plant-root pathogens and diseases.⁹⁹

For more information on cereal root disease, see [Section 8: Nematode Control](#), and [Section 9: Diseases](#).

5.10.1 Aluminium toxicity

At soil pH levels of below 5, aluminium (Al) and manganese (Mn) become available in soil solution, and can damage root growth and reduce yields. Screening work in flow-culture systems and field observations has indicated that triticale has a range of tolerances to aluminium¹⁰⁰ but it generally has a higher tolerance to aluminium than other cereals.

Triticale grows productively on acidic soils where the high availability of aluminium ions reduces the economic yield of many other crops.¹⁰¹

Many triticale cultivars are able to grow better than wheat in high aluminium toxicity soils.¹⁰²

Many of the new varieties have been screened in flow cultures for Al tolerance (Table 15). In the screening system small plants are given an aluminium stress in solution and afterwards examined for root regrowth. The presence of regrowth and its length indicate relative tolerance, with greater length of regrowth being a measure of greater Al tolerance. As expected, the wheat variety (Janz) had poor tolerance, rye was tolerant, and there was a range of tolerances within the triticales, with Canobolas(φ) being the most Al-tolerant variety.¹⁰³

99 Soilquality.org (2017) Optimising soil nutrition, Queensland. Soilquality.org, <http://www.soilquality.org.au/factsheets/optimising-soil-nutrition-queensland>

100 S Tshewang (2011) Frost tolerance in Triticale and other winter cereals at flowering. Master's thesis. University of New England, https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

101 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

102 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

103 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy, Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report.pdf

SECTION 5 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Table 18: *Aluminium tolerance of triticales.*

Variety	Regrowth length (mm)
Wheat	2.4
Rye	40.6
Tobruk(D)	21.0
JCRT 74	29.5
JCRT 75	30.8
Breakwell(D)	36.5
Tahara	35.1
AT528	27.6
H20	27.6
H55	39.6
H116	29.5
Bogong(D)	29.5
H128	35.4
H157	29.5
H249	32.8
Canobolas(D)	46.1
H426	48.7

Source: Jessop and Fittler 2009

Weed control

Key messages

- Weed control in triticale is similar to that for wheat.
- There are mixed reviews on triticale's ability to compete with weeds. Triticale is a more vigorous crop than wheat, and so offers greater competition against weeds; however, it grows a bit more slowly than spring wheat, so annual grasses and other weeds can be problematic.
- Triticale may have some allelopathic effect which can inhibit the germination and growth of weeds but this effect is not as high as cereal rye.
- Triticale is a minor crop, and as such herbicide options are not as extensive as those for wheat.
- Integrated weed management is becoming more common in Australian cropping, and shows promising results that should also be employed when growing triticale.
- Good soil fertility along with vigorous germination and fast emergence may be one of the most efficient ways to reduce weeds through competition.

Weeds are estimated to cost Australian agriculture A\$2.5–4.5 billion a year. For winter cropping systems alone the cost is \$1.3 billion, with annual rye grass being one of the biggest problems (Photo 1).¹ Consequently, any practice that can sustainably reduce the weed burden is likely to generate substantial economic benefits to growers and the grains industry.



Photo 1: Annual ryegrass is one of the most problematic weeds in Australia and around the world (left). Here (right) it is heavily infesting a cereal paddock.

Source: Southwest Farm Press

6.1 Weed competitiveness of triticale

Good soil fertility along with vigorous germination and fast emergence may be one of the most efficient ways to reduce weeds through competition. A vigorously growing crop is usually weed-free, and this is as true of triticale as it is of other grains.

The actual competitiveness of different cereals depends on growing conditions, management practices, weed load and relative growth stage of the weed and crop. Triticale's competition to weeds is provided by its leafiness and height, which impact light and moisture competition.² Even so, there is still a large number of weeds that can be a problem for triticale.

¹ R Smith (2014) Two-step program controls resistant ryegrass in wheat. 24 February. Southwest Farm Press, <http://www.southwestfarmpress.com/grains/two-step-program-controls-resistant-ryegrass-wheat>

² S Clarke, S Roques, R Weightman, D Kindred (2016) Understanding triticale. AHDB, <https://cereals.ahdb.org.uk/media/897536/pr556-understanding-triticale.pdf>

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Triticale may have some allelopathic effect which can inhibit the germination and growth of weeds but this effect is not as high as one of its parent crops, cereal rye.³

For example, trials from 2012–2014 in Wagga Wagga, explored differences in weed infestation in crop and also in postharvest crop fallows associated with grain crop cultivar and species. The results suggested that some crops were clearly more suppressive of in-crop weeds than others. Crop residues of all types resulted in greater in-fallow weed suppression, with 50–100% increases in weed management in comparison to uncropped borders with no residue following crop harvest. Witchgrass was the major weed infesting plots by May 2013 and 2014. In 2014, grazing wheat and canola plus triticale suppressed witchgrass establishment more effectively than any of the other crop sequences (Figure 1).⁴

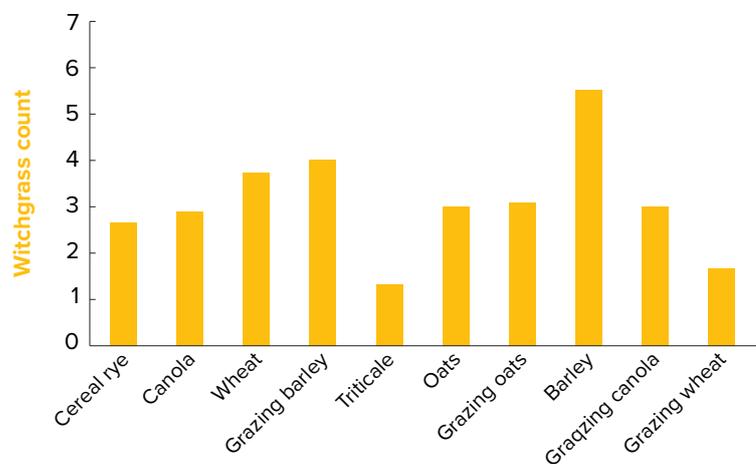


Figure 1: Witchgrass counts in plots in March 2014. The triticale plots showed the lowest count of witchgrass plants. Areas with no residues averaged 20 plants m⁻².

The grass weed annual ryegrass (*Lolium rigidum*) is one of the worst weeds of triticale (as well as other grains). Based on research in NSW the most competitive crops in the face of annual ryegrass (at 300 plants/m⁻²) are, in descending order, oats, cereal rye, triticale, oilseed rape, barley, wheat, field peas, and lupins.⁵

Suppression of annual ryegrass by wheat, triticale and rye was compared in field trials at Wagga Wagga in 1993. Triticale and cereal rye appeared to be more competitive than wheat: the biomass of mature ryegrass was 70 g/m² in triticale, compared to 170 g/m² in wheat. Triticale has large seeds which lead to rapid early growth and the capacity to suppress weeds because of a vigorous growth habit. Early seedling vigour, superior height and broad leaves appeared to influence the greater competitive ability of the triticale and cereal rye.⁶

Triticale's potential as a substitute for herbicides is of particular interest to organic growers, who could use this crop for partial control of weeds in their rotations. Although triticale's competitiveness is known, there is not a large scientific database about its effectiveness as a weed control when used in this manner.⁷

MORE INFORMATION

[Impact of crop residues on summer fallow weeds](#)

³ Albert Lea Seed (2010) Triticale, <http://www.alseed.com/UserFiles/Documents/Product%20Info%20Sheets-PDF/Basics%20Triticale-2010.pdf>

⁴ L Weston, R Stanton, H Wu, J Mwendwa, P Weston, J Weidenhamer, W Brown (2015) GRDC Update Papers: Impact of crop residues on summer fallow weeds. <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Impact-of-crop-residues-on-summer-fallow-weeds>

⁵ D Lemerle, B Verbeek, N Coombes (1995) Losses in grain yield of winter crops from *Lolium rigidum* competition depend on crop species, cultivar and season. *Weed Research*, 35 (6), 503–509.

⁶ D Lemerle, K Cooper (1996) Comparative weed suppression by triticale, cereal rye and wheat. In *Triticale: Today and Tomorrow*. Springer Netherlands, pp. 749–750.

⁷ Alberta Agriculture and Forestry (2016) Triticale crop protection. Alberta Agriculture and Forestry, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/fcd10572](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10572)

To minimise weeds, prepare the seedbed so it is as clean as possible before planting, and be sure to practice crop rotation. Planting early will help with the quick establishment of a triticale stand and may stave off early weed pressure. Triticale can also be undersown with another crop to aid in weed competition and nutrient management.⁸

6.1.1 Best management practices for weed control in triticale

Best management practices for weed control in triticale are similar to those for wheat. They include:

- Sow at higher rates (e.g. ~150 - 200 plants/m²) and ensure proper fertility
- Plan ahead. Chemical weed control options in triticale are limited, making it more important to select relatively clean paddocks in which to sow triticale.
- Apply a knockdown spray prior to sowing. Ensure that the majority of weeds have emerged prior to this spray.
- Seed early, as earlier sown triticale usually results in more competitive stand establishment, and provides a jump-start on the weeds.
- Seed at shallow depths, between 13–38 mm (optimum 25 mm). Shallow seeding generally results in uniform seedling emergence, and plants that quickly cover the ground and compete well against emerging weeds.
- Use sanitary practices: clean machinery and seeding equipment before planting.⁹

6.2 Integrated weed management

The Grains Research and Development Corporation (GRDC) supports the practice of integrated weed management (IWM). This is a system for managing weeds over the long term, and particularly includes the management of weeds so as to minimise the development of herbicide resistance. There is a need to combine herbicide and non-herbicide methods into an integrated control program. Given that there are additional costs associated with implementing IWM, the main issues for growers are whether it is cost-effective to adopt the system and whether the benefits are likely to be long term or short term in nature.

The GRDC manual, [Integrated Weed Management in Australian Cropping Systems](#), looks at these issues and breaks them down into seven clear sections, to assist the reader to make the development of an IWM plan a simple process.

6.2.1 IWM for triticale

Although triticale has been shown to be more competitive against annual ryegrass than wheat, a sound weed-control program must still be implemented to avoid a blow-out in weed seed numbers and to optimise yields.

It is vital to control weeds early in the crop's growth to give the crop a chance to get ahead. Once the crop has grown it then becomes more competitive.

When sowing dual-purpose varieties early, choose a paddock with low weed numbers and control weeds prior to the first grazing. Strategic grazing can be used to help manage weeds. When planning to graze the crop, always check grazing withholding periods before you apply post-emergent herbicides.¹⁰

MORE INFORMATION

[Weed management as a key driver of crop agronomy](#)

8 UVM Extension Crops and Soils Team (2011) Triticale. University of Vermont, <http://northerngrowingrowers.org/wp-content/uploads/TRITICALE.pdf>

9 Alberta Agriculture and Forestry (2016) Triticale crop protection. Alberta Agriculture and Forestry, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/fcd10572](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10572)

10 Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcrrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

IN FOCUS

The effect of cultivation and row spacing on the competitiveness of triticale

Research in 2007 explored the effect of cultivation and row spacing on the competitiveness of triticale against weeds. The aim of this work was to identify agronomic practices that enable triticale to express its full genetic potential for competitive growth against the vigorous weedy competitor annual ryegrass (*Lolium rigidum*). Researchers assessed the effects on triticale of cultivation (disc ploughing), or lack thereof (zero tillage) before sowing, and row spacing (15 cm, 30 cm and 45 cm).

Most of the previous experiments evaluating the effect of row spacing and level of cultivation on cereals were performed on wheat, so in 2007 there was little data specifically on triticale. The researchers hoped to identify the optimal row spacing and level of cultivation that enhance the competitive ability of triticale, to help farmers secure more sustainable yields by increasing including triticale in their cropping rotations. They hoped the results would help farmers reduce the cost of weed control, reduce weed-induced losses of yield, and see greater fertiliser uptake and utilisation by the crop at the expense of weeds.

Unfortunately, growing conditions turned out to be less than ideal. Episodic heavy rain early in the growing season caused waterlogging and poor establishment of the triticale and, late in the season, some lodging. In addition to above-average rainfall, temperatures were below average. This combination appeared to assist the growth of annual ryegrass at the expense of triticale. The data the researchers collected was highly variable. Under the conditions of the season, row spacing did not effect the biomass, grain yield or 1,000-grain weight of the triticale. However, cultivation, while not showing an early impact, increased triticale biomass and grain yield at harvest. In this trial, the wet conditions appeared to affect the expression of competitive growth habits in both the crop and weed species present, although the weeds out-competed the triticale.

All was not lost though. Several findings validated the value of the agro-ecological principles on which integrated weed management is based. They were:

- Weeds that emerge prior to or at the same time as the crop impose the greatest weed-crop interference, particularly in those weed species (e.g. *L. rigidum*) that share similar morphology and phenology to cereal crops.
- Strong selection pressure from a given agronomic practice will cause a shift in the composition of the weed flora and may contribute to the development of single species becoming a problem, e.g. *Fallopia convolvulus* under high crop densities.
- Early suppression of weeds, in terms of preventing germination or limiting biomass accumulation, is the most important aspect of crop competitive ability, as even the most tolerant crops will have lower yields if early weed-crop competition results in reduced crop tillering during early crop growth.
- The expression of competitive growth in cereal crops with strong genetic potential for competitive ability (e.g. triticale) is highly influenced by optimal plant densities and competition between individual plants in the crop.¹¹

¹¹ B Sindel (2008) UHS127: The effect of cultivation and row spacing on the competitive ability of triticale against weeds. GRDC, <http://finalreports.grdc.com.au/UHS127>

i MORE INFORMATION

[Agronomy to enhance the implementation and benefits of weed management tactics](#)

6.2.2 IWM principles and tactics

There are very effective strategic and tactical options available to manage weed competition that will increase crop yields and profitability. Weeds with herbicide resistance are an increasing problem in grain-cropping enterprises. The industry and researchers advise that growers adopt integrated weed management to reduce the damage caused by herbicide-resistant weeds.

An integrated weed management plan should be developed for each paddock or management zone. Each target weed is attacked using tactics from several tactical groups. Each tactic provides an opportunity for weed control. It is dependent on the management objectives, and the stage of growth of the target weed. Integrating tactic groups reduces weed numbers, stops replenishment of the seedbank and minimises the risk of developing herbicide-resistant weeds. The IWM groups are:

- Reduce weed seed numbers in the soil.
- Controlling small weeds.
- Stop weed seed set.
- Hygiene: prevent weed seed introduction.
- Agronomic practices and crop competition.
- Conduct a pre-harvest audit of the paddock determining species present and species density and where in the paddock they occur.
- Use HWSM (harvest weed seed management) strategies e.g. windrow burning, to reduce numbers.
- Consider bailing hay, and green and brown manuring.

There are several agronomic practices that improve crop environment and growth, along with the crop's inherent ability to out-compete weeds. These include crop choice and sequence, improving crop competition, planting herbicide-tolerant crops, improving pasture competition, using fallow phases, and using controlled traffic or tramlining.¹²

Review past actions

Knowing the historical level of selection pressure can be valuable information to give managers a 'heads up' as to which weed and herbicidal mode of action (MOA) groups are at greatest risk of breaking. Such knowledge can prompt more intensive monitoring for escapee weeds when a situation of higher risk exists. Noticing developing resistance while patches are still small and before they spread can make a big difference in the cost of management over time.

From all available paddock records, calculate or estimate the number of years in which different herbicide MOAs have been used. This is of far greater relevance than the number of applications in total. For most weeds, using a herbicide MOA in two consecutive years presents a far greater selection pressure for resistance than two applications of the same MOA in the one year. If the entire paddock history is unavailable to growers, state what is known and estimate the rest. Collate separate data on MOA use for summer and winter weed spectrums. Further subdivide these into broadleaved and grass weeds.

Account for double-knocks. Where survivors of one tactic would have been controlled in large part by the use of another tactic, reduce the number of MOA uses accordingly. An example might be: Trifluralin (Group D) has been used 20 times, but there have been six years when in-crop Group A selectives were used and several more years where in-crop group B products that targeted the same weed as the trifluralin were used. These herbicides effectively double-knocked the trifluralin, thus somewhat reducing the effective selection pressure for resistance to trifluralin.

Review the data have collected and identify which weed and MOA groups have been selected for at a frequency likely to lead to resistance in the absence of a double-

¹² DAFWA (2016) Crop weeds: Integrated weed management (IWM). DAFWA, <https://www.agric.wa.gov.au/grains-research-development/crop-weeds-integrated-weed-management-iwm>

knock. Trifluralin typically takes about 10–15 years of selection for resistance to occur (Table 1). Thus, using the above example, a watching brief would be in place for trifluralin and other Group D MOA herbicides.

Paddock history can also be useful information when evaluating the likely reasons for herbicide spray failures, in prioritising strategies for future use, and in deciding which paddocks receive extra time for scouting for patches of escaped weeds.

Information on the history of MOA use should be added to paddock records.

Table 1: Typical number of years of use to develop resistance MOA groups.

Herbicide group	Typical years of application	Resistance risk
A (fops, dims, dens)	6–8	High
B (SUs, IMIs)	4	High
C (triazines, subst. ureas)	10–15	Medium
D (trifluralin, Stomp)	10–15	Medium
F (diflufenican)	10	Medium
I (phenoxies)	>15	Medium
L (paraquat, diquat)	>15	Medium
M (glyphosate)	>12	Medium

Assess the current weed status

Record the key broadleaved and grass weed species for summer and winter, and include an assessment of weed density, with notes on weed distribution across the paddock. Include GPS locations or some other reference to spatial location of any key weed patches or areas tested for resistance.

Include any data, observations or information relating to the known or suspected herbicide resistance of weeds in this paddock.

Add this information to paddock records.

Identify weed management opportunities

Identify what different herbicide and non-herbicide tactics could be cost effectively added to the system and where in the crop sequence these can be added.

Fine-tune the list of options

Which are the preferred options to add to existing weed-management tactics, to add diversity and help drive down the weed seedbank?

Combine and test ideas

Computer simulation tools can be useful to run a number of ‘what if’ scenarios to investigate potential changes in management and the likely effect of weed numbers and crop yield. Two simulation tools being used are the [Weed Seed Wizard](#) and [RIM \(Ryegrass Integrated Management\)](#).¹³

6.2.3 IWM in the Northern Region

Key points:

- The major weeds of the Northern Region are feathertop Rhodes grass, windmill grass, flaxleaf fleabane, awnless barnyard grass, liverseed grasses, common sowthistle, wild oats, annual ryegrass, skeleton weed and spiny emex.
- Weeds cause economic losses in various ways, usually by reducing crop yields or contaminating harvested grain.

MORE INFORMATION

[Section 4: Tactics for managing weed populations](#)

¹³ GRDC (2014) Integrated weed management hub. <https://grdc.com.au/Resources/IWMhub>

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- Weeds use soil moisture during both fallow and cropping periods, so that less moisture is available for the following crop.
- Weed competition for moisture may result in poor crop establishment and growth, therefore reducing crop yield potential.
- Weed-seed contamination of harvested grain can result in seed grading being required or discounts on contaminated grain.

Broadscale herbicide resistance is continuing to spread through the Northern region. Using more herbicide is not the answer to overcoming the situation; Growers can choose from a range of chemical and non-chemical integrated weed management tactics that delay or prevent resistance developing and control herbicide-resistant weeds.

Other non-herbicidal tactics are needed to aid in weed control and to kill survivors of herbicide applications.

Crop competition is a proven tactic to reduce weed germination in the crop. In early sown crops planted using narrow spacing, the canopy can close over quickly and shade the soil surface to effectively suppress weed germination. Research conducted at Trangie Agricultural Research Centre has shown the beneficial impact of both narrow row spacing and increased crop density in wheat crops, which successfully suppressed fleabane. Increasing the seeding rate alone had a small impact on fleabane density, but narrow row spacing, decreasing from around 50 cm to 25 cm, reduced fleabane populations by about 50%. When the seeding rate was increased and the row spacing narrowed, the combination brought about a 90% reduction in the number of seed heads produced.

When looking to use crop competition as a weed-control tactic it is necessary to look for the best crop species and variety for the location. Some winter cereals, summer crops and winter pulses can achieve the desired effect of shading about 90% of the soil surface soon after being sown.

Strategic cultivation may also be a valuable tactic, particularly to kill small patches of resistant weeds or to kill large weeds that are not susceptible to herbicide.

For isolated plants, hand chipping may be a viable option.

Harvest weed-seed control is another method of reducing the amount of weed seed reaching the soil. Narrow windrow burning, brown manuring, crop topping, weed seed grinding, chaff carts and baling have all been shown to be effective against weed species that do not shed their seed before harvest and do not produce air-borne seed.

For more information, see [Section 6.12.3 Capture weed seeds at harvest](#), below.

Row direction

Deliberately orienting crop rows at 90 degrees to the direction of sunlight, i.e. east–west, works on the principle that the crop will intercept more sunlight (i.e. photosynthetically available radiation) than crops sown north–south, giving weeds less chance to develop between the rows. In winter, when the sun is at a lower angle (solar plane) shading of the inter-row can be advantageous, particularly in southern latitudes.

In summer crops and at higher latitudes, row direction has no advantage in terms of yield or weed control. This is most likely because the sun is at a higher angle and also because of the relatively lower plant populations involved and the wider rows (75 cm). Importantly east–west sowing did not yield any less than north–south sowing, meaning it would be compatible with winter crop programs that could benefit from rows oriented east–west for weed control.

Many paddocks in the northern region were set up for controlled-traffic tramlines 15 years ago. The orientation of the tramlines was based on practicalities such as reducing headland area by choosing row direction according to the longest run of the

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

MORE INFORMATION

[Costs of key integrated weed management tactics in the Northern Region](#)

paddock, and in irrigated paddocks by the fall of the land. These practicalities may override the potential weed-control benefits.

Competitive choices

Triticale, barley and rye are more competitive than wheat, and some wheat varieties are more competitive than others. Pulses are less competitive than cereals, and the competitiveness of brassicas is very dependent on sowing time. Choose varieties that have rapid early growth and early canopy closure.

If weed pressure is a concern, choose a seeding rate at the higher end of the recommended range for your crop. Calibrate your equipment and use only clean, fresh, viable seed. Even though wider row spacing may be beneficial in conservation cropping systems for ease of planting and where stubble can reduce weed emergence, crops planted in wider rows are less competitive.¹⁴

6.3 Weeds in northern cropping systems

Weed management, particularly in reduced-tillage fallows, has become an increasingly complex and expensive part of cropping in the Northern Region. Heavy reliance on glyphosate has selected for species that were naturally more glyphosate-tolerant or has selected for glyphosate-resistant populations. The four key weeds that cause major problems during fallow are:

- [awnless barnyard grass](#) (ABYG) (*Echinochloa colona*)
- [flaxleaf fleabane](#) (*Conyza bonariensis*)
- [feathertop Rhodes grass](#) (*Chloris virgata*)
- [windmill grass](#) (*Chloris truncata*)

6.3.1 Awnless barnyard grass

Key points:

- Glyphosate resistance is widespread in awnless barnyard grass. Tactics against this weed must change from glyphosate alone.
- Utilise residual chemistry wherever possible and aim to control escapees with camera-spray technology.
- Try to ensure that a double-knock of glyphosate followed by paraquat is used on one of the larger early summer flushes of ABYG.
- Restrict Group A herbicides to manage the grass in the crop, and aim for strong competition from the crop if a summer crop is being sown.

Awnless barnyard grass (ABYG) has been a key summer grass problem for many years (Photo 2). It is a difficult weed to manage for at least three main reasons:

- There are multiple emergence flushes (cohorts) each season.
- It is easily moisture-stressed, leading to inconsistent knockdown control.
- Glyphosate-resistant populations are being found more often.

¹⁴ GRDC (2014) Integrated weed management. GRDC, <https://grdc.com.au/Media-Centre/Hot-Topics/Integrated-weed-management>



Photo 2: Large specimen of glyphosate-resistant awnless barnyard grass.

Source: Agronomo

Resistance levels

Before the summer 2011–12, there were 21 cases of glyphosate-resistant ABYG. But that summer, collaborative surveys were conducted by NSW DPI, DAF Queensland and the Northern Grower Alliance, and followed up in 2012–13. Agronomists from the Liverpool Plains to the Darling Downs and west to areas including Mungindi collected ABYG samples, which were tested at the Tamworth Agricultural Institute with glyphosate CT at 1.6 L/ha (a.i. 450 g/L) at a mid-tillering growth stage. The total volume applied was 100 L/ha.

The main finding was that the number of confirmed glyphosate-resistant ABYG populations had nearly trebled. Selected populations were also evaluated in a separate glyphosate rate–response trial. The experiment showed that some of these populations were suppressed only when sprayed with 12.8 L/ha.

Therefore, growers can no longer rely on glyphosate alone to control ABYG.

Residual herbicides in fallow and in the crop

Several active ingredients are registered for use in summer crops (e.g. metolachlor, such as in Dual Gold®) and atrazine) or in fallow (e.g. imazapic, used in Flame®) that are useful in managing ABYG. The new fallow registration of isoxaflutole (Balance®) can suppress ABYG, but is more active against other problem weeds. Few (if any) residuals give consistent, complete control. However, they are important tools that need to be considered to reduce the weed population exposed to knockdown herbicides, as well as to alternate the herbicide chemistries being employed. Use of residuals together with camera-spray technology (for escapees) can be a very effective strategy in fallow.

Double-knock control

The double-knockdown approach uses two tactics in sequence. In reduced tillage situations, the frequent combination is glyphosate first followed by a paraquat-based spray as the second application or knock. This is supported by trials, which have shown that glyphosate followed by paraquat has given effective control even on glyphosate-resistant ABYG. Note that most effective results will be achieved from

paraquat-based sprays by using higher total application volumes (100 L/ha) and by targeting seedling weeds.

Several Group A herbicides, e.g. Verdict® and Select®, are effective on ABYG but should be used in registered summer crops, e.g. mungbeans. In the same situations there has been little benefit from a Group A followed by paraquat. Note that Group A herbicides appear to be more sensitive to ABYG moisture stress. Application on mature weeds can result in very poor efficacy.

The timing of the paraquat application for ABYG control has been shown to be generally flexible. The most consistent control is obtained from a delay of ~3–5 days after glyphosate, when lower rates of paraquat can also be used. Longer delays may be warranted when ABYG is still emerging at time the first herbicide is applied; shorter intervals are generally required when weed size is larger or moisture stress is expected. High levels of control can still be obtained with larger weeds but paraquat rates will need to be increased to 2.0 or 2.4 L/ha.¹⁵

6.3.2 Flaxleaf fleabane

Key points:

- Utilise residual chemistry wherever possible and aim to control escapees with camera-spray technology.
- This weed thrives in situations of low competition; avoid planting crops in wide rows unless effective residual herbicides are included.
- 2,4-D is a crucial tool for consistent double-knock control, though be wary of spray drift onto susceptible crops e.g. cotton.
- Successful growers have increased their focus on fleabane management in winter (crop or fallow) to avoid expensive and variable salvage control in the summer. This is best done with a spring application in a cereal crop with a Group I chemical.

For more than a decade, flaxleaf fleabane (*Conyza bonariensis*) has been the major weed management problem in the Northern Region, particularly in reduced-tillage systems (Photo 3).

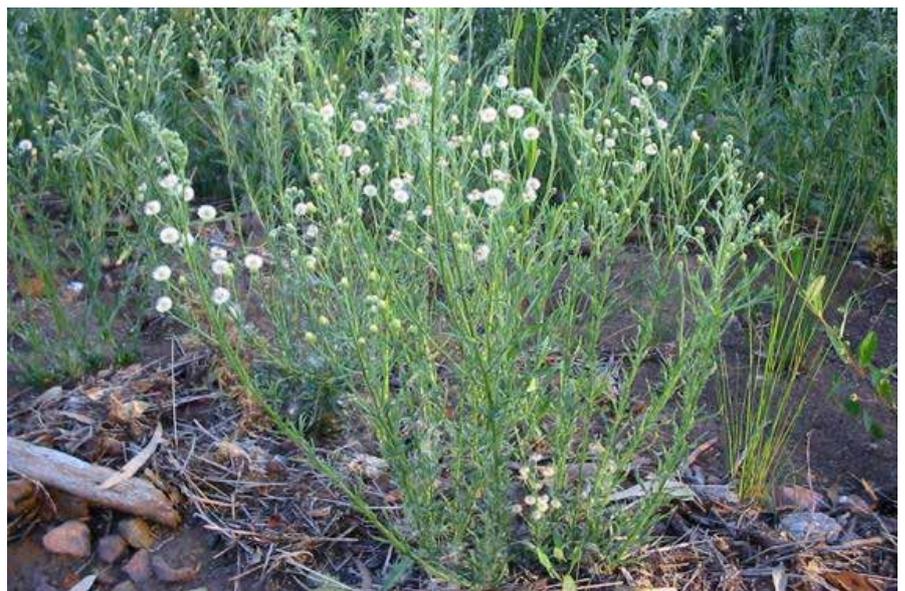


Photo 3: Flaxleaf fleabane is common through southern Queensland and northern NSW.

Source: Brisbane City Council

¹⁵ R Daniel (2013) Weeds and resistance: considerations for awnless barnyard grass, *Chloris* spp. and fleabane management. Northern Grower Alliance, <http://www.nga.org.au/module/documents/download/225>

Fleabane has a wind-borne, surface-germinating seed that sprouts readily. Germination flushes typically occur in autumn and spring, when surface soil moisture levels stay high for a few days. However, emergence can occur at nearly all times of the year. An important issue with fleabane is that knock-down control of large plants in the summer fallow is variable, and can be expensive due to reduced control rates.

Resistance levels

Glyphosate resistance has been confirmed in fleabane. There is great variability in the response of fleabane to this chemical: many samples from non-cropping areas still well controlled by glyphosate, but fleabane from reduced-tillage cropping shows increased levels of resistance. The most recent survey focused on non-cropping situations, with a large number of resistant populations found on roadsides and railway lines where glyphosate alone has been the principal weed management tool employed.

Residual herbicides in fallow and in the crop

One of the most effective strategies to manage fleabane is the use of residual herbicides during summer fallow or in the crop. Trials have consistently shown good efficacy from a range of residual herbicides commonly used in sorghum, cotton, chickpeas and winter cereals. There are now two registrations for residual fleabane management in fallow. Additional product registrations for in-crop knockdown and residual herbicide use, particularly in winter cereals, are still being sought. A range of commonly used winter-cereal herbicides exists with useful knockdown and residual fleabane activity. Trials to date have indicated that increasing water volumes from 50 L/h to 100 L/ha may help the consistency of residual control, with the timing of application to ensure good herbicide–soil contact also being important.

Knockdown herbicides in fallow and in the crop

Group I herbicides have been the major products for fallow management of fleabane, with 2,4-D amine the most consistent one evaluated. Although glyphosate alone generally gives poor control of fleabane, trials have consistently shown a benefit from tank-mixing 2,4-D amine and glyphosate in the first application. Amicide® Advance at 0.65–1.1 L/ha mixed with Roundup® Attack at a minimum of 1.15 L/ha and followed by Nuquat® at 1.6–2.0 L/ha is a registered option for fleabane knockdown in fallow. Sharpen is a product with Group G mode of action. It is registered for fallow control when mixed with Roundup® Attack at a minimum of 1.15 L/ha but only on fleabane up to a maximum size of six leaves.

Be wary of spray drift that could lead to damage to surrounding susceptible crops like cotton. For more information about the risks and management of spray drift, see [Section 6.9 Conditions for spraying](#), below.

Double-knock control

The most consistent and effective double-knock control of fleabane has included 2,4-D in the first application followed by paraquat as the second. Glyphosate alone followed by paraquat will result in high levels of leaf desiccation but plants will nearly always recover.

The timing of the second application in fleabane is generally aimed at ~7–14 days after the first. However, the interval to the second knock appears to be quite flexible. Increased efficacy is obtained when fleabane is actively growing, or when the rosette stages can be targeted. Although complete control can be obtained in some situations, control levels will frequently reach only ~70–80%, particularly when targeting large, flowering fleabane that is moisture-stressed. The high cost of fallow double-knock approaches and inconsistent degrees of control of large, mature plants are good reasons to focus on proactive fleabane management when the plant is young.¹⁶

VIDEOS

WATCH: [GCTV4: Flaxleaf fleabane](#)



¹⁶ R Daniel (2013) Weeds and resistance: considerations for awnless barnyard grass, *Chloris* spp. and fleabane management. Northern Grower Alliance. <http://www.nga.org.au/module/documents/download/225>

6.3.3 Feathertop Rhodes grass

Key points:

- Glyphosate alone or glyphosate followed by paraquat have generally poor efficacy.
- Utilise residual chemistry wherever possible and aim to control escapees with camera-spray technology.
- Where large spring flushes of the grass occur, a double-knock of Verdict followed by paraquat can be used in Queensland .
- Treat patches aggressively, even with cultivation, to avoid paddock blow-outs.

Feathertop Rhodes grass (*Chloris virgata*) emerged as an important weed management concern in southern Queensland and northern NSW in about 2008 (Photo 4). This grass is another small-seeded weed species that germinates on, or close to, the soil surface. It has rapid early growth and can become moisture stressed quickly. Although feathertop Rhodes grass (FTR) is well established in central Queensland, it remains largely an emerging threat further south. Patches should be aggressively treated to avoid whole-of-paddock blow-outs.



Photo 4: The seed heads of feathertop Rhodes grass.

Source: Brisbane City Council

Residual herbicides in fallow and in the crop

This weed is generally poorly controlled by glyphosate alone, even when sprayed under favourable conditions at the seedling stage. Trials have shown that residual herbicides generally provide the most effective control, a similar pattern to that seen with fleabane. Currently registered residual herbicides are being screened and offer promise in both fallow and crop situations. The only product currently registered for FTR control is Balance (isoxaflutole) at 100 g/ha for use fallow.

Double-knock control

A glyphosate followed by paraquat double-knock is variable and generally disappointing for FTR management. By contrast, a small number of Group A herbicides (all members of the fop class) can be effective against FTR, but need to be managed within a number of constraints:

- Although they can provide high levels of efficacy on fresh and seedling FTR, they need to be followed by a paraquat double-knock to get consistent high levels of final control.

- Group A herbicides give a high risk of resistance selection, and require follow-up treatment with paraquat.
- Many Group A herbicides have plant-back restrictions for cereal crops.
- With Group A herbicides, there is generally a narrow range of growth stages when weeds can be sprayed successfully, so they will generally give unsatisfactory results on flowering and/or moisture-stressed FTR.
- Not all Group A herbicides are effective on FTR.

For information on a permit (PER12941) issued for Queensland only for the control of FTR in summer fallow situations prior to planting mungbeans, see the website of the Australian Pesticides and Veterinary Medicines Authority ([APVMA](#)).

Timing of the second application for FTR is still being refined, but application at ~7–14 days generally provides the most consistent control. Application of paraquat at shorter intervals can be successful, when the Group A herbicide is translocated rapidly through the plant, but has resulted in more variable control in field trials. Good control can often be obtained up to 21 days after the initial application.

6.3.4 Windmill grass

Key points:

- Glyphosate alone or glyphosate followed by paraquat generally have poor efficacy.
- Preliminary data suggest that residual chemistry may provide some benefit.
- A double-knock of quizalofop-p-ethyl (e.g. Targa) followed by paraquat can be used in NSW.

While FTR has been a grass weed threat that originated in Queensland and is heading south, windmill grass is more of a problem in central NSW that is spreading north. Windmill grass is a perennial, native species found throughout northern NSW and southern Queensland (Photo 5). The main cropping threat appears to be from the selection of glyphosate-resistant populations, with control at the tussock stage providing most management challenges.



Photo 5: Windmill grass plant and seed head.

Source: Native Seeds

Resistance levels

Glyphosate resistance has been confirmed in windmill grass with three documented cases in NSW, all west of Dubbo. Glyphosate-resistant populations of windmill grass in other states have all been collected from roadsides, but in central-western NSW, two were from fallow paddocks.

Residual herbicides in fallow and in the crop

Preliminary trials have shown that some residual herbicides have useful levels of efficacy against windmill grass. These have potential for both fallow and crop situations, but currently there are no products registered for residual control of windmill grass.

Double-knock control

A double-knock of a Group A herbicide followed by paraquat has provided clear benefits compared with the disappointing results usually achieved by glyphosate followed by paraquat. Constraints apply to double-knock for windmill grass control similar to those for FTR.

The timing of the second application for windmill grass is still being refined, but for now application at ~7–14 days generally provides the most consistent control. Application of paraquat at shorter intervals can be successful when the Group A herbicide is translocated rapidly through the plant, but has resulted in more variable control in field trials and has been clearly antagonistic when the interval is one day or less. Good control can often be obtained up to 21 days after the application of the first herbicide.¹⁷ The APVMA site will also give you information on label rates.

6.3.5 Non-herbicide weed control in the Northern Region

Diversity in cropping systems and diversity in weeds in the GRDC Northern Region calls for diversity in weed management solutions, which includes the utilisation of non-herbicide tactics.

Survey work in the region has identified over 70 weed species that have an impact on grain production, and over 10% of these have confirmed populations in Australia that are resistant to glyphosate and several other chemical modes of action (Table 2).¹⁸

Table 2: Confirmed herbicide resistance in weeds found in NSW and Queensland.

Mode of action	Resistant weeds
A (fops, dims, dens)	Wild oats, paradoxa grass, annual ryegrass
B (SUs, imis, etc.)	Annual ryegrass, wild oats, paradoxa grass, Indian hedge mustard, charlock, wild radish, turnip weed, African turnip weed, common sowthistle, black bindweed
C (triazines, ureas, amides, etc.)	Awnless barnyard grass, liverseed grass
D (DNAs, benzamides, etc.)	Annual ryegrass
I (phenoxy, pyridines, etc.)	Wild radish
L (bipyridyls, i.e. diquat, paraquat)	Flaxleaf fleabane
M (glycines, i.e. glyphosate)	Annual ryegrass, awnless barnyard grass, liverseed grass, windmill grass, feathertop Rhodes grass, sweet summer grass, flaxleaf fleabane, common sowthistle
Z (dicarboxylic acids, etc)	Wild oats

Source: WeedSmart

¹⁷ Daniel R. (2013) Weeds and resistance—considerations for awnless barnyard grass, Chloris spp. and fleabane management. Northern Grower Alliance, <http://www.nga.org.au/module/documents/download/22>

¹⁸ WeedSmart (2017) Non-herbicide weed control in the Northern Region. WeedSmart, <http://weedsmart.org.au/non-herbicide-weed-control-in-the-northern-region/>

A recent survey of common sowthistle determined populations as glyphosate-resistant if treated seedlings were surviving and reshooting 21 days after the application of glyphosate. In this testing, glyphosate had been applied at the upper label rate for small plants (up to five leaves). While most of the common sowthistle samples collected in an area from central Queensland to central NSW were still susceptible to label rates of glyphosate when applied to small seedlings, resistant populations were found throughout the study area, showing that this is not a localised problem but rather the inevitable result of over-reliance on a particular herbicide.

Most Northern Region weeds are self-pollinated, so resistant plants will produce resistant seed. To reduce the likelihood of resistance, a key approach is to use multiple tactics to maintain low weed numbers. While weed numbers are low so too is the risk of resistant genes being present in the population.

Keeping these 'difficult to control' weeds in check will clearly require non-herbicide tactics to reduce germination and weed seedset. Queensland Department of Agriculture and Fisheries (DAF Queensland) researchers have been studying common weeds, particularly feathertop Rhodes grass, barnyard grass and common sowthistle, to find weaknesses in each weed's ecology to help identify non-chemical controls that could become part of an effective management system. The DAF Queensland weed research team is concentrating on non-chemical options, including cover crops, crop competition, strategic tillage, strategic burning, and harvest weed-seed controls.

Weeds researchers recognise that although growers are making good use of chemical strategies such as double-knock, residual herbicides, spot spraying and weed-sensing technology to preserve the efficacy of herbicides for as long as possible, there remains an urgent need to investigate non-chemical options that can be added to a weed management program to target resistant weeds, as outlined in the [WeedSmart 10 Point Plan](#).

Strategic tillage

Most growers are keen to preserve their zero- or minimum-till farming systems because they have delivered significant benefits, and are understandably reluctant to re-introduce cultivation to control weeds. Research is under way to investigate ways to use cultivation that will have maximum effect on driving down weed numbers while having least impact on minimum-till farming. The aim of this research is to investigate the impact of different types of tilling where the weed population has blown out and intensive patch or paddock management is required.

The key is to understand weed ecology, particularly how seed in the soil seedbank responds to different types of cultivation. Researchers used small plots to determine the effect of burying weed seeds on their persistence (long-term viability after burial in soil) and emergence. They also experimented to determine the displacement of seed throughout the cultivated zone using four different types of machine—harrows, Gyrals, off-set discs and one-way discs—compared to a zero-till control.

Sowthistle emergence occurs primarily from seeds close to the soil surface, with up to 30% of viable seeds emerging over five months.

Seed persistence in fleabane was most reduced when seed was buried to 2 cm and left undisturbed for at least two years. Seed buried to a depth of 10 cm remained viable for over three years.

Feathertop Rhodes grass seed persisted for only 12 months regardless of being left on the surface or buried to 10 cm.

Barnyard grass however, persisted on the soil surface for up to two years, and when buried to 10 cm depth remained viable for over three years.

The Gyrals machine placed the majority of weed seed in the 0–2 cm and 2–5 cm zones while the offset discs and one-way discs achieving burial of about half the seed below 5 cm depth.

All species responded to increased tilling intensity with reduced germinations. The message from this research is that infrequent but intense cultivation can be a useful weed-management tool within an otherwise zero-till system. Generally, once a paddock has been deeply cultivated there should be no cultivation of that area or paddock for at least four years so as to avoid the risk of bringing seed back to the soil surface.

Strategic burning

Feathertop Rhodes grass is known to colonise around mature plants, and may spread from here to form distinct weedy patches. Once it gets this big, killing the large plant at the centre of the colony is usually not possible using chemical treatments.

In this situation, the strategic burning of early infestations can effectively reduce the biomass of the part of the colony that survives and reduce the amount of viable seed present on the soil surface from 7,500 seeds/m² to less than 500 seeds/m². Growers have made effective use of a flame-thrower to burn large feathertop Rhodes grass plants during the fallow (Photo 6).



Photo 6: Strategic burning of feathertop Rhodes grass in a fallow can be an effective way of reducing the biomass of the survivor plant and of reducing the amount of viable seed on the soil surface.

Source: WeedSmart

Crop competition

Using crop competition by planting with a narrower row spacing and or greater planting density provides an effective offensive against common sowthistle and flaxleaf fleabane.

In recent tests, researchers looked at the effect of crop competition on its own, but realized that in commercial situations crop competition would have to be used in conjunction with herbicide. Narrowing wheat rows from a spacing of 50 cm to 25 cm had the most marked effect on fleabane seed-head production, with an added advantage that the crop density also increased from 50 plants/m² to 100 plants/m² (Figure 2 and Photo 7).

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

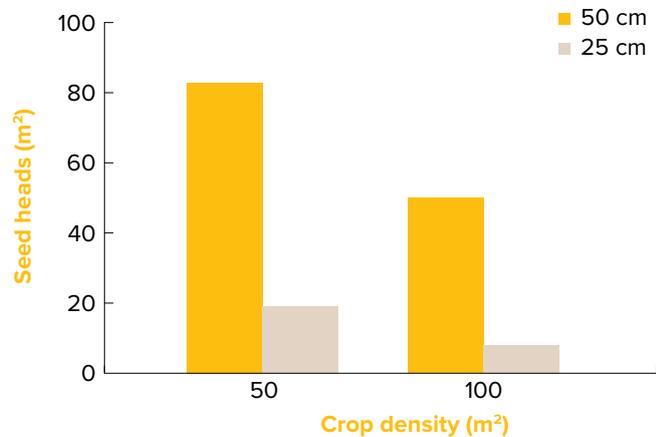


Figure 2: Fleabane seed-head production is dramatically curtailed when the crop is planted more densely.

Source: WeedSmart



Photo 7: Crop competition through narrower row spacing and or increased planting density provides an effective offensive against common sowthistle and flaxleaf fleabane.

Source: WeedSmart

i MORE INFORMATION

[Non-herbicide weed control in the Northern region](#)

Cover crops

Growers using summer for fallowing paddocks rely heavily on glyphosate as a chemical fallow to control summer grasses. Cover crops are primarily grown to provide soil cover and help increase water infiltration and decrease evaporation. In preliminary research, the use of cover crops to replace the chemical fallow has been explored. Crops such as cowpeas, lablab and French millet have the potential to smother summer-growing weeds, particularly barnyard grass and feathertop Rhodes grass, and return large amounts of organic biomass to the soil.¹⁹

¹⁹ WeedSmart (2017) Non-herbicide weed control in the Northern Region. WeedSmart, <http://www.weedsmart.org.au/bulletin-board/non-herbicide-weed-control-in-the-northern-region/>

6.4 Key weeds of Australia's cropping systems

Section 8 of GRDC's contains profiles of the common weeds of Australian crops: ²⁰

- annual ryegrass (*Lolium rigidum*)
- barley grass (*Hordeum* spp.)
- barnyard grasses (*Echinochloa* spp.)
- black bindweed (*Fallopia convolvulus*)
- bladder ketmia (*Hibiscus trionum*)
- brome grass (*Bromus* spp.)
- capeweed (*Arctotheca calendula*)
- doublegee (*Emex australis*)
- feathertop Rhodes grass (*Chloris virgata*)
- fleabane (*Conyza* spp.)
- fumitory (*Fumaria* spp.)
- Indian hedge mustard (*Sysimbrium orientale*)
- liverseed grass (*Urochloa panicoides*)
- muskweed (*Myagrum perfoliatum*)
- paradoxa grass (*Phalaris paradoxa*)
- silver grass (*Vulpia* spp.)
- sweet summer grass (*Brachiaria ericuformis*)
- turnip weed (*Rapistrum rugosum*)
- wild oats (*Avena fatua* and *Avena ludoviciana*)
- wild radish (*Raphanus raphanistrum*)
- windmill grass (*Chloris truncata*)
- wireweed (*Polygonum aviculare* and *Polygonum arenastrum*)

IN FOCUS

RIM (Ryegrass Integrated Management)

RIM (Ryegrass Integrated Management) is software that provides insights into the long-term management of annual ryegrass in dryland broadacre crops where herbicide resistance is developing. RIM enables users to test different tactics for ryegrass management and observe their predicted impacts on ryegrass populations, crop yields and long-term economic outcomes. It can be used at paddock scale, and over short and long time scales. The underlying model of the software integrates biological, agronomic and economic considerations in a dynamic and user-friendly framework.

The tool tracks the changes through time on a 10-year crop cycle for ryegrass seed germination, seed production and competition with the crop. Financial returns are also estimated annually and as a 10-year average return.

A wide variety of chemical and non-chemical weed treatment options are included, so that as chemicals are lost to herbicide resistance, the next-best substitute can be identified.

To do this by trial and error in the real world, rather than in a computer simulation, would take many years and may leave farmers with a major weed problem they could have avoided. With RIM, farmers and others can

²⁰ GRDC (2014) Section 8. Profiles of common weeds of cropping. GRDC, <https://grdc.com.au/resources-and-publications/iwmhub/common-weeds-of-cropping>

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

MORE INFORMATION

[Ryegrass Integrated Management](#)

VIDEOS

WATCH: [Managing herbicide resistant ryegrass with IWM](#)



conduct virtual experiments with a range of treatment options before they put real dollars at risk.

RIM can help farmers to tackle questions such as:

- How much income will I lose once resistance develops?
- Which combination of strategies provides the best overall system once resistance is present?
- Is it worth trying to delay the onset of resistance by using herbicides less frequently?
- Is it economically viable to maintain a continuous cropping rotation once resistance occurs?
- If a pasture phase is included, how long should it be?

6.5 Herbicides

Chemical weed controls in triticale varieties are in general similar to those for wheat, although some differences in tolerances are important. In all states, the agriculture department produces a publication giving recommended herbicide usage. This should be consulted before using herbicides with triticale.

It is important that care is taken to ensure crop and weed tolerances based on the label recommendations are adhered to. Additionally, weather conditions, herbicide rates, water-dilution rates, and the status of adjoining crops need to be assessed and managed correctly. A range of chemicals is registered for use in both wheat and triticale, but some other herbicides are only legal for use in wheat. And for triticale, some herbicides are only legal to use at specific crop stages.²¹

6.5.1 Herbicides explained

When selecting a herbicide, it is important to know crop growth stage, weeds present and plant-back period. For best results, spray weeds while they are small and actively growing. Herbicides must be applied at the correct stage of crop growth, or significant yield losses may occur. Check product labels for up-to-date registrations and application methods.

Residual and non-residual herbicides

Residual herbicides remain active in the soil for months, and can act on successive germinations of weeds. Residual herbicides are absorbed through the roots or shoots, or both. Examples of residual herbicides are imazapyr, chlorsulfuron, atrazine and simazine. The persistence of residual herbicides is determined by several factors, such as application rate, soil texture, organic matter levels, soil pH, rainfall and irrigation, temperature, and the characteristics of the herbicide. Persistence of herbicides will affect the cropping sequence in the enterprise.

Non-residual herbicides, such as the non-selective paraquat and glyphosate, have little or no soil activity, and are quickly deactivated in the soil. They are either broken down or bound to soil particles, which make them less available to growing plants. They also may have little or no ability to be absorbed by roots.

²¹ RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Rethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report.pdf

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [Over the Fence North: Weed and nutrient research delivers at Silverton](#)



WATCH: [GCTV17: Herbicide partnership](#)



Pre-emergent and post-emergent herbicides

Pre-emergent and post-emergent herbicides are chemicals that are utilised to fit in with the timing of plant growth. Pre-emergent refers to the application of the herbicide to the soil before the weeds have emerged, and post-emergent to foliar application of the herbicide after the target weeds have emerged from the soil.²²

Herbicide groups

Herbicides have been classified into a number of groups that refer to the way a chemical works: their different chemical make-up and mode of action (Table 3).²³

Table 3: *Herbicide groups and examples of chemical products in each group.*

Group	Common chemicals in the group
Group A	Hoegrass®, Nugrass®, Digrass®, Verdict®, Targa®, Fusilade®, Puma S®, Tristar®, Correct®, Sertin®, Grasp®, Select®, Achieve®, Gallant®, Topik®
Group B	Glean®, Chlorsulfuron, Siege®, Tackle®, Ally®, Associate®, Logran®, Nugran®, Amber Post®, Londax®, Spinnaker®, Broadstrike®, Eclipse®, Renovate®
Group C	Simazine, Atrazine, Bladex®, Igran®, Metribuzin, Diuron, Linuron, Tribunil®, Bromoxynil, Jaguar®, Tough®
Group D	Trifluralin, Stomp®, Yield®, Surflan®
Group E	Avadex®, BW, EPTC, Chlorpropham
Group F	Brodal®, Tigrex®, Jaguar®
Group H	Saturn®
Group I	2,4-D, MCPA, 2,4-DB, Dicamba, Tordon®, Lontrel®, Starane®, Garlon®, Baton®, Butress®, Trifolamine®
Group K	Dual®, Kerb®, Mataven®
Group L	Reglone®, Gramoxone®, Nuquat®, Spraytop®, Sprayseed®
Group M	Glyphosate, Glyphosate CT®, Sprayseed®, Roundup CT®, Touchdown®, Pacer®, Weedmaster®

Notes. List of commonly used products only. List of products does not necessarily imply state registration. Check that product is registered in your state before use. Groups G and J not included.

Source: Agriculture Victoria

6.6 Pre-emergent herbicides

Triticale is competitive against weeds once it is established. If needed, a pre-emergent knockdown should be applied, as there are limited options available post-emergence. Ideally, a non-selective knockdown should be used when sowing main season varieties to reduce the reliance on post-emergent herbicides.²⁴ There are some herbicide options available against both grass and broadleaf weeds.²⁵

A non-selective knockdown should be used in early AND main sown crops—it is a cheap way to control early weeds that does not cause crop damage.

Agronomist's view

22 GRDC Integrated weed management, Section 4: Tactics for managing weed populations. GRDC, <https://grdc.com.au/resources-and-publications/iwmhub>

23 Agriculture Victoria. Herbicide resistance and integrated weed management (IWM) in crops and pasture monitoring tools. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/herbicide-resistance>

24 Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkrcr.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

25 AGF Seeds. Triticale. AGF Seeds, <https://agfseeds.com.au/triticale>

Pre-emergent herbicides control weeds between radicle (root shoot) emergence from the seed and seedling emergence through the soil. Some may also provide post-emergent control.

6.6.1 Benefits and concerns

- The residual activity of pre-emergent herbicides controls the first few flushes of germinating weeds while the crop or pasture is too small to compete.
- Good planning is needed to use pre-emergent herbicides as an effective tactic. It is necessary to consider weed species and density, crop or pasture type, soil condition, and the rotation of crop or pasture species.
- Soil activity and environmental conditions at the time of application play an important role in the availability, activity and persistence of pre-emergent herbicides.
- Both the positive and negative aspects of using pre-emergent herbicides should be considered in the planning phase.²⁶

The important factors in getting pre-emergent herbicides to work effectively while minimising crop damage are:

- to understand the position of the weed seeds in the soil;
- the soil type (particularly amount of organic matter and crop residue on the surface);
- the solubility of the herbicide; and
- its ability to be bound by the soil.

6.6.2 Understanding pre-emergent herbicides

With the increasing incidence of resistance to post-emergent herbicides across Australia, pre-emergent herbicides are becoming more important for weed control. There are typically more variables that can affect their efficacy than for post-emergent herbicides. Post-emergent herbicides are applied when weeds are present and usually the main considerations relate to application coverage, weed size and environmental conditions that impact on performance. Pre-emergent herbicides are applied before the weeds germinate and a number of other considerations come into play. The various pre-emergent herbicides behave differently in the soil, and may behave differently in different soil types. Therefore, it is essential to understand the behaviour of the herbicide, the soil type and the farming system in order to use pre-emergent herbicides in the most effective way.

Pre-emergent herbicides have to be absorbed from the soil by the germinating seedling. So that this can happen, these herbicides need to be at least partly soluble in water and be in a position in the soil where the roots or emerging shoot can come across them. The dinitroaniline herbicides, such as trifluralin, are an exception in that they are absorbed by the seedlings as a gas. These herbicides still require water in order to be activated as a gas. Therefore, weed control with pre-emergent herbicides will always be lower under dry conditions.

Behaviour of pre-emergent herbicides in the soil

The behaviour of pre-emergent herbicides in the soil is driven by three key factors:

- the solubility of the herbicide;
- how tightly the herbicide binds to soil components; and
- the rate of breakdown of the herbicide in the soil.

The characteristics of some common pre-emergent herbicides are given in Table 4.

The water solubility of herbicides ranges from very low values for trifluralin to very high values for chlorsulfuron. Water solubility influences how far the herbicide will move in the soil profile in response to rainfall events. Herbicides with high solubility

26 DAFWA (2016) Herbicides. DAFWA, <https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C2>

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

are at greater risk of being moved into the crop seed row by rainfall and potentially causing crop damage. If the herbicides move too far through the soil profile they risk moving out of the weed root zone and failing to control the weed species at all. Herbicides with very low water solubility are unlikely to move far from where they are applied.

Table 4: Water solubility, binding characteristics, and degradation half-life of some common pre-emergent herbicides.

Herbicide	Water solubility		Koc		Degradation half-life (days)
	mg/L-1 (at 20°C and neutral pH)	Rating	mL/g-1 (in typical neutral soils)	Rating	
Trifluralin	0.22	Very low	15,800	Very high	181
Pendimethalin	0.33	Very low	17,800	Very high	90
Pyroxasulfone	3.9	Low	223	Medium	22
Triallate	4.1	Low	3000	High	82
Prosulfocarb	13	Low	2000	High	12
Atrazine	35	Medium	100	Medium	75
Diuron	36	Medium	813	High	75.5
S-metolachlor	480	High	200	Medium	15
Triasulfuron	815	High	60	Low	23
Chlorsulfuron	12,500	Very high	40	Low	160

The values are for the Koc, the soil organic carbon-water partitioning coefficient. High Koc values mean that more herbicide will be bound to organic matter and less herbicide will be available to move in the soil solution.

Source: GRDC

It is complex managing all the factors that result in the herbicide working effectively, without damage to the crop, but some rules of thumb are:

- Soils with low organic matter, especially sandy soils, are particularly prone to crop damage from pre-emergent herbicides, and rates should be reduced where necessary to lower the risk of crop damage.
- The more water-soluble herbicides will move more readily through the soil profile, and are better suited to post sowing pre-emergent applications than the less water-soluble herbicides. They are also more likely to produce crop damage after heavy rain.
- Pre-emergent herbicides need to be at sufficient concentration at or below the location of the weed seed (except for triallate which needs to be above the weed seed) to provide effective control. Keeping weed seeds on the soil surface will improve control by pre-emergent herbicides.
- High crop-residue loads on the soil surface will impair the effectiveness of pre-emergent herbicides as they keep the herbicide from contact with the seed. More water-soluble herbicides cope better with crop residue, but the solution is to manage crop residue so that at least 50% of the soil surface is exposed at the time of application.
- If the soil is dry on the surface but moist underneath there may be sufficient moisture to germinate the weed seeds, but not enough to activate the herbicide. Poor weed control is likely under these circumstances. The more water-soluble herbicides are less adversely affected under these conditions.
- Many pre-emergent herbicides can cause crop damage. Separation of the product from the crop seed is essential. In particular, care needs to be taken

i MORE INFORMATION[Understanding pre emergent cereal herbicides](#)[Using pre-emergent herbicides in conservation farming systems](#)[Gearing up to use pre-emergent herbicides](#)[GRDC factsheet, Pre-emergent herbicides](#)[How pre-emergent herbicides work](#)[Seeding systems and pre emergence herbicides](#)

with disc seeding equipment in choice of product and maintaining an adequate seeding depth.²⁷

6.6.3 Top tips for using pre-emergent herbicides

- Only use pre-emergent herbicides as part of an integrated weed control plan that includes both chemical and non-chemical practices.
- Preparation starts at harvest. Minimise compaction and maximise trash spreading from the header.
- Minimise soil disturbance so that weed seeds are more likely to remain on the soil surface.
- Leave stubble standing rather than laying it over.
- Knife points and press wheels allow greatest crop safety. Avoid harrows.
- If using a disc seeder understand the mechanics of your machine and its limitations compared to a knife point and press wheel. Note that not all pre-emergent herbicides are registered with disc machines so make sure to check the label prior to application.
- Pay attention to detail in your sowing operation and ensure soil throw on the inter-row while maintaining a seed furrow free of herbicide.
- Ensure the seed furrow is closed to prevent herbicide washing onto the crop seed.
- Ensure even seed placement, typically 3–5 cm of loose soil on top of seed in cereals, for best crop safety.
- Use incorporate by sowing (IBS) rather than post-sowing pre-emergent (PSPE) cropping for crop safety.
- Understand herbicide chemistry. Choose the right herbicide in the right paddock at the right rate.²⁸

6.6.4 Incorporation by sowing

Incorporation by sowing (IBS) is when a herbicide is applied just before sowing (usually in conjunction with a knockdown herbicide such as glyphosate and soil throw from the sowing operation incorporates the herbicide into the seedbed.

This is the preferred method of applying pre-emergent herbicides in conservation farming systems, as crop safety is maximised, stubble remains standing to protect the seedbed, and soil disturbance is minimised.

Applying pre-emergent herbicides before sowing and then incorporating them into the seedbed during planting usually increases the safety of the crop because the sowing operation moves a certain amount of herbicide away from the seed row. Sowing can reduce weed control for the same reason. In this case, it is wise to include a water-soluble herbicide into the mix aiming to have some herbicide wash into the seed furrow.

Two trials were conducted in 2013 to evaluate the crop safety and efficacy of registered residual herbicides for the control of annual ryegrass in wheat. This work was conducted due to concerns about commercial crop safety. The majority of treatments were managed by using IBS, which specifies the use of narrow-point tyres on the planting equipment. This approach helps to ensure sufficient soil is thrown across the inter-row space to effectively incorporate the herbicide, add it removes most of the herbicide-treated soil from the planting furrow, thus improving crop safety. The negative consequence is that IBS generally provides poor weed control in the zone immediately around the planting row. In many cases, PSPE application is also being evaluated as it provides more uniform weed efficacy but requires herbicides or

27 C Preston (2014) Understanding pre-emergent cereal herbicides. GRDC Update Paper. GRDC, <https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2014/03/understanding-pre-emergent-cereal-herbicides>

28 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW DPI, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

rates with improved crop safety together with reduced incorporation characteristics. The main results of the study were that:

- The use of a disc planter for IBS of residual herbicides resulted in significantly reduced wheat emergence for all four herbicides evaluated.
- The disc planter set up actually increased the risk of crop damage (Figure 3).²⁹
- The results reinforce the need to only use narrow-point tynes when using residual herbicides with IBS.

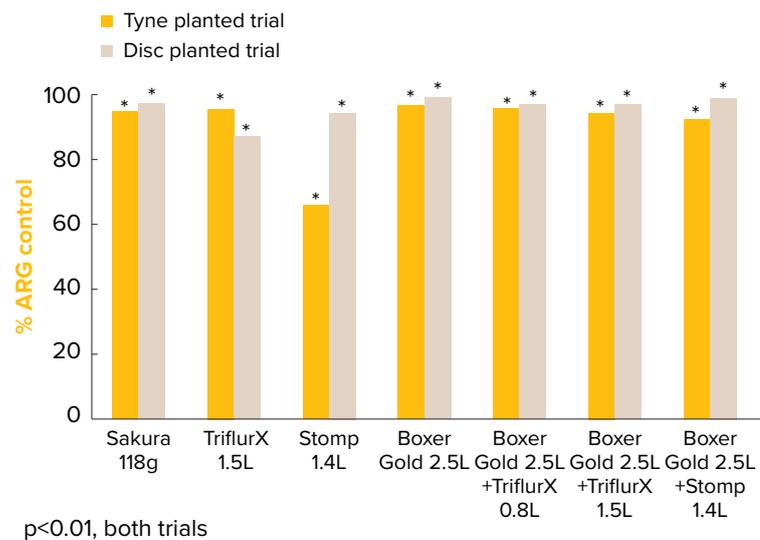


Figure 3: Per cent annual ryegrass control based on counts taken 94 days after planting, on 22 September 2013.

UTC = untreated control. All treatments applied in 70 L/ha total volume using AIXR110015 nozzles at 300 kPa * = significant annual ryegrass control compared to untreated within same trial. Source: GRDC

During the trials, the researchers noted variations in efficacy, depending on treatment:

- High levels of annual ryegrass control were achieved by most IBS treatments.
- The most consistent products were Boxer Gold® or Sakura®.
- Weed control from Boxer Gold® was significantly reduced in one of the two trials when applied by PSPE.

The trials highlighted problems with the use of disc planters:

- Crop safety was significantly reduced when a disc planter was used for incorporation.
- The disc set up appeared to have exacerbated crop safety concerns by planting seed in an area of greater herbicide concentration.
- In this scenario, observation suggested that small differences in planting depth may have made a difference to crop safety.

This work reinforces some of the difficulties growers (and agronomists) face with the use of residual herbicides. Crop safety and efficacy are influenced by a range of factors including planting equipment, planting depth, soil type and stubble load, together with how much rain falls and when. More research is needed to give everyone in the industry a more thorough understanding of the impact of these

²⁹ R Daniel, A Mitchell (2014) Pre-emergent herbicides part of the solution but still much to learn. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Pre-emergent-herbicides-part-of-the-solution-but-much-still-to-learn>

i MORE INFORMATION

Weed control in winter crops 2016, Table 12. [Herbicides for pre-emergent and post-sowing pre-emergent weed control](#)

factors (and perhaps others) to ensure not only that weed management tools are effective, but that they remain effective for decades to come.³⁰

6.7 Post-sowing pre-emergent herbicides

Post-sowing pre-emergent (PSPE) herbicides are, as the name indicates, applied to the seedbed after sowing and before the crop emerges. Post-sown pre-emergent herbicides are absorbed primarily through the roots, but there may also be some foliar absorption (e.g. with Terbyne®). When applied to soil, best control is achieved when the soil is flat and relatively free of clods and trash. Sufficient rainfall (20–30 mm) to wet the soil through the weed root zone is necessary within two or three weeks of application. The best weed control is achieved from PSPE application because rainfall improves incorporation. Mechanical incorporation pre-sowing is less uniform, and so weed control may be less effective. If applied pre-sowing and sown with minimal disturbance, incorporation will essentially be by rainfall after application. Weed control in the sowing row may be less effective because a certain amount of herbicide will be removed from the crop row.

6.8 In-crop herbicides: knockdowns and residuals

Knockdown and residual herbicides control weeds that have emerged after crop or pasture establishment, and can be applied with little damage to the crop or pasture plants.

There are numerous herbicide options for early post-emergent and late post-emergent control of broadleaf weeds; however, there are only early-post emergent control options for grass weeds.³¹

The benefits are:

- Post-emergent herbicides give high levels of target weed control, with the additional benefit of improved crop or pasture yield.
- Observations made just before application allow fine-tuning of herbicide selection to match the weeds present.
- The timing of application can be flexible to suit weed size, the stage of crop growth and environmental conditions.

To avoid problems emerging from the use of these herbicides:

- Carefully consider the best post-emergent herbicide to use in any one situation.
- Choose the most suitable formulation of herbicide for each situation.
- Application of post-emergent herbicides to stressed crops and weeds can result in reduced levels of weed control and increased crop damage.
- Crop competition is important for effective weed control when using selective post-emergent herbicides.
- The technique used for application must be suited for the situation in order to optimize control.
- Always use the correct adjuvant to ensure effective weed control.
- The effectiveness of post-emergent herbicides is influenced by a range of plant and environmental factors.³²

6.8.1 Applying in-crop herbicides

When applying in-crop herbicides:

³⁰ R Daniel, A Mitchell (2014) Pre-emergent herbicides part of the solution but much still to learn. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Pre-emergent-herbicides-part-of-the-solution-but-much-still-to-learn>

³¹ Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkrcr.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

³² DAFWA (2016) Herbicides. DAFWA, <https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C2>

SECTION 6 TRITICALE**TABLE OF CONTENTS****FEEDBACK**

- Knowledge of a product's translocation and formulation type is important for selecting nozzles and application volumes.
- Evenness of deposit is important for poorly or slowly translocated products.
- Crop growth stage, canopy size and stubble load should influence decisions about nozzle selection, application volume and sprayer operating parameters.
- Travel speed and boom height can affect control and the likelihood of drift.
- Appropriate conditions for spraying are always important.

Uptake, translocation and application volume

Products that have a slow uptake or slow or limited translocation (such as Group A herbicides) should be applied at higher water rates (typically 70–100 L/ha in cereals and higher in many pulses).

Products that are phloem and xylem transported (such as Groups B, i and M herbicides) can often be applied at lower application volumes—50–70 L/ha in low stubble situations and small crop canopy—but normally need to be applied at 70 L/ha or more where high stubble loads exist or the crop canopy is dense. Always check product labels and the manufacturer's technical information for specific advice about appropriate application volumes and timing in relation to a crop's growth stage.

Water volume and spray quality

Depositing droplets onto foliar targets is a numbers game. Increasing application volumes produces more droplets, which usually increases the evenness of the application, provided droplets reach where they are required. Anything that is situated between the nozzle and the desired target weed, such as stubble or a large crop canopy, has the potential to intercept spray droplets. Where crop canopies are large or stubble load is heavy, it is always advisable to use robust or higher water rates. More droplets can be produced by decreasing the droplet size. However, fine spray qualities do not penetrate dense canopies as well as medium spray qualities from non-air induction nozzles or air inducted coarse droplets (unless they are used with an air-assisted spray system). Finer spray qualities also increase spray drift risk and are likely to be intercepted by stubble when the load is high.

Adjuvant choice

Choosing the most appropriate adjuvant can improve control, whereas the wrong adjuvant choice may reduce it. Non-ionic surfactants will generally improve droplet spread on the leaf surface and normally will not adversely interact with products. However, a non-ionic may not improve product performance in situations where an oil-based adjuvant is recommended due to the way oil-based products are absorbed into the plant. Oil-based adjuvants are usually mixed with oil-based formulations, some emulsifiable concentrates and some low volatile ester-based formulations. The addition of oil-based surfactants to water-soluble products such as glyphosate is not recommended by most manufacturers. Always check the label recommendations and the manufacturer's recommendations about the most suitable adjuvant for mixing with a particular product.

Interactions between nozzle type and formulation or adjuvants

When it comes to choosing a nozzle, select the nozzle size to deliver the desired volume, but choose the nozzle type to produce the desired pattern and spray quality. Most product labels will suggest either a medium or larger spray quality, or a coarse or larger spray quality. When a medium spray quality is required, it is often best to do this with a standard pre-orifice (low drift) nozzle or a larger orifice flat fan (capable of producing a medium spray quality). This is particularly important where labels specify that only a medium spray quality can be used, or when oil-based formulations or adjuvants are to be used.

In some instances, oil-based formulations and adjuvants have the ability to collapse the air within the droplets produced by air induction nozzles, especially when they are operated at the lower end of their pressure range and the spray quality

approaches the larger end of the coarse spectrum (towards very coarse). This becomes an issue when speeds are reduced at the ends of paddocks, around trees and over contours, when the automatic rate controller reduces the pressure to maintain the application rate. Using the minimum hold (or lower limit function) in the controller can reduce this, but can also encourage overdosing leading to crop damage.

In some instances, using larger headlands can help to reduce overdosing. In other situations where larger headlands cannot be achieved, a small increase in application volume can reduce the speed at which the minimum hold engages, which reduces the amount of overdosing.

When operated at the high end of their pressure range some air induction nozzles produce medium droplets. When a nonionic surfactant is used with an air induction nozzle, it is possible to produce less-dense droplets that have the potential to drift due to the air inclusion within the droplet. In some instances, air induction nozzles producing air-filled medium droplets may actually drift more than other nozzle types that don't include air, such as standard orifice or low-drift nozzles.

Travel speed and nozzle design

Travel speed and nozzle design can affect coverage and the evenness of application. With standard nozzle patterns that face straight down, as travel speed increases the net droplet movement is often in a forward direction, which can result in more droplets depositing on one side of the weed, or increasing retention on stubble. The use of offset (angled) nozzles or twin designs can improve the evenness of deposition, provided the travel speed is not excessive. Control-based trials in fallow have shown that a number of angled and twin designs perform well at speeds up to 21 km/h. Overseas control-based trials have also shown more even deposition from angled or twin nozzles compared with standard patterns that face directly downwards.³³

How to get the most out of post-emergent herbicides

Consider the timing of the spray: the younger the weeds, the better. Frequent crop monitoring is critical.

Also consider the growth stage of the crop:

- Consider the crop variety being grown and applicable herbicide tolerances.
- Know which species were historically in the paddock and the resistance status of the paddock (and if unsure, send plants away for a [Quick-Test](#)).
- Do not spray a crop stressed by waterlogging, frost, high or low temperatures, drought or, for some chemicals, cloudy or sunny days. This is especially pertinent for frosts with grass-weed chemicals.
- Use the correct spray application:
- Consider droplet size with grass-weed herbicides, water volumes with contact chemicals and time of day.
- Observe the plant-back periods and withholding periods.
- Consider compatibility if using a mixing partner.
- Add correct adjuvant.³⁴

6.9 Conditions for spraying

When applying herbicides, the aim is to maximise the amount of chemical that reaches the target and to minimise the amount reaching off-target areas. This results in:

- improved herbicide effectiveness

i MORE INFORMATION

GRDC factsheet, [In-crop herbicide use](#)

GRDC factsheet, [Pre-harvest herbicide use factsheet](#)

³³ GRDC (2014) In-crop herbicide use Factsheet. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/08/grdc-fs-incropherbicideuse>

³⁴ WeedSmart. Post-emergents. WeedSmart, <http://www.weedsmart.org.au/post-emergents/>

- reduced damage and/or contamination of off target crops and areas

In areas where a range of agricultural enterprises coexist, conflicts can arise, particularly from the use of herbicides. All herbicides are capable of drifting. When spraying an herbicide, you have a moral and legal responsibility to prevent it from drifting into and contaminating or damaging neighbours' crops and other sensitive areas. Record weather conditions, herbicide and water rates, and operating details for each paddock.

Any of the following stress conditions can significantly impair both uptake and translocation of the herbicide within the plant, which is likely to result in an incomplete kill or only suppression of weeds:

- Moisture stress and drought.
- Waterlogging.
- High temperature, low humidity conditions.
- Extreme cold or frosts.
- Nutrient deficiency, especially of nitrogen.
- Use of pre-emergent herbicides that affect growth and root development; i.e. simazine, Balance®, trifluralin, and Stomp®.
- Excessively heavy dews resulting in poor spray retention on grass leaves.

6.9.1 Minimising spray drift

Before spraying:

- Always check for susceptible crops in the area (see Photo 8), for example broadleaf crops such as grape vines, cotton, vegetables and pulses, if you are using a broadleaf herbicide. The [Cotton Map](#) is a resource to help growers minimise off-target damage from downwind herbicide and pesticide application.
- Check sensitive areas such as houses, schools, waterways and riverbanks.
- Notify neighbours of your spraying intentions.

During spraying:

- Always monitor weather conditions carefully and understand their effect on drift hazard.
- Don't spray if conditions are not suitable, and stop spraying if conditions change and become unsuitable.
- Record weather conditions (especially temperature and relative humidity), wind speed and direction, herbicide and water rates, and operating details for each paddock.
- Supervise all spraying, even when a contractor is employed. Provide a map marking the areas to be sprayed, buffers to be observed and sensitive crops and areas.
- Spray when temperatures are less than 28°C.
- Where surface temperature inversion conditions exist, it is unsafe for spraying due to the potential for spray drift.
- Maintain a downwind buffer. This may be in the crop, e.g. keeping a boom's width from the downwind edge of the paddock.
- Minimise spray release height.
- Use the largest droplets that will give adequate spray coverage.
- Always use the least-volatile formulation of herbicide available.
- If there are sensitive crops in the area, use the herbicide that is the least damaging.

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 8: *Triticale plants showing classic signs of damage from spray drift.*

Source: Delaware Valley University

6.9.2 Types of drift

Sprayed herbicides can drift as droplets, as vapours or as particles (Photo 9).



Photo 9: *Using a boom spray on the crop when there is only a very light breeze helps prevent spray drift.*

Source: DAFWA

Droplet drift is the easiest to control because, under good spraying conditions, droplets are carried down by air turbulence and gravity, to collect on plant or soil surfaces. Droplet drift is the most common cause of off-target damage caused by

herbicide application. For example, spraying fallows with glyphosate under the wrong conditions often leads to severe damage to establishing crops.

Particle drift occurs when water and other carriers of herbicides evaporate quickly from the droplet, leaving tiny particles of concentrated herbicide. This can occur with herbicide formulations other than esters. Instances of this form of drift have damaged susceptible crops up to 30 km from the source.

Vapour drift is confined to volatile herbicides such as 2,4-D ester. Vapours may arise directly from the spray or as a result of the herbicide evaporating from sprayed surfaces. Use of 2,4-D ester in summer can lead to vapour-drift damage of highly susceptible crops such as tomatoes, cotton, sunflowers, soybeans and grapes. This may occur hours after the herbicide has been applied.

In 2006, the federal regulator of pesticide use, the APVMA, restricted the use of highly volatile forms of 2,4-D ester. The changes are now seen with the substitution of lower volatile forms of 2,4-D and MCPA. Products with lower-risk ester formulations are commonly labelled LVE, short for low volatile ester. These formulations have a much lower tendency to volatilise (vaporise), but caution is still needed as they are still prone to droplet drift.

Vapours and minute particles float in the airstream and are poorly collected on catching surfaces. They may be carried for many kilometres in thermal updraughts before being deposited.

Surrounding crops may be far more sensitive to herbicides than the crops targeted for spraying. Even small quantities of drifting herbicide can cause severe damage to highly sensitive plants.

6.9.3 Factors influencing the risk of spray drift

Any herbicide can drift. The drift hazard, or off-target potential, of a herbicide in a particular situation depends on the following factors.

- Volatility of the formulation applied—volatility refers to the likelihood that the herbicide will evaporate and become a gas. Esters volatilise whereas amines do not.
- Proximity of crops susceptible to the particular herbicide being applied, and their growth stage. For example, cotton is most sensitive to Group I herbicides in the seedling stage.
- Method of application and equipment used. Aerial application releases spray 3 m above the target and uses relatively low application volumes, while ground rigs have lower release heights and generally higher application volumes, and a range of nozzle types. Misters produce large numbers of very fine droplets that use wind to carry them to their target.
- Size of the area treated—the greater the area treated the longer it takes to apply the herbicide. If local meteorological conditions change, particularly in the case of 2,4-D ester, then more herbicide is able to volatilise.
- Amount of active ingredient (herbicide) applied—the more herbicide applied per hectare the greater the amount available to drift or volatilise.
- Efficiency of droplet capture—bare soil does not have anything to catch drifting droplets, unlike crops, erect pasture species and standing stubbles.
- Weather conditions during and shortly after application.

Changing weather conditions can increase the risk of spray drift.

Volatility

Many ester formulations are highly volatile when compared with the non-volatile amine, sodium salt and acid formulations. Table 5³⁵ is a guide to the more common active ingredients of herbicides that are marketed in more than one formulation.

35 A Storrie, T Cook (2015) Reducing herbicide spray drift. Revised. NSW DPI, <http://www.dpi.nsw.gov.au/biosecurity/weeds/weed-control/herbicides/spray-drift>

Table 5: *Relative herbicide volatility.*

Form of active ingredient	Full name	Product example
Non-volatile		
<i>Amine salts</i>		
MCPA DMA	dimethyl amine salt	MCPA 500
2,4-D DMA	dimethyl amine salt	2,4-D Amine 500
2,4-D DEA	diethanolamine salt	2,4-D Amine 500 Low Odour®
2,4-D IPA	isopropylamine salt	Surpass® 300
2,4-D TIPA	triisopropanolamine	Tordon® 75-D
2,4-DB DMA	dimethyl amine salt	Buttress®
dicamba DMA	dimethyl amine salt	Banvel® 200
triclopyr TEA	triethylamine salt	Tordon® Timber Control
picloram TIPA	triisopropanolamine	Tordon® 75-D
clopyralid DMA	dimethylamine	Lontrel® Advanced
clopyralid TIPA	triisopropanolamine	Archer®
aminopyralid K salt	potassium salt	Stinger®
aminopyralid TIPA	triisopropanolamine	Hotshot®
<i>Other salts</i>		
MCPA Na salt	sodium salt	MCPA 250
MCPA Na/K salt	sodium & potassium salt	MCPA 250
2,4-DB Na/K salt	sodium & potassium salt	Buticide®
dicamba Na salt	sodium salt	Cadence®
Some volatility		
<i>Esters</i>		
MCPA EHE	ethylhexyl ester	LVE MCPA
MCPA IOE	isooctyl ester	LVE MCPA
triclopyr butoxyl	butoxyethyl ester	Garlon® 600
Picloram IOE	isooctyl ester	Access®
2,4-D ehe	ethylhexyl ester	2,4-D LVE 680
fluroxypyr M ester	meptyl ester	Starane® Advanced

Source: NSW DPI

6.9.4 Minimising drift

A significant part of minimising spray drift is the selection of equipment to reduce the number of small droplets produced. However, this in turn may affect coverage of the target, and therefore the possible effectiveness of the pesticide application.

As the number of smaller droplets decreases, so does the coverage of the spray. A good example of this is the use of air-induction nozzles that produce large droplets that splatter. These nozzles produce a droplet pattern and number that are unsuitable for targets such as seedling grasses, which present a small vertical target.

In 2010, the APVMA announced new measures to ensure the number of spray-drift incidents are minimised (Table 6).³⁶ The changes are restrictions on the droplet

³⁶ A Storrie, T Cook (2015) Reducing herbicide spray drift. Revised. NSW DPI, <http://www.dpi.nsw.gov.au/biosecurity/weeds/weed-control/herbicides/spray-drift>

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [IWM: Spray application of herbicides—nozzle selection](#)



WATCH: [IWM: Spray application of herbicides—travel speed](#)



WATCH: [IWM: Spray application of herbicides—spray deposition](#)



MORE INFORMATION

[Review speed and boom height to improve spray deposition](#)

size spectrum an applicator can use, the wind speed suitable for spraying, and the downwind buffer zone between spraying and a sensitive target. These changes should be evident on current herbicide labels. Hand-held spraying application is exempt from these regulations.

Table 6: Nozzle selection guide for ground application.

Factor	Distance downwind to susceptible crop is <1 km	Distance downwind to susceptible crop is 1–30 km and more
Risk	High	Medium
Preferred droplet size (to minimise risk)	coarse to very coarse	medium to coarse
Volume median diameter (microns)	310	210
Pressure (bars)	2.5	2.5
Flat fan nozzle size #	11008	11004
Recommended nozzles (examples only)	Raindrop: Whirljet® Air induction: Yamaho Turbodrop® Hardi Injet® Al Teejet® LurmarkDrift-beta®	Drift reduction: DG TeeJet® Turbo TeeJet® Hardi® ISO LD 110 Lurmark® Lo-Drift
Caution	Can lead to poor coverage and control of grass weeds Requires higher spray volumes	Suitable for grass control at recommended pressures Some fine droplets

Volume median diameter (VMD): 50% of the droplets are less than the stated size and 50% greater.

Refer to manufacturer's selection charts, as range of droplet sizes will vary with recommended pressure. Always use the lowest pressure stated to minimise the small droplets.

Source: DPI NSW

6.9.5 Spray release height

- Operate the boom at the minimum practical height. Drift hazard doubles as nozzle height doubles. If possible, angle nozzles forward 30° to allow lower boom height with double overlap. Lower heights, however, can lead to more striping, as the boom sways and dips below the optimum height.
- 110° nozzles produce a higher percentage of fine droplets than 80° nozzles, but they allow a lower boom height while maintaining the required double overlap.
- Operate within the pressure range recommended by the nozzle manufacturer. The production of fine droplets that can drift increases as the operating pressure is increased.

6.9.6 Size of area treated

When large areas are treated relatively large amounts of active herbicide are applied and the risk of off-target effects increases due to the length of time taken to apply the herbicide. Conditions such as temperature, humidity and wind direction may change during spraying. Applying volatile formulations to large areas increases the chances of vapour drift damage to susceptible crops and pastures.

6.9.7 Capture surface

Targets vary in their ability to collect or capture spray droplets. Well grown, leafy crops are efficient collectors of droplets. Turbulent airflow normally carries spray droplets down into the crop.

Fallow paddocks or seedling crops have poor catching surfaces. Therefore, drift hazard is far greater when applying herbicide in these situations or adjacent to these poor capture surfaces.

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [IWM: Spray application of herbicides—water volume with contact sprays](#)



WATCH: [IWM: Spray application of herbicides—application volume in stubble](#)



WATCH: [Advances in weed management: Webinar 2—Spray application in summer fallows](#)



MORE INFORMATION

[Surface temperature inversions and spraying factsheet](#)

6.9.8 Weather conditions to avoid

The ideal wind speed at which to spray is 3–10 km/h, a light breeze, when leaves and twigs are in constant motion.

Avoid using herbicidal sprays in the following conditions.

- Midday turbulence
- Up-drafts during the heat of the day cause rapidly shifting wind directions, so avoid spraying in the middle of the day.
- High temperatures
- Avoid spraying when temperatures exceed 28°C.
- Humidity
- Avoid spraying under low relative humidity, i.e. when the difference between wet and dry bulbs (Delta T, ΔT) exceeds 10°C.
- High humidity extends droplet life and can greatly increase the drift hazard under inversion conditions. This results from the increased life of droplets smaller than 100 microns.
- Inversions
- The most hazardous condition for herbicide spray drift is an atmospheric inversion, especially when combined with high humidity.
- Wind
- Avoid spraying under still conditions.
- 11–14 km/h (a moderate breeze, when small branches move, dust is raised or loose paper moves) is suitable for spraying only if using low-drift nozzles or higher volume application, say 80–120 L/ha.

An inversion exists when temperature increases with altitude instead of decreasing. An inversion is like a cold blanket of air above the ground, and is usually less than 50 m thick. Air will not rise above this blanket; and smoke or fine spray droplets and particles of spray deposited within an inversion will float until the inversion breaks down. Inversions usually occur on clear, calm mornings and nights. Windy or turbulent conditions prevent the formation of inversion layers.

Blankets of fog, dust or smoke and the tendency for sounds and smells to carry long distances indicate inversion conditions. Smoke generators or smoky fires can be used to detect inversion conditions. Smoke will not continue to rise but will drift along at a constant height under the inversion blanket.³⁷

6.10 Testing for herbicide tolerance

In most cases, the herbicides and pesticides that work on wheat and rye will work on triticale. However, some studies indicate that triticale may be less tolerant to some herbicide cocktails than wheat. Newer herbicides as well as pesticides are being released with recommendations for use on triticale in many parts of the world.³⁸

National Variety Trials (NVT) herbicide-tolerance trials undertaken in NSW from 1996 to 2015 give an indication of triticale's response to a range of herbicides.

Cultivars of many broadacre crop species have been found to vary in sensitivity to commonly used herbicides and tank mixes. Using the wrong mixture for a cultivar may result in a loss of grain yield and in reduced farm profit. So the industry can fine-tune understanding of what chemicals can work in a complementary way with different cultivars, GRDC and state government agencies across Australia fund a series of cultivar × herbicide tolerance trials are conducted annually.

³⁷ A Storrie, T Cook (2015) Reducing herbicide spray drift. Revised. NSW DPI, <http://www.dpi.nsw.gov.au/content/agriculture/pests-weeds/weeds/images/wid-documents/herbicides/spray-drift>

³⁸ M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

 MORE INFORMATION[Cultivar herbicide tolerance trial protocols](#)

The trials aim to provide grain growers and advisers with information on cultivar sensitivity to commonly used in-crop herbicides and tank mixes for a range of crop species including wheat, barley, triticale, oats, lupins, field peas, lentils, chickpeas and faba beans. The intention is to provide data from at least two years of testing at the time of wide-scale commercial propagation of a new cultivar.

To provide growers with clear information about the herbicide interactions of a variety for their region, four regionally based projects were established. They have now been combined under a national program.

The good news is that >70% of all crop varieties tolerate most herbicides. The remaining varieties may show yield losses of 10–30%, and in some cases a 50% yield loss has been recorded. These results have occurred with the use of registered herbicides applied at label rates under good spraying conditions at the appropriate crop growth stage.

6.11 Potential herbicide damage of triticale

Excessive herbicide treatments may limit germination in triticale. The successive effect of five herbicide variants (isoxaben, chlorsulfuron, isoproturon, chlortoluron and control) on the germination and plant growth of triticale cultivars has been explored. Germination of winter triticale seeds, obtained from plants treated with herbicide, was generally lower, in particular for the isoproturon and chlorsulfuron variants.³⁹

6.11.1 Avoiding crop damage from residual herbicides

When researching the residual activity and cropping restrictions following herbicide application, the herbicide label is the primary source of information and it should be read thoroughly and followed precisely to minimise the development of resistance, and to maximise paddock health and crop yield.

What are the issues?

Some herbicides can remain active in the soil for weeks, months or even years. This can be an advantage, as it ensures good long-term weed control. However, if the herbicide stays in the soil longer than intended it may damage sensitive crop or pasture species sown in subsequent years.

For example, chlorsulfuron (e.g. Glean®) is used in wheat and barley, but it can remain active in the soil for several years and damage legumes and oilseeds. A real difficulty for growers lies in identifying herbicide residues before they cause a problem.

Currently, growers rely on information provided on the labels about soil type and climate. Herbicide residues are often too small to be detected by chemical analysis, or if testing is possible it is too expensive to be part of routine farming practice. Once the crop has emerged, diagnosis is difficult because the symptoms of residual herbicide damage can be confused with, and/or make the crop vulnerable to, other stresses, such as nutrient deficiency or disease.⁴⁰

An option for assessing the potential risk of herbicide residues is to conduct a bioassay involving hand planting small test areas of crop into the field in question.

Which herbicides are residual?

The herbicides listed in Table 7 all have some residual activity or planting restrictions. Glean® is registered for use in triticale, cereal rye, wheat, and oats. Activity occurs through root and foliar uptake. There are no plant-back recommendations on alkaline

39 S Sławomir, M Robert (1996) Successive effect of herbicides on triticale seed germination and plant growth. In *Triticale: Today and Tomorrow*. Springer Netherlands, pp. 743–747.

40 Agriculture Victoria (2013) Avoiding crop damage from residual herbicides. Updated. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides>

soils for triticale and wheat. Ally® is registered for use in triticale, wheat, barley and cereal rye. Activity is by foliar translocation but also root absorption after rain.⁴¹

Table 7: A representative range of active constituents by herbicide group.

Herbicide group	Active constituent
Group B: Sulfonylureas	Chlorsulfuron (Glean®), iodosulfuron (Hussar®), mesosulfuron (Atlantis®), metsulfuron (Ally®), triasulfuron (Logran®)
Group B: Imidazolinones	Imazamox (Raptor®), imazapic (Flame®), imazapyr (Arsenal®)
Group B: Triazolopyrimidines (sulfonamides)	Florasulam (Conclude®)
Group C: Triazines	Atrazine, simazine
Group C: Triazinones	Metribuzin (Sencor®)
Group C: Ureas	Diuron
Group D: Dinitroanilines	Pendimethalin (Stomp®), trifluralin
Group H: Pyrazoles	Pyrasulfotole (Precept®)
Group H: Isoxazoles	Isoxaflutole (Balance®)
Group I: Phenoxyacetic acids	2,4-Ds
Group I: Benzoic acids	Dicamba
Group I: Pyridine carboxylic acids	Clopyralid (Lontrel®)
Group K: Chloroacetamides	Metolachlor
Group K: Isoxazoline	Pyroxasulfone (Sakura®)

How can I avoid damage from residual herbicides?

Select a herbicide appropriate for the weed population you have. Make sure you consider what the re-cropping limitations may apply to future rotation options.

Consider your soil types; sandy soils can leach herbicides, whereas heavier soils will have longer residuals

Look at the weather forecast prior to applying. If heavy rainfall expected post sow, pre-emergent, do not apply the herbicide as this may be washed into the furrow and cause damage to the emerging seedling.

Soil surface condition; cloddy soil surfaces can result in more damage.

Agronomist's view

Users of chemicals are required by law to keep good records, including weather conditions, but particularly spray dates, rates, batch numbers, rainfall, soil type and pH (including different soil types in the paddock) (Photo 10).⁴² In the case of unexpected damage, good records can be invaluable.

⁴¹ L Lenaghan. Residual herbicides: Group B and C carry-over. [http://www.croppro.com.au/resources/BCGGroupBResidual_herbicides\(2\)\[1\].pdf](http://www.croppro.com.au/resources/BCGGroupBResidual_herbicides(2)[1].pdf)

⁴² D Lush (2014) Water solubility key to effective pre-emergents. Ground Cover. No. 110. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover/GC110/Water-solubility-key-to-effective-pre-emergents>

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 10: *The crop in this trial plot is showing damage from pre-emergent herbicides due to poor separation of herbicide and crop seed.*

Photo: C Preston

If residues could be present, choose the least susceptible crops; refer to product labels. Optimise growing conditions to reduce the risk of compounding the problem with other stresses such as herbicide spray damage, disease and nutrient deficiency. These stresses make a crop more susceptible to herbicide residues.⁴³

MORE INFORMATION

[Herbicide residues in soil and water](#)

6.11.2 Plant-back intervals

Plant-back periods are the obligatory times between the herbicide spraying date and safe planting date of a subsequent crop.

Some herbicides have a long residual period. This is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original amount (the half-life), what remains can persist for long periods (the residual period), as sulfonylureas such as chlorsulfuron do (Table 8⁴⁴). Herbicides with long residuals can affect later crops, especially if they are effective at low levels of the active ingredient, such as with the sulfonylureas. On product labels, this will be shown by plant-back periods (Table 9⁴⁵), which are usually listed under a separate plant-back heading or under a heading such as ‘Protection of crops’ in the general instructions section.

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonyl urea, triazines) may be a problem in some paddocks. Remember that plant-back periods begin after rain.⁴⁶

⁴³ Agriculture Victoria (2013) Avoiding crop damage from residual herbicides, Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides>

⁴⁴ B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW DPI, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

⁴⁵ W Hawthorne (2007) Residual herbicides and weed control. Southern Pulse Bulletin, Pulse Australia, http://www.pulseaus.com.au/storage/app/media/crops/2007_SPB-Pulses-residual-herbicides-weed-control.pdf

⁴⁶ B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW DPI, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

SECTION 6 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 8: Known residual persistence of common pre-emergent herbicides.

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Logran® (triasulfuron)	19	High. Persists longer in high pH soils. Weed control commonly drops off within 6 weeks.
Glean® (chlorsulfuron)	28–42	High. Persists longer in high pH soils. Weed control longer than Logran®.
Diuron	90 (range 1 month to 1 year, depending on rate)	High. Weed control will drop off within 6 weeks, depending on rate. Has had observed long-lasting activity on grass weeds such as black/stink grass (<i>Eragrostis</i> spp.) and to a lesser extent broadleaf weeds such as fleabane.
Atrazine	60–100, up to 1 year if dry	High. Has had observed long-lasting (>3 months) activity on broadleaf weeds such as fleabane.
Simazine	60 (range 28–149)	Medium–high, with 1 year residual in high pH soils. Has had observed long-lasting (>3 months) activity on broadleaf weeds such as fleabane.
Terbyne® (terbulthylazine)	6.5–139	High. Has had observed long-lasting (>6 months) activity on broadleaf weeds such as fleabane and sow thistle.
Triflur® X (trifluralin)	57–126	High. 6–8 months residual. Higher rates longer. Has had observed long-lasting activity on grass weeds such as black grass and stink grass (<i>Eragrostis</i> spp.).
Stomp® (pendimethalin)	40	Medium. 3–4 months residual.
Avadex® Xtra (triallate)	56–77	Medium. 3–4 months residual.
Balance® (isoxaflutole)	1.3 (metabolite 11.5)	High. Reactivates after each rainfall event. Has had observed long-lasting (> 6 months) activity on broadleaf weeds such as fleabane and sow thistle.
Boxer Gold® (prosulfocarb)	12–49	Medium. Typically quicker to break down than trifluralin, but tends to reactivate after each rainfall.
Sakura® (pyroxasulfone)	10–35	High. Typically quicker breakdown than trifluralin and Boxer Gold, however, weed control persists longer than Boxer Gold®.

Note residual persistence in broadacre trials and paddock experiences.
Source: NSW DPI

SECTION 6 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 9: Minimum re-cropping intervals and guidelines.

Group and type	Product	pH (H ₂ O) or product rate (mL/ha) as applicable		Minimum re-cropping interval (months after application), and conditions
B, sulfonyl urea (SU)	Chlorsulfurons e.g. Glean®, Seige®, Tackle®	<6.5		3 months
		6.6–7.5	3 months, minimum 700 mm	
		7.6–8.5	18 months, minimum 700 mm	
B, sulfonyl urea (SU)	triasulfuron, e.g. Logran®, Nugrain®	7.6–8.5		12 months, >250 mm for grain, 300 mm for hay
		>8.6	12 months, >250 mm grain, 300 mm hay	
B, Sulphonamide	Flumetsulam e.g. Broadstrike®			0 months
B, sulfonyl urea (SU)	metsulfuron e.g. Ally®, Associate®	5.6–8.5		1.5 months
		>8.5	Tolerance of crops grown through to maturity should be determined (small scale) previous season before sowing larger area	
B, sulfonyl urea (SU)	Metsulfuron + thifensulfuron, e.g. Harmony® M	7.8–8.5 organic matter >1.7%	3 months	
	>8.6 or organic matter <1.7%	Tolerance of crops grown through to maturity should be determined (small scale) previous season before sowing larger area		
B, sulfonyl urea (SU)	Sulfosulfuron e.g. Monza®	<6.5	0 months	
		6.5–8.5	10 months	

Note: always read labels to confirm product specifications and use details.
Source: Pulse Australia

MORE INFORMATION

[Avoiding crop damage from residual herbicides](#)

For up-to-date plant-back periods, see [Weed control in winter crops](#).

Conditions required for breakdown

Warm, moist soils are required to break down most herbicides through the processes of microbial activity. For the soil microbes to be most active they need good moisture and an optimum soil temperature range of 18–30°C. Temperatures above or below this range can adversely affect soil microbial activity and slow herbicide breakdown. Very dry soil also reduces breakdown. Once the soil profile gets very dry it requires a lot of rain to regain and then maintain sufficient topsoil moisture for the microbes to be active again.

6.12 Herbicide resistance

Key points:

- Resistance is the inherited ability of an individual plant to survive and reproduce following a herbicide application that would kill a ‘wild’ individual of the same species.
- Thirty-six weed species in Australia currently have populations that are resistant to at least one herbicide mode of action (MOA).
- As of August 2016, Australian weed populations had developed resistance to 25 at least one MOA group. ([Information is kept up to date by the International Survey of Herbicide Resistant Weeds.](#))

- Herbicide resistant individuals are present at very low frequencies in weed populations before the herbicide is first applied.
- The frequency of naturally resistant individuals within a population will vary greatly within and between weed species.
- A weed population is defined as resistant when a herbicide at a label rate that once controlled the population is no longer effective. (Sometimes an arbitrary figure of 20% survival is used for defining resistance in testing.)
- The proportion of herbicide-resistant individuals will rise (due to selection pressure) in situations where the same herbicide MOA is applied repeatedly and the survivors are not subsequently controlled.
- Herbicide resistance in weed populations is permanent as long as seed remains viable in the soil. Only weed density can be reduced, not the ratio of resistant-to-susceptible individuals. The exception is when the resistance gene(s) carry a fitness penalty so that resistant plants produce less seed than susceptible ones, but this is rare.

Resistance remains for many years, until all resistant weed seeds are gone from the soil seedbank. It evolves more rapidly in paddocks where chemicals from the same herbicide group are used frequently, especially if no other types of control are used.

Action points:

- Assess your level of risk with the online glyphosate resistance toolkit.
- Aim for maximum effectiveness in control tactics, because resistance is unlikely to develop in paddocks with low weed numbers.
- Do not rely on the same mode of action group.
- Monitor your weed control regularly.
- Stop the seedset of survivors.⁴⁷

As herbicide resistance becomes more widespread, it reduces the effectiveness of a wide range of herbicide MOAs (see Photo 11)⁴⁸. Rapid expansion of herbicide resistance and the lack of new MOA require that non-herbicide tactics must be a significant component of any farming system and weed management strategy. Inclusion of non-herbicide tactics is critical to prolong the effective life of remaining herbicides, as well as for new products and modes of action that have not yet been released or indeed invented. Effective herbicides are key components of profitable cropping systems. Protecting their efficacy directly contributes to the future sustainability and profitability of cropping systems.



Photo 11: 2,4-D-resistant radish, Wongan Hills.

Photo: A Storrie

47 DAF Qld (2015) Stopping herbicide resistance in Queensland. DAF Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance>

48 GRDC (n.d.) Section 1. Herbicide resistance. In Integrated Weed Management Hub. GRDC, <https://grdc.com.au/resources-and-publications/iwmhub/section-3-herbicide-resistance>

SECTION 6 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Herbicide resistance is an increasing threat across Australia's northern grain region for both growers and agronomists. Many weeds are confirmed as being resistant to herbicides of Groups A, B, C, I, M or Z (Table 10).⁴⁹ As well, barnyard grass, liverseed grass, common sowthistle and wild oat are at risk of developing resistance to Group M (glyphosate) herbicides (Table 11).⁵⁰

Table 10: Weeds confirmed as resistant in northern NSW.

Weed	Herbicide group and product/chemical (examples only)	Areas with resistance in NSW	Future risk	Detrimental impact
Wild oats	A. Topik®, Wildcat® B. Atlantis® Z. Mataven®	Spread across the main wheat-growing areas More common in western-cropping areas	Areas growing predominantly winter crops	High
Paradoxa grass	A. Wildcat®	North and west of Moree	Areas growing predominantly winter crops	High
Awnless barnyard grass	C. Triazines M. Glyphosate	Mainly between Goondiwindi and Narrabri	No-till or minimum-till farms with summer fallows	High Very high
Charlock, black bindweed, common sowthistle, Indian hedge mustard, turnip weed	B. Glean®, Ally®	Spread across the main wheat-growing areas	Areas growing predominantly winter crops	Moderate
Annual ryegrass	M. Glyphosate B. Glean® A. Verdict®	Group M resistance widespread in Liverpool Plains Group A and B resistance in central west NSW	Areas with predominantly summer fallows Winter cropping areas	High
Fleabane	M. Glyphosate	Spread uniformly across the region	Cotton crops and no-till or minimum-till systems	Moderate
Wild radish	I. 2,4-D amine	Central-west NSW	Continuous winter cereal cropping	High
Windmill grass	M. Glyphosate	Central-west NSW	Continuous winter cropping and summer fallows	High
Liverseed grass	M. Glyphosate	A few isolated cases	No-till or minimum-till systems	Moderate
Sowthistle ^A	M. Glyphosate	Liverpool Plains	Winter cereal contaminated areas with minimum tillage	High

Source: NSW DPI

49 A Storrie, T Cook, P Moylan, A Maguire, S Walker, M Widderick (n.d.) Managing herbicide resistance in northern NSW. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/155148/herbicide-resistance-brochure.pdf

50 A Storrie, T Cook, P Moylan, A Maguire, S Walker, M Widderick (n.d.) Managing herbicide resistance in northern NSW. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/155148/herbicide-resistance-brochure.pdf

SECTION 6 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 11: Weeds that may become resistant in northern NSW.

Weed	Herbicide group and product/chemical (examples only)	Future risk	Detrimental impact
Barnyard, liverseed and windmill grasses	A. Verdict® L. Paraquat	No-till and minimum-till systems	Very high
Common sowthistle	I. 2,4-D amine	Winter cereals	High
Paradoxa grass	B. Glean®, Atlantis®	Western wheat growing areas	High
Other brassica weeds, including wild radish	B. Glean®, Ally®	Areas growing predominantly winter crops	Moderate
Annual ryegrass	L. Paraquat	Areas with predominantly summer fallows	Very high
Wireweed, black bindweed, melons and cape weed	I. 2,4-D amine, Lontrel®, Starane®	Areas growing predominantly winter crops	High
Fleabane	I. 2,4-D amine L. Paraquat	Cotton crops and no-till or minimum-till systems	Very high
Other fallow grass weeds	M. Glyphosate	No-till or minimum-till systems	High

Source: NSW DPI

In southern Queensland, seven weeds are confirmed to be resistant to Groups A, B or C herbicides (see Table 11).⁵¹ A further four weeds are confirmed resistant to glyphosate (e.g. Roundup®).

Table 12: Weeds confirmed as resistant in southern Queensland.

Weed	Herbicide group	Extent of resistance in SQ	Future risk	Detrimental impact
Wild oats	A, e.g. Topik®, Wildcat®	Spread across the main wheat growing areas	Areas growing predominantly winter crops	High
African turnip weed, black bindweed, common sowthistle, Indian hedge mustard, turnip weed	B, e.g. Glean®, Ally®	Spread across the main wheat growing area	Areas growing predominantly winter crops	Moderate
Liverseed grass	C, e.g. atrazine	A few paddocks in eastern Darling Downs	Areas growing predominantly sorghum	High
Barnyard grass	M, e.g. glyphosate	Western Darling Downs	Summer fallows	Very high
Flaxleaf fleabane Common sowthistle	M, e.g. glyphosate	Eastern and western Darling Downs	Fallows	Very high

Source: DAF Qld

⁵¹ DAF Qld (2015) Stopping herbicide resistance in Queensland. DAF Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance>

In Central Queensland (CQ), the first case of herbicide resistance was confirmed in 2014 with a sweet summer grass population found to be resistant to glyphosate.

The first glyphosate-resistant liverseed grass was found on the Liverpool plains area of northern NSW, and has recently become more widespread (Table 13).

Table 13: Weeds that may become resistant in central and southern Queensland.)

Weed	Herbicide group	Future risk	Detrimental impact
Wild oats	M , e.g. glyphosate	No-till and minimum-till systems (southern Queensland only)	High
Barnyard grass	C , e.g. atrazine	Areas growing predominantly sorghum	High
Parthenium	B , e.g. Ally®	Areas growing predominantly winter crops	High
Other brassica weeds	B , e.g. Glean®, Ally®	Areas growing predominantly winter crops	Moderate

Source: DAF Qld

Other broadleaf and grass weeds are also at risk of developing resistance, depending on weed numbers and management practices used.

i MORE INFORMATION

[Preventing herbicide resistance in specific weeds.](#)

GRDC IWM Hub, [Herbicide resistance](#)

6.12.1 How does resistance start?

Resistance starts in a paddock in several ways. Some rare mutations can occur naturally in weeds already in the paddock, with the likelihood varying from 1 plant in 10,000 to 1 in a billion, depending on the weed and the herbicide used against it. A grower may also import weed seed with the herbicide-resistant gene in contaminated feed, seed or machinery. Resistance may also be introduced by natural seed spread by wind and water or by pollen, which may blow in from a contaminated paddock.

6.12.2 General principles to avoid resistance

Herbicides have a limited life before resistance develops, and that usable life is even shorter if they are used repeatedly and as the sole means of weed control, particularly in zero- and minimum-till systems. Resistance can develop within four to eight years for Group A and B herbicides, and after 15 years for Group L and M herbicides (see Table 14 and Figure 4). This can be avoided by:

- keeping weed numbers low
- changing herbicide groups
- using tillage
- rotating crops and agronomic practices ⁵²

Table 14: Rules of thumb for the number of years of herbicide application before resistance evolves.

Herbicide group	Years to resistance
A	6–8
B	4–6
C	10–15
D	10–15
L	15+
M	15+

Source: DAF Qld

52 DAF Qld (2015) Stopping herbicide resistance in Queensland. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance>

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

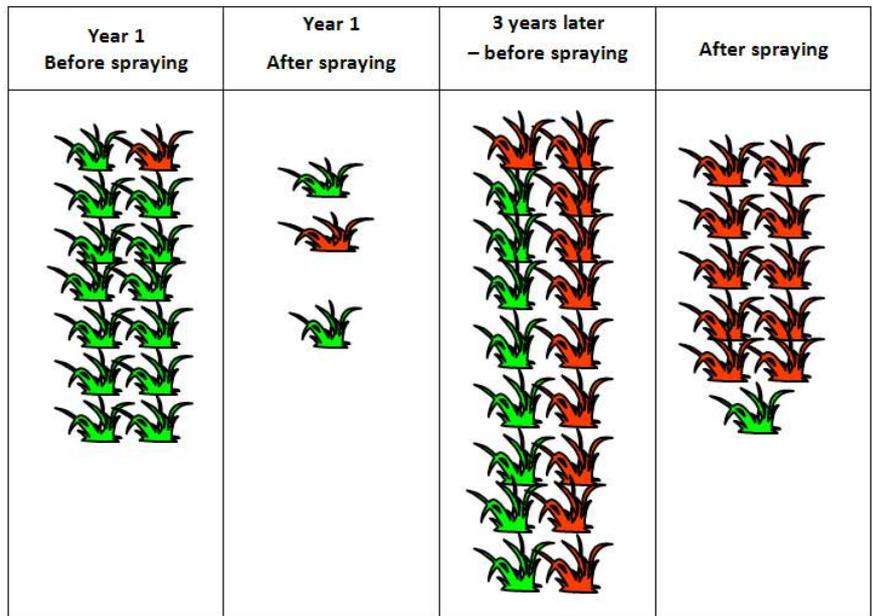


Figure 4: How a weed population becomes resistant to herbicides.

Source: GRDC

Strategies to prevent or minimise the risk of resistance developing are based on IWM principles as outlined below.

- Ensure survivors do not set seed and replenish the soil seedbank.
- Keep accurate paddock records of herbicide application and levels of control. Monitor weeds closely for low levels of resistance, especially in paddocks with a history of repeated use of the same herbicide group.
- Rotate between the different herbicide groups, and/or tank mix with an effective herbicide from another MOA group. It is important to use effective stand-alone rates for both herbicides in the mix.
- Aim for maximum effectiveness to keep weed numbers low. The primary aim of weed control is to minimise their impact on productivity, and resistance is much less likely to develop in paddocks with few weeds than in heavily infested paddocks.
- Use a wide range of cultural weed control tools in your weed management plan. Sowing different crops and cultivars provides opportunities to use different weed management options on key weeds. Tillage is useful when it targets a major weed flush and minimises soil inversion, as buried weed seed generally persists longer than on the soil surface. Competitive crops will reduce seed production on weed survivors.
- Avoid introduction or spread of weeds by contaminated seed, grain, hay or machinery. Also, manage weeds in surrounding non-crop areas to minimise risk of seed and pollen moving into adjacent paddocks.

Specific guidelines for reducing the risk of glyphosate resistance are outlined in Table 15. Aim to include as many as possible of the risk-decreasing factors in your crop and weed management plans.

Table 15: *Balancing the risk of weeds developing glyphosate resistance, devised by the national Glyphosate Sustainability Working Group, with minor modifications for the Queensland cropping region.*

Risk increasing	Risk decreasing
Continuous reliance on glyphosate pre-seeding	Double-knock technique
Lack of tillage	Strategic use of alternative knockdown groups
Lack of effective in-crop weed control	Full-disturbance cultivation at sowing
Inter-row glyphosate use (unregistered)	Effective in-crop weed control
Frequent glyphosate-based chemical fallow	Use alternative herbicide groups or tillage for inter-row and fallow weed control
High weed numbers	Non-herbicide practices for weed-seed kill
Pre-harvest desiccation with glyphosate	Farm hygiene to prevent resistance movement

Source: DAF Qld

Glyphosate-resistant weeds in Australia

Glyphosate resistance was first documented for annual ryegrass in 1996 in Victoria. Since then glyphosate resistance has been confirmed in another 13 weed species. Resistance is known in eight grass species and six broadleaf species of which four are winter-growing weed species and 10 are non-seasonal or summer-growing weed species (Photo 12).⁵³



Photo 12: *Winter fallow showing an early glyphosate-resistant sowthistle problem.*

Photo A. Storrie

All of the glyphosate-resistant weed populations have occurred in situations where there has been intensive use of glyphosate, often over 15 years or more, with few or no other effective herbicides used and few other weed control practices are used. This suggests the following are the main risk factors for the evolution of glyphosate resistance:

- Intensive use of glyphosate over 15 years or more.
- Heavy reliance on glyphosate for weed control.
- No other weed controls targeted to stop seedset.

⁵³ Australian Glyphosate Sustainability Working Group (n.d.) Glyphosate-resistant weeds in Australia. Australian Glyphosate Sustainability Working Group . http://glyphosateresistance.org.au/register_summary.html

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

MORE INFORMATION

[Australian glyphosate resistance register](#)

[Strategic risk management](#)

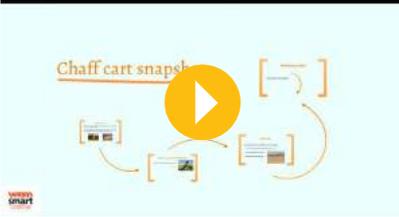
[Farm business management: making effective business decisions](#)

VIDEOS

WATCH: [Act now: Plan your weed management program](#)



WATCH: [Chaff carts 101](#)



WATCH: [Capture weed seeds at harvest: Harrington Seed Destructor](#)



The [online glyphosate-resistance toolkit](#) enables growers and advisers to assess their level of risk for developing glyphosate-resistant weeds on their farm.

6.12.3 Ten-point plan to weed out herbicide resistance

WeedSmart has developed a 10-point plan that farmers can use to protect the longevity of chemicals and slow down the development of resistance. ⁵⁴

1. Act now to stop weed seedset

Creating a plan of action is an important first step in integrated weed management. A little bit of planning goes a long way!

- Destroy or capture weed seeds.
- Understand the biology of the weeds present.
- Remember that every successful weed-smart practice can reduce the weed seedbank over time.
- Be strategic and committed: herbicide resistance management is not a one-year decision.
- Research and plan your weed-smart strategy.
- You may have to sacrifice yield in the short term to manage resistance: be proactive.

2. Capture weed seeds at harvest

Destroying or capturing weed seeds at harvest is the number one strategy for combating herbicide resistance and driving down the weed seedbank. There are several ways to do this:

- [Tow a chaff cart behind the header.](#)
- [Use a Harrington Seed Destructor](#) (Photo 13). ⁵⁵
- [Create and burn narrow windrows.](#)
- Produce hay where suitable.
- [Funnel seed onto tramlines in controlled-traffic farming \(CTF\) systems.](#)
- Use a green or brown manure crop to achieve 100% weed control and build soil nitrogen levels.

Controlling weed seeds at harvest is emerging as the key to managing the increasing levels of herbicide resistance, which is putting Australia's no-till farming system at risk.



Photo 13: *Harrington weed-seed destructor at work in the paddock.*

Source: GRDC

⁵⁴ WeedSmart. Ten-point plan. WeedSmart, <http://weedsmart.org.au/10-point-plan/>

⁵⁵ A Roginski (2012) Seed destructor shows its national potential. Ground Cover. No. 100. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-issue-100/Seed-destructor-shows-its-national-potential>

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [Strategic narrow windrow burning](#)



WATCH: [The art of narrow windrow burning](#)



WATCH: [Chaff funnelling onto tramlines](#)



WATCH: [Capture weed seeds at harvest: Bale Direct System](#)



For information on harvest weed-seed control and its application, see [Section 12: Harvest](#).

3. Rotate crops and herbicide modes of action

Crop rotation is great for farming systems! Make sure weed management is part of the decision when planning crop rotation. [Crop rotation](#) offers many opportunities to use different weed control tactics, both herbicide and non-herbicide, against different weeds at different times. Rotating crops also gives farmers a range of intervention opportunities. For example, we can crop-top lupins and other pulses, swath canola, and delay sowing some crops (e.g. field peas).

Rotations that include both broadleaf crops (e.g. pulses and oilseeds) and cereals allow the use of a wider range of tactics and chemistry.

Growers also have the option of rotating to non-crop options, e.g. pastures and fallows.

Within the rotation it is also important to not repeatedly use herbicides from the same MOA group. Some crops have fewer registered-herbicide options than others, so this needs to be considered too, along with the opportunities to use other tactics, such as the control of harvest weed seed, in place of one or more herbicide applications.

4. Test for resistance to establish a clear picture of paddock-by-paddock status

- Before harvest, sample weed seeds and resistance test to determine effective herbicide options. One such service is provided by [Plant Science Consulting](#).
- Use the '[quick test](#)' option to test emerged ryegrass plants after sowing to determine effective herbicide options before applying in-crop selective herbicides.
- Collaborate with researchers by collecting weeds for surveys
- Visit [WeedSmart](#) for more information on herbicide-resistance survey results.

It is clearly too late to prevent the evolution of resistance to many of our common herbicides. However, a resistance test when something new is observed on the farm can be very useful in developing a plan to contain the problem, and in developing new strategies to prevent this resistance evolving further.

Perhaps the best use for herbicide-resistance tests is to use them to determine if a patch of surviving weeds are worse than what the grower has observed before. Take a GPS recording of the site location of potentially resistant weeds. These weeds may give insight into the future resistance profile of the farm if it is not contained and resistance testing in these situations can be very useful in building preventative strategies.

5. Never cut the rate

Australian Herbicide Resistance Initiative (AHRI) researcher Dr Roberto Busi found that ryegrass being sprayed at below the advised rate of Sakura® evolved resistance not only to Sakura® but to Boxer Gold® and Avadex® too. To avoid this problem occurring:

- Use best management practice in spray application: apply according to the directions on the label.
- Consider selective weed sprayers.

SECTION 6 TRITICALE

TABLE OF CONTENTS

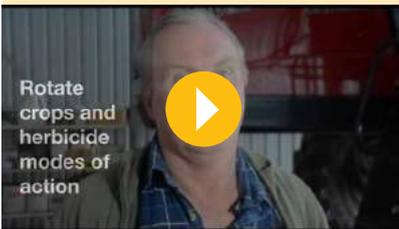
FEEDBACK

VIDEOS

WATCH: [IWM: Weed seed destruction—beer can height](#)



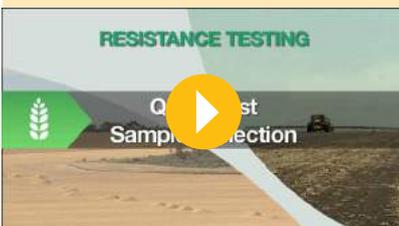
WATCH: [Crop rotation with Colin McAlpine](#)



WATCH: [Test for resistance to establish a clear picture of paddock-by-paddock farm status](#)



WATCH: [IWM: Resistance testing—Quick Test sample collection](#)



6. Don't automatically reach for glyphosate

Glyphosate has long been regarded as the world's most important herbicide, so it's natural to reach for it at the first sign of weeds. Resistance to this herbicide is increasing rapidly, and in some areas it may fail completely. This can be due to too much reliance on one herbicide group, giving the weed opportunity to evolve resistance.

Instead, introduce paraquat products when dealing with smaller weeds, and for a long-term solution farm with a very low seedbank. Also:

- Use a diversified approach to weed management.
- Consider post-emergent herbicides where suitable.
- Consider strategic tillage.

7. Carefully manage spray events

It's important to set up your spray gear to maximise the amount of herbicide that directly hits the target. This makes the spray application more cost-effective by killing the maximum number of weeds possible, and it also protects other crops and pastures from potential damage and/or contamination.

Spray technology has improved enormously in the last 10 years, making it far easier for growers to get herbicides precisely where they need to be. Also, many herbicide labels specify the droplet spectrum to be used when applying the herbicide.

As a general rule, medium to coarse droplet size combined with higher application volumes provides better coverage of the target. Using a pre-orifice nozzle slows droplet speed so that droplets are less prone to bouncing off the target.

Using oil-based adjuvants with air-induction nozzles can reduce herbicide deposition by reducing the amount of air in the droplets. These droplets then fail to shatter when they hit the target, which increases droplet bounce.

- Stop resistant weeds from returning into the farming system.
- Focus on management of survivors in fallows.
- Where herbicide failures occur, do not let the weeds seed. Consider cutting for hay or silage, fallowing or brown manuring the paddock.
- Patch-spray areas of resistant weeds only if appropriate.

8. Plant clean seed into clean paddocks with clean borders

With herbicide resistance on the rise, planting clean seed into clean paddocks with clean borders has become a top priority. Controlling weeds is easiest before the crop is planted, so once that is done plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant ones.

Introducing systems that increase farm hygiene will also prevent new weed species and resistant weeds. These systems could include crop rotations, reducing weed burdens in paddocks or a harvest weed-seed control such as the Harrington Seed Destructor or windrow burning.

Lastly, roadsides and fence lines are often a source of weed infestations. Weeds here set enormous amounts of seed because they have little competition, so it's important to control these initial populations by keeping clean borders.

- It is easier to control weeds before the crop is planted.
- Plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant weeds.
- A recent AHRI survey showed that 73% of grower-saved crop seed was contaminated with weed seed.
- The density, diversity and fecundity of weeds are generally greatest along paddock borders and areas such as roadsides, channel banks and fence lines.

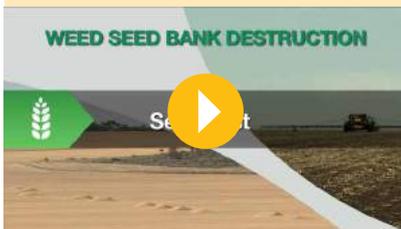
SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

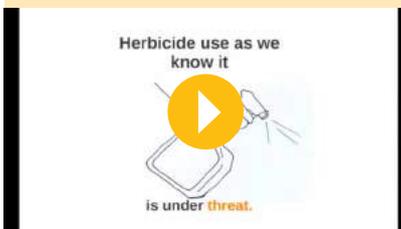
WATCH: [IWM: Seed test—what's involved](#)



WATCH: [Don't cut the rate](#)



WATCH: [Don't automatically reach for glyphosate](#)



WATCH: [Manage spray drift](#)



WATCH: [Plant clean seed into clean paddocks with clean borders](#)



9. Use the double-knock technique

The beauty of the double-knock technique is in combining two weed-control tactics with different modes of action, on a single flush of weeds. These two 'knocks' happen sequentially, with the second application being designed to control any survivors from the first.

One such strategy is the glyphosate–paraquat double-knock. These two herbicides use different MOAs to eliminate weeds and so make an effective team when paired. When using this combination ensure the paraquat rate is high. The best time to initiate this double-knock is after rainfall. New weeds will quickly begin to germinate and should be tackled at this small stage.

10. Employ crop competitiveness to combat weeds

Help your crops win the war against weeds by increasing their competitiveness against weeds. There are numerous options to do this:

- Consider [narrow row spacing](#) and [increasing seeding rates](#).
- Consider twin-row seeding points.
- Consider east-west [crop orientation](#).
- Use triticale and varieties that tiller well.
- Use high-density pastures as a rotation option.
- Consider brown-manure crops.
- Rethink bare fallows.

6.12.4 If you think you have resistant weeds

As soon as resistance is suspected, growers should contact their local agronomist. The following steps are then recommended.

First, consider the possibility of other common causes of herbicide failure by asking:

- Was the herbicide applied in conditions and at a rate that should kill the target weed?
- Did the suspect plants miss herbicide contact or emerge after the herbicide was applied?
- Does the pattern of surviving plants suggest a spray miss or other application problem?
- Has the same herbicide or herbicides with the same MOA been used in the same field or in the general area for several years?
- Has the uncontrolled species been successfully controlled in the past by the herbicide in question or by the current treatment?
- Has a decline in the control been noticed in recent years?
- Is the level of weed control generally good on the other susceptible species?

If resistance is still suspected:

- Contact crop and food-science researchers in your state agricultural department for advice on sampling suspect plants for testing of resistance status..
- Ensure all suspect plants do not set seed.
- If resistance is confirmed, develop a management plan for future years to reduce the impact of resistance and likelihood of further spread.⁵⁶

⁵⁶ DAF Qld (2015) Stopping herbicide resistance in Queensland. DAF Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance>

SECTION 6 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [Best results with double knock tactic](#)



WATCH: [Double knock application: a grower's experience](#)

DOUBLE KNOCK APPLICATIONS

Manage Logistics of Glyphosate Resistant Weeds in Summer Fallow

WATCH: [Spray application of herbicides: double knock](#)



WATCH: [Double knock applications: target weed species and application strategy](#)

DOUBLE KNOCK APPLICATIONS

Target Species and Application Strategy

Testing services

For testing of suspected resistant samples, contact:

- Charles Sturt University Herbicide Resistance Testing School of Agricultural and Wine Sciences Charles Sturt University Locked Bag 588 Wagga Wagga, NSW 2678 Phone (02) 6933 4001
- [Charles Sturt University's Graham Centre weed research group](#)
- Plant Science Consulting 22 Linley Avenue, Prospect SA 5082 email: info@plantscienceconsulting.com.au Phone: 0400 664 460

6.12.5 Monitoring weeds

Monitoring weed populations before and after any spraying is an important part of management. It encompasses:

- Keeping accurate records.
- Monitoring weed populations and recording results of the herbicide used.
- If herbicide resistance is suspected, preventing weed seedset.
- If a herbicide does not work, finding out why.
- Checking that weed survival is not due to spraying error.
- Conducting your own paddock tests to confirm herbicide failure and determine which herbicides remain effective.
- Obtaining a herbicide-resistance test on seed from suspected plants, testing for resistance to other herbicide MOA groups.
- Working hygienically so as not to introduce or spread resistant weeds in contaminated grain or hay.

Regular monitoring is required to assess the effectiveness of weed management and the expected situation following weed removal or suppression. Without monitoring, it is impossible to accurately assess the effectiveness of a management program or determine how it might be modified for better results. Effective weed management begins with monitoring weeds to assess current or potential threats to crop production, and to determine best methods and timing for control measures.

Regular monitoring and recording details of each paddock allows the grower to:

- spot critical stages of crop and weed development for timely cultivation or other intervention;
- identify the weed flora (species composition), which helps to determine best short- and long-term management strategies; and
- detect new invasive or aggressive weed species while the infestation is still localized and able to be eradicated.

Watch for critical aspects of the weed–crop interaction, such as:

- Weed-seed germination and seedling emergence.
- Weed growth sufficient to affect crops if left unchecked.
- Weed density, height, and cover relative to crop height, cover, and stage of growth.
- The impact of the weed on crops, including harbouring pests, pathogens, or beneficial organisms; or modifying microclimate, air circulation, or soil conditions; as well as direct competition for light, nutrients, and moisture.
- Flowering, seedset, or vegetative reproduction in weeds.
- Efficacy of cultivation and other weed-management practices.

Information gathered through regular and timely field monitoring helps growers to select the best tools and timing for weed-control tactics. Missing vital cues in weed and crop development can lead to costly efforts to rescue a crop, efforts that may not be fully effective. Good paddock scouting can help the grower to obtain the most effective weed control for the least fuel use, labour cost, chemical application, crop damage and soil disturbance.

SECTION 6 TRITICALE

[TABLE OF CONTENTS](#)

[FEEDBACK](#)

VIDEOS

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WATCH: [Crop competition: increasing wheat seeding rate](#)



WATCH: [Crop competition: row spacing](#)



MORE INFORMATION

[CropLife Australia](#)

[Australian Glyphosate Sustainability Working Group](#)

[Australian Herbicide Resistance Initiative](#)

Cotton Info, [Weed pack](#)

[Managing herbicide resistance in Northern NSW](#)

Tips for monitoring

To scout for weeds, walk slowly through the paddock, examining any vegetation that you have not planted. In larger paddocks, walk back and forth in a zigzag pattern to view all parts of the paddock, using GPS technology to record areas of particularly high or low weed infestation. Identify weeds with the help of a good weed guide or identification key for your region, and note the weed species that are most prominent or abundant. Observe how each major weed is distributed through the paddock, noting whether they are randomly scattered, clumped or concentrated in one part of the paddock.

Keep records in a field notebook. Prepare a page for each paddock or crop sown, and take simple notes of weed observations each time the paddock is monitored. Over time, your notes become a timeline of changes in the weed flora over the seasons and in response to crop rotations, cover crops, cultivations and other weed control practices. Many growers already maintain separate records for each paddock. Weed observations (species, numbers, distribution, size) can be included with these.

Insect control

Key messages

- To date, triticale varieties are affected by only a few insect pests.
- Triticale has the same insect predators during growth as other cereals. In general, fewer insect control measures are required with the exception of grain storage insects, to which triticale is very susceptible.
- Triticale is vulnerable to grasshoppers, aphids, armyworms, earth mites, *Helicoverpa* and cutworms. Russian Wheat Aphid is also an emerging pest that could be a problem in triticale.
- Insects are not usually a major problem in cereals but sometimes they build up to an extent that control may be warranted.
- Integrated pest management (IPM) strategies encompass chemical, cultural and biological control mechanisms to help improve pest control and limit damage to the environment, and are suitable for use with triticale in the Northern Region.
- For current chemical control options refer to the Pest Genie or Australian Pesticides and Veterinary Medical Authority.

Although triticale varieties are affected by only a few insect pests,¹ where they are vulnerable, the risks from insect damage are similar to those for wheat. Hence, management practices for these insects are the same as for other cereals, and they should be applied only when continual scouting indicates that the problem has reached an economic threshold for control.²

Earth mites (redlegged and blue oat mites) can be a problem in early growth, and chemical control may be necessary depending on insect numbers and damage. Aphids may occur in late winter and spring and while usually not a cause of major damage themselves they do transmit Barley yellow dwarf virus (BYDV) and this may warrant control in severe infestations. Monitor seedling crops for lucerne flea, redlegged earth mite and blue oat mite. Seek local advice to determine if the application of insecticide is warranted and, if so, ensure grazing withholding periods are met. Aphids can infest early-sown crops and attack the crop again in spring. Early in the season they spread viral disease, while in spring they cause yield damage. Seek local advice on thresholds and management options.³ Where chemical control is warranted, farmers are increasingly being strategic in their management and avoiding broad-spectrum insecticides where possible. Thresholds and potential economic damage are carefully considered.

7.1 Potential insect pests

Pest insects can damage agricultural production and market access, the natural environment, and people's lifestyles. They may cause problems by damaging crops (Tables 1, 2 and 3⁴) and food production, parasitising livestock, or being a nuisance or health hazard to humans. Integrated pest management (IPM) guidelines provide an extensive collection of tools and strategies to manage pests in grain-cropping systems.

However, in winter cereals, insects are not normally a major problem, although there will be times when they build up to an extent that control may be warranted.

MORE INFORMATION

[IPM in winter cereals](#)

¹ M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

² Alberta Agriculture and Forestry (2016) Triticale crop protection. Alberta Agriculture and Forestry, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/fcd10572](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10572)

³ Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcra.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

⁴ Queensland Government, GRDC (2016) Winter cereals: insect pest risk. In IPM Guidelines, <http://ipmguidelinesforgrains.com.au/crops/winter-cereals/>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Table 1: Insect pest risk for winter cereals in the Northern Region.

High risk	Moderate risk	Low risk
Soil insects, slugs and snails		
<p>Some crop rotations increase the likelihood of soil insects:</p> <ul style="list-style-type: none"> cereal sown into a long term pasture phase; high stubble loads; above-average rainfall over summer-autumn. <p>History of soil insects, slugs and snails</p> <p>Summer volunteers and brassica weeds will increase slug and snail numbers</p> <p>Cold, wet establishment conditions exposes crops to slugs and snails</p>	<p>Information on pest numbers prior to sowing from soil sampling, trapping and/ or baiting will inform management</p> <p>Implementation of integrated slug management strategy (burning stubble, cultivation, baiting) where history of slugs</p> <p>Increased sowing rate to compensate for seedling loss caused by establishment pests</p>	<p>Slugs and snails are rare on sandy soils</p>
Earth mites		
<p>Cereals adjacent to long-term pastures may get mite movement into crop edges</p> <p>Dry or cool, wet conditions that slows crop growth increases crop susceptibility to damage</p> <p>History of high mite pressure</p>	<p>Leaf-curl mite populations (which transmit Wheat streak mosaic virus) can be increased by grazing and mild, wet summers</p>	<p>Seed dressings provide some protection, except under extreme pest pressure</p>
Aphids		
<p>Higher risk of Barley yellow dwarf virus (BYDV) disease transmission by aphids in higher-rainfall areas where grass weeds are present prior to sowing</p> <p>Wet summer and autumn promotes survival of aphids on weed and volunteer hosts</p>	<p>Wet autumn and spring promotes the growth of weed hosts (aphids move into crops as weed hosts dry off)</p> <p>Planting into standing stubble can deter aphids landing</p> <p>Use of seed dressings can reduce levels of virus transmission and delay aphid colonisation</p> <p>Use of SPs and OPs to control establishment pests can kill beneficial insects and increase the likelihood of aphid survival</p>	<p>Low rainfall areas have a lower risk of BYDV infection.</p> <p>High beneficial activity (not effective for management of virus transmission)</p>
Armyworms		
<p>Large larvae present when the crop is at late ripening stage</p>	<p>High beneficial insect activity (particularly parasitoids)</p> <p>Rapid crop dry down</p>	<p>No armyworm present at vegetative and grainfilling stages</p>

OPs = organophosphates; SPs = synthetic pyrethroids.
Source: IPM Guidelines

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Table 2: Impact of insect according to crop stage.

Pest	Crop stage			
	Emergence	Vegetative	Flowering	Grainfill
<u>Wireworms</u>	Damaging	Present		
<u>Cutworms</u>	Damaging			
<u>Blackheaded cockchafer</u>	Damaging	Present		
<u>Earth mites</u>	Damaging	Present		
<u>Slugs, snails*</u>	Damaging			
Brown wheat mite		Damaging		
<u>Aphids</u>	Present	Damaging	Present	Present
<u>Armyworms</u>		Present	Present	Damaging
<i>Helicoverpa armigera</i>				Damaging

Present	Present in crop but generally not damaging
Damaging	Crop susceptible to damage and loss

* Snails are also a grain contaminant at harvest
Source: IPM Guidelines

Use Table 3 to help identify problem insects in northern crops.

Table 3: Winter cereal pests affecting northern region crops.

Insect	Pre-season	Establishment	Winter	Spring
Aphids (Note that information for Russian Wheat Aphid may be slightly different)	Remove green bridge (weed and volunteer hosts)	High risk: <ul style="list-style-type: none"> wet summer/autumn history of virus If high risk, consider seed dressings Targeted early control along crop edges or infested patches may delay build-up in the crop	High risk: warm conditions favour aphids Monitor and record aphids and beneficials. Review to determine if populations increase/decrease or are stable. Rainfall >20 mm will reduce aphid populations. Consider delaying insecticide application if rain is forecast. If spray is required, use a selective insecticide.	A warm, dry spring encourages population growth. No yield loss will occur if infestations occur later than milky grain. Monitor and record aphids and beneficials. Use suggested thresholds. If spray required, use a selective insecticide. Use of broad-spectrum pesticides will kill beneficial insects and increase likelihood of aphid population resurgence.
Common armyworms	Control host weeds (especially ryegrass) Ensure correct ID (armyworm v. <i>Helicoverpa</i>)	Use traps to indicate moth activity (lures of 10% port, 15% raw sugar and 75% water)	High risk: good local rain following a dry period encourages egg laying Monitoring: <ul style="list-style-type: none"> use traps to monitor for moth activity monitor for larvae at dusk with a sweep net. ground search for larvae and droppings look for scalloped leaf margins Control larvae when small	Increase monitoring as crop starts to dry down Small larvae take 8–10 days to reach size capable of head lopping. Determine if crop will be susceptible (dry except for green nodes) when larvae reach damaging size. Control late in the day when larvae are actively feeding. Use of SPs to control armyworms early can increase likelihood of <i>Helicoverpa</i> survival and damage by killing beneficials that would control them.

SECTION 7 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Insect	Pre-season	Establishment	Winter	Spring
<i>Helicoverpa armigera</i>	If large numbers of <i>Helicoverpa</i> present in previous crop, pupae busting may reduce pest incidence		<p>Monitor for larvae with sweep net (can be done when checking for armyworms), or with a beat sheet.</p> <p>Control small larvae (<7 mm) with NPV</p>	<p>Monitor for larvae using a sweep net or beat sheet.</p> <p>Large larvae are most damaging to developing grain. (Small larvae <7 mm can be controlled with NPV.)</p> <p>Be aware that <i>H. armigera</i> have resistance to SPs in all regions</p>

NPV = nucleopolyhedrosis virus; SPs = synthetic pyrethroids

Source: IPM Guidelines

7.2 Integrated pest management

Integrated pest management is an approach that uses a combination of biological, cultural and chemical control methods to reduce insect pest populations. A key aim of IPM is to reduce reliance on insecticides as the sole or primary means of control. The use of IPM can improve growers' profitability while reducing environmental damage, reducing the incidence of insecticide resistance, and limiting the risk of pesticide exposure on the farm.

7.2.1 Key IPM strategies for winter cereals

- Where the risk of establishment pest incidence is low (e.g. earth mites) regular monitoring can be substituted for the prophylactic use of seed dressings.
- Where establishment pests and aphid infestations are clearly a result of invasion from weed hosts around the field edges or neighbouring pasture, a border spray of the affected crop may be sufficient to control the infestation.

Insecticide choices

- The redlegged earth mite (RLEM), blue oat mite (BOM), and other mite species can occur in mixed populations. Determine species composition before making decisions, as they have different susceptibilities to chemicals.
- Establishment pests have differing susceptibilities to insecticides, synthetic pyrethroids (SPs) and organophosphates (OPs) in particular. Be aware that the use of some pesticides may select for pests that are more tolerant.

Insecticide resistance

- RLEM has been found to have high levels of resistance to synthetic pyrethroids such as bifenthrin and alpha-cypermethrin.
- *Helicoverpa armigera* has historically had high resistance to pyrethroids and the inclusion of nucleopolyhedrosis virus (NPV) is effective where mixed populations of armyworms and *Helicoverpa* larvae occur in maturing winter cereals.⁵

Bees

As for all chemical use in the paddock, it is recommended that users consider the risks to bees of the chemicals against RWA. Chemical users are encouraged to contact hive owners as soon as possible so the owners can take steps to minimise the risks to their hives. Contact details can generally be found on the hives, or you can contact the land owner on which the hives are located.

Insecticides and beneficial insects

When deciding whether to use chemical control in managing crop pests, ensure to consider the effects of insecticides on beneficial insects (Table 4).

VIDEOS

WATCH: [GCTV2: Integrated Pest Management](#)



⁵ Queensland Government, GRDC (2016) Winter cereals: insect pest risk. In IPM Guidelines, <http://ipmguidelinesforgrains.com.au/crops/winter-cereals/>

SECTION 7 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 4: Impact of common insecticides on beneficial insects. Note that the values provided here are generalisations and there may be exceptions (e.g. relating to specific species or time of application). Pest resurgence is included as there may be an increase in non-targeted pests following application of insecticides. This is mainly due to the demise of beneficials that may keep pests in check.

Insecticide group ⁽¹⁾	Persistence	Overall ranking	Impact on beneficial insects				
			Predatory beetles	Predatory bugs	Parasitic wasps	Spiders	Bees
FOLIAR-APPLIED							
Bio-pesticides							
Bt	Short	Low	L	L	L	L	L
Helicoverpa NPV	Short	Low	L	L	L	L	L
Metarhizium	Short	Low	L	L	L	L	L
Petroleum spray oils	Short	Low	L	L	L	L	L
Organophosphates							
omethoate	Medium	Moderate	M	M	M	L	H
dimethoate (low rate)	Short	Moderate	M	M	M	L	H
dimethoate (high rate)	Short	High	M	M	H	M	H
methidathion	Short	High	H	H	H	H	H
Indoxacarb	Medium	Low	L	L	L	L	no data
Phenyl pyrazoles (fipronil)	Medium	Low	L	L	L	M	H
Carbamates							
pirimicarb	Short	Low	L	L	L	L	L
thiodicarb	Long	High	H	M	M	M	M
methomyl	Short	High	H	M	M	M	H
Avermectins (emamectin benzoate)	Medium	Moderate	L	H	M	M	H
Synthetic pyrethroids	Long	High	H	H	H	H	H
SEED DRESSINGS							
fipronil	Medium	Low	Limited data available. Seed dressings generally less disruptive than foliar-applied formulations.				
imidacloprid	Medium	Low					
imidacloprid + thiomethoxam	Medium	Low					

Symbols used in the table:

L – Low toxicity	nil or low impact on beneficials
M – Moderate toxicity	activity is significantly reduced but beneficial populations are able to recover in a week or so
H – High toxicity	high proportion of beneficial population killed and re-establishment will not occur for several weeks

Persistence of pest control: Foliar applications: short = <3 days, medium = 3–7 days, long = >10 days Seed treatments: short = 2–3 weeks, medium 3–4 weeks, long = 4–6 weeks *Insecticides and the groups they belong to can be found in the insecticide groups table.

Information in this table has been derived from the Cotton Pest Management Guide (2014–15).

7.2.2 Emerging insect threats in northern crops

Key points:

- Monitor crops frequently so as not to be caught out by new or existing pests.

SECTION 7 TRITICALE

TABLE OF CONTENTS

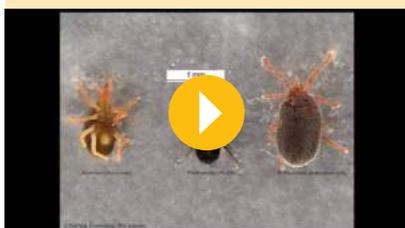
FEEDBACK

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[Emerging insect threats in northern grain crops](#)

VIDEOS

WATCH: [Over the Fence North: Vigilance needed for changing insect patterns](#)



- Look for and report any unusual pests and symptoms of damage—photographs are useful.
- Just because a pest is present in large numbers in one year doesn't mean it will necessarily be so in the next year: it may be the turn of another spasmodic pest, e.g. soybean moth, to make its presence felt.
- However, be aware of cultural practices that favour the harbouring of pests, and rotate crops each year to minimise the build-up of pests and plant diseases.

Recent seasons have seen a plethora of seemingly new pests and unusual damage in pulse and grain crops. The most notable examples are *Etiella behrii* up to 60/ m² in vegetative and podding soybeans and mungbeans, severe scarab damage in sorghum and winter cereals, bean pod borer west of the Great Dividing Range, the appearance of soybean stem fly in regions adjoining the Darling Downs, well south of its 'normal' range, and plague numbers of a mystery plant hopper in mungbeans, sorghum and millet in the summer of 2014–15.⁶

7.2.3 Insect sampling methods

Monitoring for insects is an essential part of successful integrated pest management programs. Correct identification of immature and adult stages of both pests and beneficials, and accurate assessment of their presence in the field at various crop stages, will ensure appropriate and timely management decisions. Good monitoring procedure involves not just a knowledge of and the ability to identify the insects present, but also good sampling and recording techniques and a healthy dose of common sense.

Factors that contribute to quality monitoring

- Knowledge of likely pests and beneficials and their life cycles is essential when planning your monitoring program. As well as visual identification, you need to know where on the plant to look and the best time of day to get a representative sample.
- Monitoring frequency and pest focus should be directed at the crop at stages when you are likely to incur economic damage. Critical stages may include seedling emergence and flowering and grain formation.
- Sampling technique is important to ensure that a representative portion of the crop has been monitored, since pest activity is often patchy. Having defined sampling parameters (e.g. number of samples per paddock and number of leaves per sample) helps you maintain sampling consistency. The actual sampling technique, including sample size and number, will depend on crop type, age and paddock size, and is often a compromise between the ideal number and location of samples and what is practical regarding time constraints and distance to be covered.
- Balancing random sampling with areas of obvious damage is a matter of common sense. Random sampling aims to give a good overall picture of what is happening in the paddock, but any obvious hotspots should also be investigated. The relative proportion of hotspots in a field must be kept in perspective with less heavily infested areas.

Keeping good records

Accurately recording the results of sampling is critical for good decision making and being able to review the success of control measures (Figure 1).⁷ Monitoring record sheets should show the following:

- numbers and types of insects found (including details of adults and immature stages)
- size of insects—this is particularly important for larvae

⁶ H Brier, M Miles (2015) Emerging insect threats in northern grain crops. GRDC Update Paper, 31 July, GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Emerging-insect-threats-in-northern-grain-crops>

⁷ DAF Queensland (2012) Insect monitoring techniques for field crops. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/insect-monitoring>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- date and time
- crop stage and any other relevant information (e.g. row spacing, weather conditions, and general crop observations)

Consider putting the data collected into a visual form that enables you to see trends in pest numbers and plant condition over time. Being able to see whether an insect population is increasing, static or decreasing can be useful in deciding whether an insecticide treatment may be required, and if a treatment has been effective. If you have trouble identifying damage or insects present, keep samples or take photographs for later reference.

Site: *Cameron's*
 Date: *15/9/06*
 Row spacing: *75cm*

Sample (1 m row beat)	VS	S	M	L
1	8	5	1	0
2	1	1	1	0
3	3	3	0	1
4	3	2	1	0
5	2	6	0	0
Average		3.4	0.6	0.2
Adjust for 30% mortality (S*0.7)	$3.4 \times 0.7 = 2.4$			
Mean estimate of larval number (Adjusted S)+M+L	$2.4 + 0.6 + 0.2 = 3.2$			
Adjust for row spacing divide by row spacing (m)	$\frac{3.2}{0.75} = 4.2$			
	4.2 Density Estimate per square metre			

Figure 1: An example of a field check sheet, showing adjustments for field mortality and row spacing.

Source: DAF Qld

Records of spray operations should include:

- date and time of day
- conditions (wind speed, wind direction, temperature, presence of dew and humidity)
- product(s) used (including any additives)
- amount of product and volume applied per hectare
- method of application including nozzle types and spray pressure
- any other relevant details

Sampling methods

Beat sheet

A beat sheet is the main tool used to sample row crops for pests and beneficial insects (Photo 1). It is particularly effective for sampling caterpillars, bugs, aphids and mites. A standard beat sheet is made from yellow or white tarpaulin material with a heavy dowel on each end. Beat sheets are generally between 1.3–1.5 m wide by 1.5–2.0 m deep, with the larger dimensions being preferred for taller crops. The extra width on each side catches insects thrown out sideways when sampling and the sheet's depth allows it to be draped over the adjacent plant row. This prevents insects being flung through or escaping through this row.

To use the beat sheet:

- Place the sheet with one edge at the base of plants in the row to be sampled.

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- Drape the other end over the adjacent row. This may be difficult in crops with wide row spacing (one metre or more) and in this case spread the sheet across the inter-row space and up against the base of the next row.
- Using a one metre stick, shake the plants in the sample row vigorously in the direction of the beat sheet 5–10 times to will dislodge insects from the sample row onto the sheet.
- Reducing the number of beat sheet shakes per site greatly reduces sampling precision. The use of smaller beat sheets, such as small fertiliser bags, reduces sampling efficiency by as much as 50%.
- Use data sheets to record type, number and size of insects found on the beat sheet.
- One beat does not equal one sample. The standard sample unit is five non-consecutive one-metre long lengths of row, taken within a 20m radius; i.e. 5 beats = 1 sample unit. This should be repeated at six locations in the paddock (i.e. 30 beats per paddock).
- The more samples that are taken, the more accurate is the assessment of pest activity, particularly for pests that are patchily distributed such as pod-sucking bug nymphs.

When to use the beat sheet:

- Crops should be checked weekly during the vegetative stage, and twice weekly from the start of budding.
- Caterpillar pests are not mobile within the canopy, and checking at any time of the day should result in reporting similar numbers.
- Pod-sucking bugs, particularly green vegetable bugs, often bask on the top of the canopy during the early morning and are more easily seen at this time.
- Some pod-sucking bugs, such as brown bean bugs, are more flighty in the middle of the day and therefore more difficult to detect when beat-sheet sampling. Other insects (e.g. mirid adults) are flighty no matter what time of day they are sampled, so it is important to count them first.
- In very windy weather, bean bugs, mirids and other small insects are likely to be blown off the beat sheet.
- Using the beat sheet to determine insect numbers is difficult when the field and plants are wet.

While the recommended method for sampling most insects is the beat sheet, visual checking in buds and terminal structures may also be needed to supplement beat sheet counts of larvae and other more minor pests. Visual sampling will also assist in finding eggs of pests and beneficial insects.

Most thresholds are expressed as pests per square metre (pests/m²). Hence, insect counts in crops with row spacing less than one metre must be converted to pests/m². To do this, divide the average insect count per row metre across all sites by the row spacing (in metres). For example, in a crop with 0.75 m row spacing, divide the average pest counts by 0.75.

Other sampling methods

- **Visual checking** is not recommended as the sole form of insect checking, although it has an important support role. Leaflets or flowers should be separated when looking for eggs or small larvae, and leaves checked for the presence of aphids and silverleaf whitefly. If required, dig below the soil surface to assess soil-insect activity. Visual checking is also important for estimating how the crop is going in terms of average growth stage, pod retention and other agronomic factors.
- **Sweep-net sampling** is less efficient than beat-sheet sampling and can underestimate the abundance of pest insects in the crop. Sweep netting can be used for flighty insects and is the easiest method for sampling mirids in broadacre crops or crops with narrow row spacing (Photo 1). It is also useful if the paddock is wet. Sweep netting works best for smaller pests found in the tops

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

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WATCH: [How to use a sweep net to sample for insect pests](#)



WATCH: [GCTV11: GRDC's Insect ID app](#)



WATCH: [Biopesticides emerge as an alternative cropping tool](#)



of smaller crops (e.g. mirids in mungbeans), is less efficient against larger pests such as pod-sucking bugs, and it is not at all useful in tall crops with a dense canopy such as coastal or irrigated soybeans. At least 20 sweeps must be taken along a single 20 m row.

- **Suction sampling** is a quick and relatively easy way to sample for mirids. Its main drawbacks are unacceptably low sampling efficiency, a propensity to suck up flowers and bees, noisy operation, and high purchase cost of the suction machine.
- **Monitoring with traps** (pheromone, volatile, and light traps) can provide general evidence of pest activity and the timing of peak egg laying for some species. However, it is no substitute for in-field monitoring of actual numbers of pests and beneficials.⁸

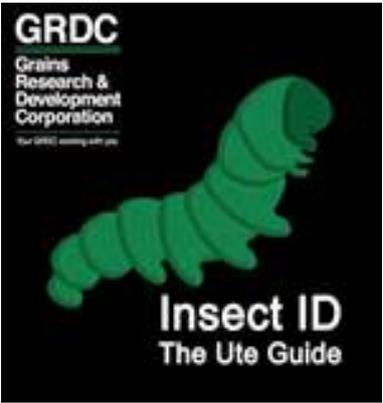


Photo 1: Sweep netting for insects (left) and use of a beat sheet (right).

Sources: DAFWA and The Beatsheet

Identifying insects

For pest identification see the Queensland Department of Agriculture and Fisheries' [A–Z pest list](#) or consult the GRDC's app or online resource, [Insect ID: The Ute Guide](#).



The ute guide is a comprehensive reference for insect pests that commonly affect broadacre crops across Australia, and includes the beneficial insects that may help to control them. Photos have been provided for multiple life-cycle stages, and each insect is described in detail, with information on the crops they attack, how they can be monitored, and other pests that they may be confused with. Use of this app should result in better management of pests, increased farm profitability and improved chemical usage.⁹

The app features:

- Region selection.
- Predictive search by common and scientific names.

⁸ DAF Queensland (2012) Insect monitoring techniques for field crops. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/insect-monitoring>

⁹ GRDC. Apps, <https://grdc.com.au/Resources/Apps>

SECTION 7 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

MORE INFORMATION

IPM Guidelines, [Resources](#)

IPM Guidelines, [Monitoring tools and techniques](#)

- Ability to compare photos of insects side by side with insects in the app
- Identification of beneficial predators and parasites of insect pests.
- An option to download content updates inside the app to ensure you're aware of the latest pests affecting crops for each region.
- Ensure awareness of international biosecurity pests.

Insect ID is available on [Android](#) and [iPhone](#).

7.3 Russian wheat aphid

Key points:

- Triticale and rye are thought to be moderately resistant–resistant to Russian wheat aphid (RWA).
- Russian wheat aphid is a major pest of cereal crops that is found in all major cereal production regions around the world, but only recently in Australia.
- While it is feeding, the aphid injects toxins into the plant and these retards growth. Heavy infestations can kill the plant.
- Affected plants will show whitish, yellow and red–purple leaf markings and rolled leaves.
- Russian wheat aphid is approximately 2 mm long, and pale yellowish-green with a fine waxy coating. The body is elongated compared with other cereal aphid species (Photo 2).¹⁰



Photo 2: *The Russian wheat aphid (Diuraphis noxia).*

Photo: M. Nash

RWA is a major pest of cereal crops worldwide. It is easily spread by the wind and on live plant material.

It was not present in Australia until 2016. It was first identified in a wheat crop at Tarlee in South Australia on 13 May 2016, and has since been seen in many cropping areas in South Australia. At this time, the RWA National Management Group said that it was not technically feasible to eradicate it. The NSW Department of Primary Industries confirmed the first NSW detection of Russian wheat aphids (*Diuraphis*

¹⁰ A Lawson (2016) Paddock practices, Southern, June 2016: Monitor RWA numbers closely over winter. GRDC, <https://portal.biosecurityportal.org.au/rwa/Documents/Paddock%20Practices%20Southern%20June%202016.pdf>

noxia) in a wheat crop in the State's south. Scientists at NSW DPI Biosecurity Collections Unit confirmed the sample from the Barham area in the Murray region contained Russian wheat aphid.¹¹ Though Queensland is yet to report a case of RWA, Biosecurity Queensland has urged landholders to continue maintaining good biosecurity practices on their properties to prevent the introduction of the aphid to Queensland farms.¹²

Early research on triticale, rye and wheat resistance to RWA suggests that triticale and rye are moderately resistant–resistant to RWA. In this study, the highest level of resistance was found in three triticale cultivars that originated in Russia, the source of the RWA.¹³ In descending order, RWA tends to prefer barley, durum wheat, bread wheat, triticale, cereal rye, then oats.

Grain growers and advisers are urged to monitor cereal paddocks closely for signs of damage caused by this aphid. Following national management group declaration, experts called on growers and advisers to find, identify, consider aphid numbers and economic thresholds and enact a management (FITE) strategy if needed.¹⁴

RWA is asexual, meaning it does not need males and females in order to breed. The aphid takes about three weeks in winter and 10–14 days in mid-spring to reach maturity. The female then produces about two nymphs a day for 2–4 weeks, totalling 30–60 nymphs. This means it has a great capacity to increase numbers rapidly.

Further research is required to determine the impact of local environment factors on RWA population dynamics.¹⁵ Grain growers are encouraged to contact their agronomist or seek advice from NSW DPI or NSW Local Land Services, or refer to the GRDC website for information on how to manage the pest in cereal crops.

There are tools available to help manage the aphid, including an APVMA [emergency use permit \(PDF, 114.6 KB\)](#) for specific chemicals. Grain growers planning to spray are encouraged to adhere to all general chemical use practices. To limit the spread of the pests and diseases hygiene is important. It is important to put best practice biosecurity measures into place to reduce the risk of transport on clothing, footwear, vehicles and machinery when moving between paddocks and farm.¹⁶

The advice to growers and agronomists is to continue to monitor crops for aphids and symptoms, and if you suspect the presence of the Russian wheat aphid, take a sample for identification.

7.3.1 Damage caused by RWA

RWA differs from other common cereal aphid species in that it injects salivary toxins into the leaf of the host plant during feeding. The toxins kills the photosynthetic chloroplasts and causes chlorosis and necrosis of the infested leaves. This retards growth and, in cases of heavy infestation, kills the plant. The effect of the toxins is localised and hence only infested leaves will show symptoms. Once the RWA infestation has been controlled, the new leaf growth is unaffected.¹⁷

Yield losses are proportionate to RWA abundance, measured as either the percentage of plants infested or aphid numbers per shoot. According to overseas data, losses of one tonne per hectare occurred in plants 95% infested with RWA at

11 DPI NSW (2016) First case of Russian wheat aphid confirmed in NSW. <http://www.dpi.nsw.gov.au/about-us/media-centre/releases/2016/first-case-of-russian-wheat-aphid-confirmed-in-nsw>

12 DAFF. (2016). Industry alert: Russian wheat aphid found in South Australia. <https://www.daff.qld.gov.au/plants/health-pests-diseases/industry-alert-russian-wheat-aphid-found-in-south-australia>

13 KK Nkongolo, JS Quick, WL Meyer, FB Peairs (1989) Russian wheat aphid resistance of wheat, rye, and triticale in greenhouse tests. Cereal Research Communications, 227–232.

14 S Watt (2016) Gloves are up in sustained FITE against Russian wheat aphid. GRDC, <https://grdc.com.au/Media-Centre/Media-News/South/2016/06/Gloves-are-up-in-sustained-FITE-against-Russian-wheat-aphid>

15 Farming Ahead (2016) Monitor RWA numbers closely over winter. 29 June 2016. Farming Ahead, <http://www.farmingahead.com.au/articles/1/12169/2016-06-29/cropping/monitor-rwa-numbers-closely-over-winter>

16 DPI NSW (2016) First case of Russian wheat aphid confirmed in NSW. DPI NSW, <http://www.dpi.nsw.gov.au/about-us/media-centre/releases/2016/first-case-of-russian-wheat-aphid-confirmed-in-nsw>

17 Farming Ahead (2016) Monitor RWA numbers closely over winter. 29 June. Farming Ahead, <http://www.farmingahead.com.au/articles/1/12169/2016-06-29/cropping/monitor-rwa-numbers-closely-over-winter>

growth stage (GS) 59. In another overseas study, losses increased from 18% with 15–20 aphids per shoot to 79% with 185–205 aphids per shoot.¹⁸

7.3.2 Where to look and what to look for

According to entomologists at the South Australian Research and Development Institute (SARDI), RWA is being regularly found in early sown crops or those sown into paddocks containing volunteer cereals. There are also a number of grass weed and pasture hosts of RWA, including barley grass, brome grass (which it particularly likes, based on overseas information), fescue, ryegrass, wild oats, phalaris and couch grass.

Symptoms of RWA damage include longitudinal rolling of leaves where the aphids shelter, and whitish, yellowish to pink–purple chlorotic streaks along the length of the leaves. These symptoms can easily be confused with nutrient deficiency or herbicide damage from bleaching herbicides such as diflufenican, so care is needed in identifying the cause.

RWA is approximately 2 mm long, and a pale yellowish-green colour with a fine, waxy coating. The lack of visible cornicles and the elongated body distinguishes RWA from common cereal aphid species.

RWA can be confused with the rose grain aphid; however, RWA differs due to its dark or black eyes, double short 'tails' (caudal processes), short antennae and apparent lack of cornicles (Figure 2).

Distinguishing characteristics/description

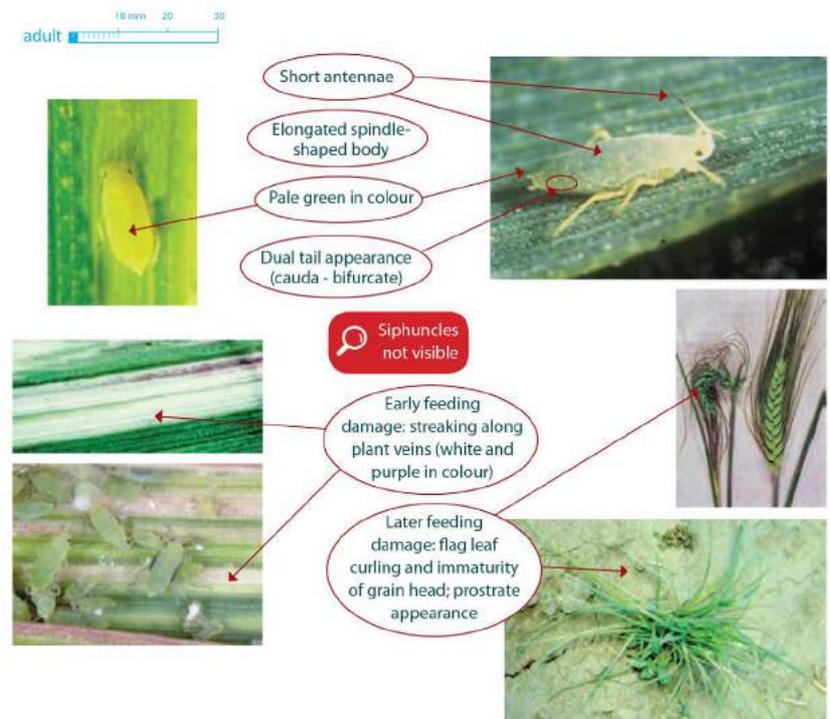


Figure 2: Distinguishing characteristics of the Russian wheat aphid.

Source: GRDC

Growers are encouraged to work with their agronomist or seek expert advice from an entomologist to help positively identify RWA if they are unsure. State agriculture departments are keen to take samples of RWA in order to build up scientific information about the pest, including by sampling different populations.

¹⁸ A Lawson (2016) Paddock practices, Southern, June 2016: Monitor RWA numbers closely over winter. GRDC, <https://portal.biosecurityportal.org.au/rwa/Documents/Paddock%20Practices%20Southern%20June%202016.pdf>

Measures to increase the likelihood of detecting RWA

- Target early sown cereal crops and volunteer cereals (and brome grass, if present), particularly along crop edges.
- Follow a repeatable sampling pattern which targets early sown and volunteer plants. A perimeter search and a W-shaped search pattern through each paddock will give a consistent sampling effort.
- Symptoms to look for:
 - Rolling of terminal and sub-terminal leaves (GS 20 and above).
 - Longitudinal whitish to pink–purplish streaking of leaves (GS 20 and above, Photo 3).
 - Deformed ‘fish hook’ head as result of awn being trapped by unrolled flag leaves (GS 50 and above, Photo 4).



Photo 3: Plants damaged by toxins from feeding Russian wheat aphid (*Diuraphis noxia*), showing stunting and longitudinal striping on tightly rolled leaves.

Source: [FAO](#)

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 4: 'Fish hook' deformation of a cereal head (right) caused by feeding Russian wheat aphid, compared to normal cereal head (left).

Source: [FAO](#)

- To find the RWA, search within:
- rolled leaves, particularly in the leaf base (Photo 5)
- leaf sheaths
- exposed parts of the plant at base of plants (when number of RWA are high)
- At low densities plant beating has proven to be a successful means of detection.¹⁹



Photo 5: Colony of Russian wheat aphids.

Photo: F. Peairs

i MORE INFORMATION

[Russian wheat aphid: Taking and submitting samples for identification](#)

¹⁹ PIRSA (2016) Russian wheat aphid. PIRSA, http://www.pir.sa.gov.au/biosecurity/plant_health/exotic_plant_pest_emergency_response/russian_wheat_aphid

7.3.3 Thresholds for control

While registered chemical control tactics will be important in managing infestations of RWA, growers are encouraged to consider international economic thresholds (below) as a guide for when to spray for the pest, as economic thresholds still need to be determined under Australian conditions. In the meantime, the key message is not to implement prophylactic insecticide applications, and to avoid spraying where RWA is only present in very low numbers.

Current international advice suggests an economic threshold of 20% of plants infested up to the start of tillering and 10% of plants infested thereafter. These thresholds serve as a guide, and need to be considered based on the individual situation. The decision to spray should be based upon a wide range of factors including:

- aphid numbers
- growth stage of crop and time of season
- crop yield potential
- cost of the control option to be employed
- presence of populations of beneficial insects
- yield loss likely in Australian conditions
- forecast weather conditions
- other insect pest species present

In the majority of cases identified to date, RWA has been present in very low numbers and infestations have been well below international economic thresholds. Regular monitoring of aphid numbers through winter and spring will be required to ensure appropriate control measures can be implemented when required. Overseas data indicate that RWA is susceptible to heavy winter rainfall, and the combination of cold and wet weather will help check its build-up during mid-winter.

To ensure protection of the major yield-contributing leaves it is most important to control RWA to below threshold levels from the start of stem elongation, through flag leaf development and ear emergence (GS 30–60). As a result, vigilant monitoring for RWA is encouraged during these crop stages, and should continue through flowering to dough development.²⁰

7.3.4 Management of RWA

Control options

An emergency Australian Pesticides and Veterinary Medicines Authority permit (PER82792) has been issued for the use of products containing 500 g/L chlorpyrifos (rate: 1.2 L/ha), with a LI700 surfactant (rate: 240 mL/ha), and products containing 500 g/kg pirimicarb (rate: 200–250 g/ha) to control RWA in winter cereals.

APVMA has also issued a permit (PER82304) for the use of products containing 600 g/L imidacloprid as their only active constituent. The application rate is 120 mL product per 100 kg seed. This is for seed treatment only for the control of Russian wheat aphid in winter cereals.

All sections of the chemical labels and permits must be read and understood by all persons before use, and used in accordance with instructions given:

- [Permit 82792 PDF](#)
- [Permit 82792 Word](#)
- [Permit 82304 PDF](#)
- [Permit 82304 Word](#)

VIDEOS

WATCH: [GCTV20: Russian wheat aphid—recommendations for ongoing treatment](#)



WATCH: [Integrated pest management to combat the Russian wheat aphid](#)



²⁰ A Lawson (2016) Paddock practices, Southern, June 2016: Monitor RWA numbers closely over winter. GRDC, <https://portal.biosecurityportal.org/au/rwa/Documents/Paddock%20Practices%20Southern%20June%202016.pdf>

i MORE INFORMATION

[Russian wheat aphid a new pest for Australian cereal crops](#)

[Ramp up monitoring for Russian wheat aphid](#)

[Monitor RWA numbers closely over winter](#)

Plant Health Australia, [Russian wheat aphid](#)

[Russian wheat aphid surveillance reporting sheet](#)

NSW DPI, [Russian wheat aphid exotic pest alert](#)

[Russian wheat aphid: paddock decontamination protocol](#)

Russian Wheat Aphid Technical Group, [RWA distribution map](#)

[A pictorial guide to distinguish winged aphids](#)

There are numerous statements (e.g. 'do not' statements) on the product labels that it is critical to follow so as to properly manage the risks associated with the use of chemicals. Examples of such statements include:

- Do not spray any plants in flower while bees are foraging.
- Do not re-apply to the same crop within seven days (unless specifically recommended in the directions for use).
- Do not apply if heavy rains or storms that are likely to cause surface run-off are forecast in the immediate area within two days of application.
- Do not allow animals, including poultry, access to treated area within three days of application.

General instructions

- Read and follow the APVMA permit and labels of associated chemical products.
- Ensure all 'do not' statements and relevant withholding periods, export slaughter intervals (ESIs) and export grazing intervals (EGIs) are observed.
- Adopt best-practice farm-hygiene procedures to retard the spread of the pest between paddocks and adjacent properties.
- Keep traffic out of affected areas, and minimise movement in adjacent areas.²¹

7.4 Other aphids

Aphids are usually regarded as a minor pest of winter cereals, but in some seasons they can build up to very high densities. Aphids are most prevalent on cereals in late winter and early spring. High numbers often occur in years when there is an early break in the season and mild weather in autumn and early winter provide favourable conditions for colonisation and multiplication.

Four species of aphid infest winter cereals:

1. [oat or wheat aphid](#)
2. [corn aphid](#)
3. [rose-grain aphid](#)
4. [rice root aphid](#)

Aphids are a group of soft-bodied bugs commonly found in a wide range of crops and pastures. Identification of crop aphids is very important when making control decisions. Distinguishing between aphids can be easy in the non-winged form but challenging with winged aphids.

7.4.1 Oat or wheat aphid

The oat aphid (*Rhopalosiphum padi*) is an introduced species. It is a relatively common pest that is found in all states of Australia and is most prevalent in wheat and oats. Oat aphids typically colonise the lower portion of plants, with infestations extending from around the plant's base, up on to the leaves and stems.

This aphid has an olive green to greenish-black body with a characteristic rust-red patch on the end of the abdomen, although sometimes this is not apparent. Adults are approximately 2 mm long, pear-shaped, and have antennae that extend half the body length (Figure 3).²² Adults may be winged or wingless and tend to develop wings when plants become overcrowded or unsuitable.²³

Oat aphids are an important vector of Barley yellow dwarf virus (BYDV). They can affect cereals by spreading BYDV as well as by direct-feeding damage to plants when in sufficient numbers. Triticale is not as susceptible to BYDV as other cereals.

²¹ Agriculture Victoria (2016) Russian wheat aphid treatment advice. Agriculture Victoria, agriculture.vic.gov.au/_data/assets/word_doc/0017/321164/Final-RWA-Treatment-Factsheet.docx-docx

²² P Umina, S Hangartner (2015) Oat aphid. cesar, <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Oat-aphid>

²³ P Umina, S Hangartner (2015) Oat aphid. cesar <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Oat-aphid>

When populations exceed thresholds, the use of targeted spraying with selective insecticides is recommended.

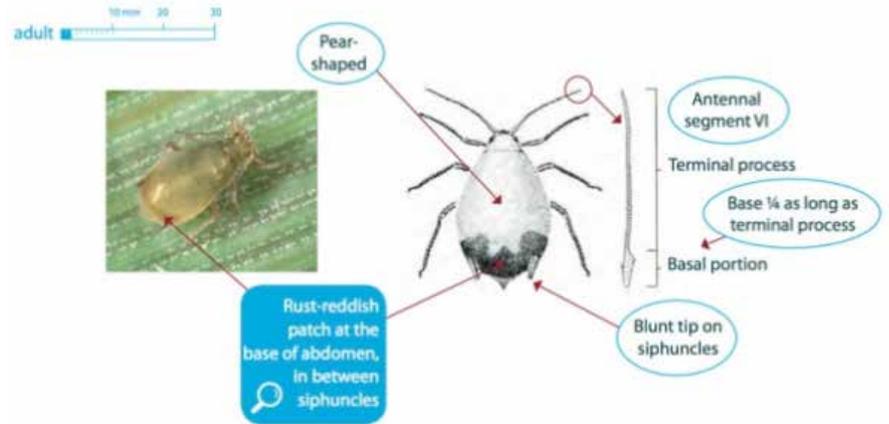


Figure 3: Distinguishing characteristics of the oat or wheat aphid.

Source: cesar

7.4.2 Corn aphid

The corn aphid (*Rhopalosiphum maidis*) is introduced, and is a relatively minor pest of cereal crops. It attacks all crop stages, but most damage occurs when high populations infest cereal heads. The corn aphid is most prevalent in years when there is an early break to the season followed by mild weather conditions in autumn. It transmits a number of plant viruses, which can cause significant yield losses.

Corn aphids are light green to dark green, with two darker patches at the base of each cornicle (siphuncle). Adults grow up to 2 mm long, have an oblong-shaped body, and antennae that extend to about a third of the body length (Figure 4). The legs and antennae are typically darker in colour.

Nymphs are similar to adults but smaller in size and always wingless, whereas adults may be winged or wingless.²⁴

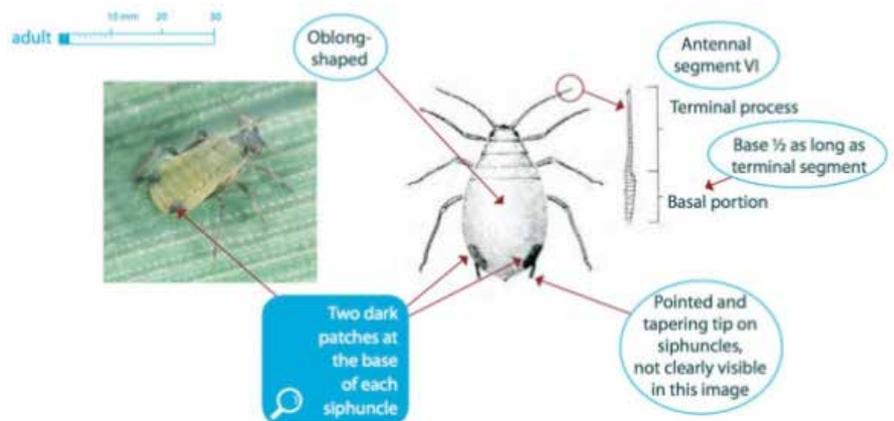


Figure 4: Distinguishing characteristics of the corn aphid.

Source: cesar

²⁴ P Umina, S Hangartner (2015) Corn aphid. cesar, <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Corn-aphid>

7.4.3 Rose-grain aphid

The rose-grain aphid (*Metopolophium dirhodum*) is an introduced species that has been recorded in New South Wales, Queensland, South Australia, Victoria and Tasmania.

Adults and nymphs are sap-suckers. Under heavy infestations, plant may turn yellow and appear not to thrive. They can spread Barley yellow dwarf virus in wheat and barley.

Adults are 3 mm long, green to yellow-green, with long and pale siphunculi (tube-like projections on either side at the rear of the body). They may have wings (Photo 6).²⁵ There is a dark green stripe down the middle of the back. Antennae reach beyond the base of the siphunculi. Nymphs are similar, but smaller in size. Because of its distinctive colour, it is unlikely to be confused with other aphids.



Photo 6: Adult rose-grain aphid with nymphs.

Source: DAF Qld

7.4.4 Rice root aphid

The rice root aphid (*Rhopalosiphum rufiabdominalis*) colonises the roots of the plants under the soil surface, although colonies may extend up to the base of the plant. They are most noticeable when the bases of plants are exposed, often during periods of moisture stress.²⁶

Fully grown aphids are 1.2–2.2 mm long, and dark green to grey-brown (Photo 7). Nymphs are lighter in colour, with a reddish area at the tip of the abdomen. Rice root aphids suck fluids from the plant roots, but only do so when the bases of plants are exposed.

They cannot be controlled using contact insecticides because they are below the ground. Seed dressings may be effective.²⁷

²⁵ DAF Queensland (2011) Rose-grain aphid. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/aphid-overview/rose-grain-aphid>

²⁶ DAF Queensland (2010) Rice root aphid. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/aphid-overview/rice-root-aphid>

²⁷ DAF Queensland (2010) Rice root aphid. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/aphid-overview/rice-root-aphid>



Photo 7: *Adult rice root aphid.*

Source: University of California

7.4.5 Damage caused by aphids

Aphids can impair crop growth in the early stages, and prolonged infestations can reduce tillering and result in earlier leaf senescence. Infestations during booting to the milky dough stage, particularly where aphids are colonising the flag leaf, stem and ear, will result in yield loss, and aphid infestations during grainfill may result in low protein grain (Photo 8).²⁸



Photo 8: *Corn aphids are found in furling leaves and tillers any time from seedling to head emergence.*

Source: cesar

As aphids may compete for nitrogen (N) with the crop, crops grown with marginal levels of N may be more susceptible to the impact of an aphid infestation. In barley, aphids can spread BYDV. Significant yield losses occur when aphids transmit the virus in the first 8–10 weeks after emergence. While the virus can have a large effect

28 P Umina, S Hangartner (2015) Corn aphid. cesar, <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Corn-aphid>

on barley yield in some areas, it is not considered a major problem in Queensland in most seasons. In virus-prone areas, use resistant plant varieties to minimise losses due to BYDV.

Adults and nymphs suck sap and produce honeydew. Very high numbers may cause stress in the plants, which will show up as yellowing or wilting in extreme infestations. The symptoms are more common in moisture-stressed crops.

Direct-feeding damage may occur when colonies develop on stems, heads or leaves. Aphids can affect root development, the number of tillers, seed set and grain size.

Aphid infestations may initially be detected on crop edges. Winged aphids will disperse throughout the field and colonise, creating hotspots across the field. As populations grow, infestations will become more uniform across the field.²⁹

Inspect for aphids throughout the growing season by monitoring leaves, stems and heads as well as exposed roots. Choose six widely-spaced positions in the crop and at each position examine five consecutive plants. Research is under way into damage thresholds and control options for aphids that affect cereals. Some research indicates that aphid infestations can reduce yield by around 10% on average.

7.4.6 Conditions favouring aphid development

Aphids can be found all year round, often persisting on a range of volunteer grasses and self-sown cereals during summer and early autumn. Winged aphids fly into crops from grass weeds, pasture grasses or other cereal crops, and colonies of aphids start to build up within the crop.

Aphids are most prevalent on cereals in late winter and early spring. High numbers often occur in years when there is an early break in the season and mild weather in autumn and early winter provide favourable conditions for colonisation and multiplication.

The different species prefer different parts of the plant:

- Oat aphid—basal leaves, stems and back of ears of wheat, barley and oats.
- Corn aphid—inside the leaf whorl of the plant, where cast skins indicate their presence, but seldom on cereals.
- Grain aphid—the younger leaves and ears of wheat, oats and barley.
- Rose grain aphid—the underside of lower leaves and moves upwards as these leaves die.³⁰

Aphids can reproduce both asexually and sexually, although in Australia the sexual phase is often lost and most aphids reproduce asexually, whereby females give birth to live young.

In the Northern Region, temperatures during autumn and spring are optimal for aphid survival and reproduction. During these times, several generations of aphids may breed. Populations peak in late winter and early spring; development rates are particularly favoured when daily maximum temperatures reach 20–25°C.

Young, wingless aphid nymphs develop through several growth stages, moulting at each stage into a larger individual.

Plants can become sticky with honeydew excreted by the aphids. When plants become unsuitable or overcrowding occurs, the population produces winged aphids (alates), which can migrate to other plants or crops.

29 IPM Guidelines (2016) Aphids in winter cereals. Queensland Government and GRDC, <http://ipmguidelinesforgrains.com.au/pests/aphids/aphids-in-winter-cereals/>

30 IPM Guidelines (2016) Aphids in winter cereals. Queensland Government and GRDC, <http://ipmguidelinesforgrains.com.au/pests/aphids/aphids-in-winter-cereals/>

7.4.7 Thresholds for control

Key points:

- Control may be warranted if populations reach 10–15 aphids per tiller. Though these thresholds have been designed for wheat, they can also be relevant to triticale.

When determining economic thresholds for aphids, it is critical to consider several other factors before making a decision. Most importantly, the current growing conditions and moisture availability should be assessed. Crops that are not moisture stressed have a greater ability to compensate for aphid damage and will generally be able to tolerate far higher infestations than moisture-stressed plants before a yield loss occurs.

Thresholds for managing aphids to prevent the incursion of aphid-vectored virus have not been established and will be much lower than any threshold to prevent yield loss via direct feeding.³¹

Aphid populations can decline rapidly, which may make control unnecessary. In many years aphid populations will not reach threshold levels.

Management decisions need to be based on a number of key criteria as well as some more obscure ones that are still valid parts of the system and therefore the decision framework. The obvious criteria are disease spread (barley yellow dwarf virus), aphid numbers per plant or per tiller on average across the field and their likely build up, predator and parasite numbers and their likely build up, cost of control including application costs, effectiveness of control choice, soil moisture and nutrient status, potential yield reduction caused, and expected value of the commodity at time of sale. Less obvious things to consider include: a crop with low vigour will not be as good a weed competitor, nor will it recover as well from being checked by an herbicide application or frost. Secondary root development (critical to subsoil moisture use and plant stability) appears to be affected by oat aphid. Stubble cover following the crop will be reduced in areas of heavy pressure. Management of operations on the farm must also be considered. Crop uniformity and timing to harvest can be affected.

A guide to thresholds being evaluated by the NGA in conjunction with the Qld DPI indicates that a level of 10–15 aphids per tiller—and increasing—appears a realistic trigger population for control. Early in the crop, during the establishment phase, sample the crown and sub crown roots for oat aphid, particularly in years with a dry start. This threshold number will be lower if application costs are reduced by piggy backing on another in-crop spray. If a spray is timed too early or does not clean up the population sufficiently their numbers may flare again later in the crop.³²

7.4.8 Managing aphids

Controlling aphids during early crop development generally results in the roots and shoots recovering to the normal rate of development, but there can be a delay. Aphids are more readily controlled in seedlings and pre-tiller crops, which are less bulky than post-tiller crops. Corn aphids in the terminal leaf tend to disappear as crops come into head, and other species generally also decline in abundance about this time as natural enemy populations build up. A locally wet summer and autumn is generally a precursor to an aphid outbreak, as there are abundant alternative hosts to breed up on.

Chemical control

Seed treatments and foliar sprays can be used to control aphid infestations. Seed treatments frequently give 70–100 days suppression of aphid numbers. In heavy aphid years, particularly if the infestation occurs early in the crop, there is a clear

³¹ P Umina, S Hangartner (2015) Oat aphid. cesar. <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Oat-aphid>

³² T Lockrey (2010) Aphids in wheat and barley—they are already there! Northern Growers Alliance. <http://www.nga.org.au/results-and-publications/download/40/australian-grain-articles/pests-1/aphids-in-cereals-july-2010.pdf>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

advantage using an aphicide seed treatment against not treating at all. In recent NGA trials an economic advantage of \$25-\$50 per hectare was realised from seed treatment in a year with high pressure. However, if aphid pressure was very low there would be an economic disadvantage to treating seed. If aphids came late and in high numbers a foliar spray may still be required to top up control. It appears now that with a couple of seed treatment registrations to choose from, lower per hectare cost and more regular aphid pressure, the seed treatments are coming back into contention. They are soft on beneficial arthropods because they are only picked up by sap feeders. Seed treatments may also be effective in minimising the spread of Barley yellow dwarf virus.

Some useful foliar spray options also exist for in-crop control. Products include conventional chemistry with some systemic activity as well as pirimicarb that has some fumigant activity (if it is warm enough) and is softer on beneficials. Cost of products are approx \$5-\$8/ha plus application with returns similar to the seed treatments of a \$25-\$50 per hectare in recent trials under moderate to heavy aphid pressure. The advantage of a foliar spray is that money is not spent until there is a clear advantage in doing so. Careful monitoring is required to ensure timing is correct. The correct product and rate along with adequate coverage are the keys to getting good control.

Early control of infestations around the edge of the crop by using a border spray may delay or prevent more widespread infestation of the crop.

If rain is forecast, delay any planned chemical control, and check the crop again after rain before deciding on the control method, as intense rainfalls can reduce aphid infestations by dislodging aphids from the plants.

Foliar insecticides registered for aphid control are generally broad-spectrum, meaning that, as well as killing aphids, they also kill aphids' natural enemies, beneficial insects such as ladybird beetles and larvae, hover fly larvae, lacewing larvae or parasitic wasps. Broad-spectrum insecticides also increase the likelihood of aphid infestations later in the season. Refer to the beneficial impact table (Table 4, Section 7.2 Integrated weed management) from the IPM Guidelines website to identify products least likely to harm beneficials that aren't being targeted.

For up to date information for chemical registrations, see the APVMA website.

MORE INFORMATION

Aphid management in winter cereals—necessary or just an added cost?

IN FOCUS

Aphids in cereals—Northern region

Key point:

- Parasites and predators will control aphid populations but speed of control can be a problem
- Oat aphids appear to affect yield by reducing the number of viable tillers.
- Seed treatments give economic control. Average net benefit was up to \$36/ha.
- Foliar sprays effective if timing is right.

The Northern Growers Alliance conducted two intensive 'in-house' trials at Moree and Edgeroi evaluating a range of management options on Grout and Fitzroy barley. In addition, eight trials were conducted in collaboration with I&I NSW and DEEDI at Dalby, Lundavra, Yallaroi, Bullarah, Cryon, Tamworth, Spring Ridge and Gilgandra. These trials compared the impact of aphids on a barley, bread wheat and durum under the same conditions. The imidacloprid seed treatment did not give season long control in 2008. In 2009, a higher rate of imidacloprid was included in all trials. All treatments had the equivalent loading of fungicide seed treatment

SECTION 7 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

MORE INFORMATION

[Aphids in cereals](#)

(triadimenol (Baytan®) in barley and tebuconazole (Raxil®) in wheat and durum).

Key treatments in all 2009 trials were:

- Imidacloprid at 'low' label rate (Imid 1x) - Zorro® on barley, Hombre® on wheat and durum, both at 400 mL/100 kg seed
- Imidacloprid at 'high' label rate (Imid 2x) - Emerge® at 240 mL/ 100 kg seed on all crops
- Foliar applications of pirimicarb (Pirimor®) when the aphid population was at 10/tiller and rising

Crops were monitored for aphid populations, and the resulting expenses and yield was accounted for.

The results suggest that insecticidal seed treatments will give an economic benefit on all three cereal types. The seed treatments returned a net benefit, even at sites where the aphid pressure was low (average net benefit \$14/ha). Where aphid pressure was higher a net \$ benefit was achieved in 75% of cases, with an average return of \$41/ha. These results show that foliar sprays for aphid control can give an economic benefit. If the sprays can be combined with other paddock operations or cheaper products used these benefits could be higher. In these trials a threshold of 10 aphids per tiller was used assuming the aphids were above ground and that the population was increasing.³³

Biological control

In most seasons, aphids build up in winter cereal crops and then decline rapidly without any intervention. The activity of natural enemies—predators, parasitoids and occasionally disease—are responsible for this population decline.

Preserving natural enemies is important in managing aphid populations in the long term, as the beneficials can effectively control small to moderate aphid infestations. However, as they may not arrive early enough to prevent the build-up of aphids to above threshold, they are generally considered to be most useful in controlling individuals and small colonies that may survive an insecticide application, preventing the need for subsequent treatments.³⁴ For this reason, the use of soft options (e.g. pirimicarb) for aphid control should be considered, particularly if the aphid infestation is being treated in the early stages of crop development (prior to grainfill) when there is the potential for aphid infestations to resurge. Beneficials may also control large aphid populations, but often not until the crop is maturing, which may be too late to prevent an impact on yield.

The presence of bloated aphids with pale gold or bronze sheen (mummies) indicates parasitoid activity in the crop.

Aphid fungal diseases can cause a rapid reduction in aphid population in wetter seasons. Fungal infection is detected by the presence of white, fluffy growth on aphids, particularly on the lower leaves and stems.

Cultural control

Control weeds and volunteers to minimise early infestation of crops. Aphids and BYDV survive over summer on self-sown cereal and perennial grasses.

³³ L Price (2009) Aphids in cereals. Northern Grower Alliance. <http://nga.org.au/results-and-publications/download/19/grdc-update-papers-pests/aphids-in-winter-cereals/>

³⁴ DAF Queensland (2012) Insect pest management in winter cereals. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals>

In some seasons, aphid may move over large distances, in which case local weed management will have little impact.

Encourage beneficial populations through the preservation of native vegetation which provides a refuge for them.³⁵

7.4.9 Monitoring

Monitor all crop stages from seedling stage onwards. Look on leaf sheaths and stems, and within whorls and heads, and record the number of large and small aphids (adults and juveniles), beneficials (including parasitised mummies), and the impact of the infestation on the crop.

Stem elongation to late flowering is when the crop is most vulnerable to aphids. Frequent monitoring is required to detect rapid increases in populations.

Check regularly—and check at least five points in the paddock, sampling 20 plants at each point. Densities at crop edges may not be representative of the whole paddock, because populations can be patchy. When sampling, averaging the number of aphids per stem or tiller gives a useful measurement of their density. Repeated sampling will provide information on whether the population is increasing (lots of juveniles relative to adults), stable, or declining (lots of adults and winged adults).³⁶

7.5 Cutworms

Several species of cutworms (*Agrotis* spp.) attack establishing cereal crops in Queensland and New South Wales (as well as South Australia, Tasmania, Victoria and Western Australia). They are sporadic pests. As their name suggests, cutworm larvae sever the stems of young seedlings at or near ground level, causing the collapse of the plant. The moths emerge in late spring and summer, and females lay eggs onto summer and autumn weeds, from where the larvae emerge onto newly sown crops.

Cutworms are caterpillars of several species of night-flying moths, one of which is the well-known Bogong (D) moth. All are similar in appearance, with the mature grubs being plump, smooth caterpillars up to 50 mm long. They have dark heads and usually darkish bodies, often with longitudinal lines and/or dark spots (Figure 5).³⁷ Larvae curl up and remain still if picked up (Photo 9). The moths are a dull brown–black colour,³⁸ with dark brown or grey–black forewings with dark arrow markings on either wing above a dark streak broken by two lighter-coloured dots (Figure 6). Moths of the pink cutworm have grey-brown forewings with darker markings and streaks and a large inner light mark and darker outer mark. Moths of the black cutworm have brown or grey–black forewings with a dark arrow-mark streak broken by two dark ring-shaped dots.

They are most damaging when caterpillars transfer from summer and autumn weeds onto newly emerged seedlings. Natural predators and early control of summer and autumn weeds will help reduce larval survival prior to crop emergence. If required, cutworms can be controlled with insecticides; spot spraying may provide adequate control.

An abundance of top growth that is poorly incorporated may cause poor seed-to-soil contact in the subsequent crop and may attract armyworms or cutworms.

35 IPM Guidelines (2016) Aphids in winter cereals. Queensland Government and GRDC, <http://ipmguidelinesforgains.com.au/pests/aphids/aphids-in-winter-cereals/>

36 IPM Guidelines (2016) Aphids in winter cereals. Queensland Government and GRDC, <http://ipmguidelinesforgains.com.au/pests/aphids/aphids-in-winter-cereals/>

37 S Hangartner, G McDonald, P Umina (2015) Cutworm. cesar, <http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Cutworm>

38 DAF Queensland (2010) Cutworm. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/soil-insects/cutworm>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Distinguishing characteristics/description



No distinct lines on sides of body and subtle longitudinal line may be present along midline upper (dorsal) surface

Larva

8th abdominal segment spiracle (breathing hole)

4 abdominal prolegs

Spiracles

Dark head region

Plump, smooth, and greasy appearance with relatively few stout hairs with dark pigmentation at their base

Cervical shield stripe can be present or absent

4 abdominal prolegs

Figure 5: Distinguishing characteristics of the cutworm.

Source: cesar



Photo 9: Cutworm larva in the typical curled position it assumes when disturbed.

Source: cesar

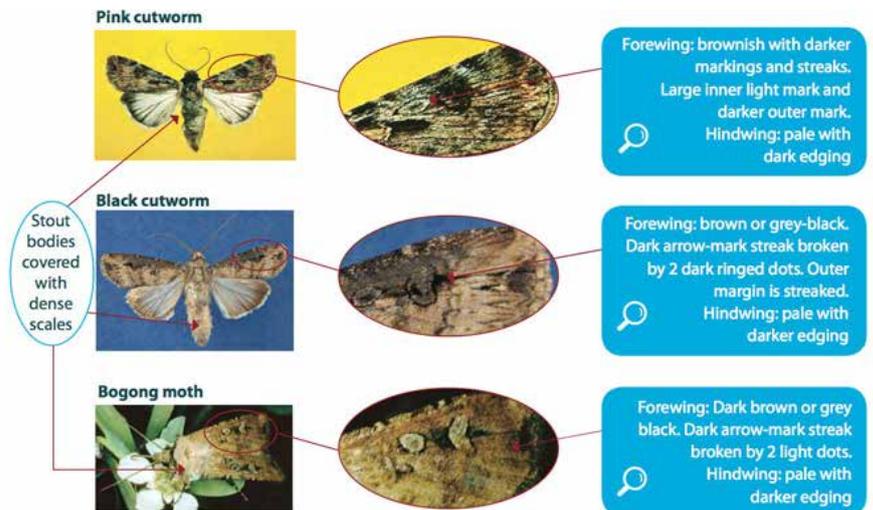


Figure 6: Distinguishing characteristics of the adult forms of the pink, black and common cutworm.

Source: cesar

Triticale has had mixed response to cutworm damage in Australia. In trials in WA, researchers found that triticale could regenerate quickly after being attacked by cutworm four weeks after sowing.³⁹ In the south-west slopes of New South Wales near Tarcutta, cutworms were reported to have caused severe damage to several germinating triticale crops. The damage observed was quite patchy, with some areas suffering 100% plant death. Most problems were observed in paddocks that had held weeds and stubble over summer, while ‘clean’ paddocks that had been cropped in previous years typically had few problems. Prolonged autumn green feed is likely to have allowed caterpillars to develop to a large size by the time crops started to emerge. Chemical control was required in the worse-affected paddocks, after which the crop was re-sown and emerged well.⁴⁰

7.5.1 Damage caused by cutworms

All field crops can be attacked. Crops are at most risk during seedling and early vegetative stages.⁴¹ Winter crops are most susceptible in autumn and winter, although damage can occur throughout the year, especially in irrigated crops. Larvae feed at ground level, chewing through leaves and stems, and stems are often cut off at the base. Damage mostly occurs at night, which is when the larvae are active. When numbers of larvae are high, crops can become severely thinned (Photo 10). When smaller larvae feed on the surface tissue of the leaf, they can cause similar damage to the lucerne flea. Young plants are favoured and are worse affected than older plants.

³⁹ C Johnstone (2011) Triticale variety demonstration 2011. Online Farm Trials, <http://www.farmtrials.com.au/trial/10587>

⁴⁰ G McDonald, A Govender, P Umina (2010) Cutworms. PestFacts. Issue 3, 21 May 2010. cesar, <http://www.cesaraustralia.com/sustainable-agriculture/pestfacts-south-eastern/past-issues/2010/pestfacts-issue-no-3-21st-may-2010/cutworms/>

⁴¹ DAF Queensland (2010) Cutworm. DAF Qld, <https://www.daf.qld.gov.au/business-priorities/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/soil-insects/cutworm>



Photo 10: Pink cutworm damage to the plant and paddock.

Source: cesar

7.5.2 Conditions favouring development

Usually cutworms have a single generation during the early vegetative stages of the crop. Moths prefer to lay their eggs in soil in lightly vegetated (e.g. a weedy fallow) or bare areas. Early autumn egg-laying results in the most damage to young cereals. Larvae hatch, and feed on host plants right through to maturity, when they descend to the soil to pupate below ground. Under favourable conditions, the duration from egg-laying to adult emergence is 8–11 weeks, depending on the species.⁴²

7.5.3 Thresholds for control

Inspect the crop twice weekly in the seedling and early vegetative stage. Larvae feed late afternoons and evenings.

Chemical control is warranted when there is a rapidly increasing area or proportion of crop damage.

Chemical control may be warranted if larval numbers exceed one per square metre in emerging crops.⁴³

7.5.4 Management of cutworms

Controlling weeds in the fallow at least 3–4 weeks before planting will assist in reducing the cutworm population and therefore crop damage also.

The best time to monitor is late afternoons and evenings when larvae feed. If inspecting the crop during the day, scratch away soil around damaged plants to find larvae sheltering in the soil. For more information read [how to recognise and monitor for soil insects](#).⁴⁴

Biological control

Naturally occurring insect fungal diseases that affect cutworms can reduce populations. Wasp and fly parasitoids, including the orange caterpillar parasite (*Netelia producta*), the two-toned caterpillar parasite (*Heteropelma scaposum*) and the orchid dupe (*Lissopimpla excelsa*) can suppress cutworm populations. Spiders, which are generalist predators, will also prey upon cutworms.

⁴² DAF Queensland (2010) Cutworm. DAF Qld, <https://www.daf.qld.gov.au/business-priorities/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/soil-insects/cutworm>

⁴³ DAF Queensland (2010) Cutworm. DAF Qld, <https://www.daf.qld.gov.au/business-priorities/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/soil-insects/cutworm>

⁴⁴ DAF Queensland (2012) Insect pest management in winter cereals. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals>

i MORE INFORMATION

PestNotes: Cutworm

Cultural control

As autumn cutworm populations may be initiated from populations harboured by crop weeds or volunteers in and around the crop, removal of this green bridge 3–4 weeks before crop emergence will remove food for the young cutworms.

If required, cutworms can be easily controlled with insecticides, and spot spraying may provide adequate control. Spraying in the evening is likely to be most effective.

Chemical control

If required, cutworms can be easily controlled with insecticides. Several chemicals are registered for controlling them, the choice depending on the state and crop of registration. Spot spraying often provides adequate control in situations where cutworms are confined to specific regions within paddocks. Spraying in the evening is likely to be more effective as larvae are emerging to feed and insecticide degradation is minimised.⁴⁵

Insecticide application is cost-effective. The whole crop may not need to be sprayed if distribution is patchy; spot spraying may suffice. See Pest Genie or APVMA for current control options.

Refer to the beneficial impact table (Table 4, Section 7.2 Integrated weed management) from the IPM Guidelines website to identify products least likely to harm beneficials that aren't being targeted.

For up to date information for chemical registrations, see the APVMA website.

7.6 Armyworm

The armyworm is the caterpillar stage of certain moths (Photo 11)⁴⁶ and can occur in large numbers, especially after good rain follows a dry period. During the day armyworms shelter in the throats of plants or in the soil, and emerge after sunset to feed. They like to eat young leaf tissue, which gives the leaf margins a tattered appearance. After heavy feeding, only the midrib of the leaf is left. Control is rarely warranted except where large numbers attack small plants.⁴⁷

Barley, oats and rice are most susceptible to economic damage, but armyworms are also commonly found in wheat, triticale and grass pastures where extreme defoliation or head loss does occasionally occur.

Larvae shelter in the throats of plants or in the soil and emerge after sunset to feed on the leaves of all winter cereals, particularly barley and oats, generally during September and October. Leafy cereal plants can tolerate considerable feeding, so control in the vegetative stage is seldom warranted unless large numbers of armyworms are distributed throughout the crop or are moving in a 'front', destroying young seedlings or stripping older plants of leaves. The most serious damage occurs when larvae feed on the upper flag leaf and stem node as the crop matures, or in barley when the older larvae start feeding on the green stem just below the head as the crop matures.

The most common species in the Northern Region are common armyworm and northern armyworm (*Leucania convecta* and *L. separate*, respectively), and lawn armyworm (*Spodoptera mauritia*). They are all native pests.

45 S Hangartner, G McDonald, P Umina (2015) Cutworm. cesar, <http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Cutworm>

46 The Beatsheet (2010) Avenger of the caterpillars ... The Beatsheet, <https://thebeatsheet.com.au/avenger-of-the-caterpillars%E2%80%A6/>

47 DAF Queensland (2010) Armyworms in field crops. DAF Qld, <https://www.daf.qld.gov.au/business-priorities/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/armyworm-overview>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 11: Common armyworm (*Leucania convecta*).

Source: The Beatsheet

The common armyworm is found in all states of Australia and potentially will invade all major broadacre-cropping regions year round, but particularly spring and summer.

The caterpillars of the various armyworm species are similar in appearance. They grow from about 2 mm on hatching to 40 mm in length at maturity. They have three prominent white or cream stripes running down the back and sides of their bodies. These are most obvious where they start on the thoracic segment ('collar') behind the head, and become particularly apparent in larvae that are >10 mm. Armyworms have four abdominal prolegs.⁴⁸ They have no obvious hairs, and feel smooth to touch. They curl up when disturbed.

For an accurate identification, they must be reared through to the adult (moth) stage (Figure 7).

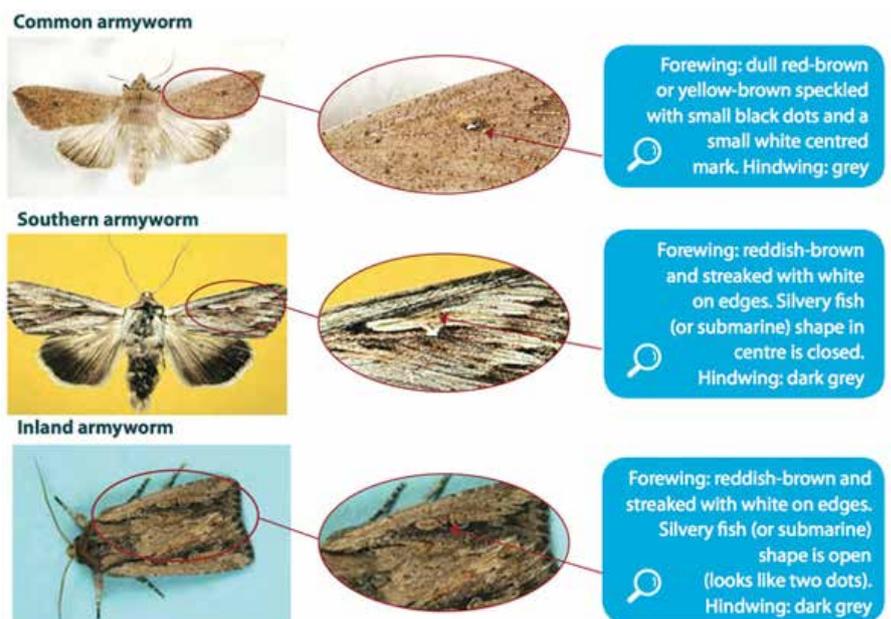


Figure 7: Adult (moth) phase of the three armyworm species that can affect crops.

Source: cesar

48 G McDonald (2015) Armyworm. cesar, <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/armyworm>

However, armyworms can be distinguished from other caterpillar pests that may be found in the same place by their stripes, which stay constant no matter what variation there may be in the colour of the body (Figure 8). Other species of caterpillar which may be confused with armyworms include:

- loopers (tobacco looper or brown pasture looper), which walk with a distinct looping action and have one or two pairs of abdominal prolegs—whereas armyworms have four pairs, and do not walk with a looping action once they are >10 mm.
- budworm larvae, which have prominent but sparse hairs and bumps on their skin, or antherid larvae which are covered in hairs—whereas armyworms are smooth-bodied with no obvious hairs.
- cabbage moth larvae, which wriggle vigorously when disturbed—whereas armyworms curl up into a tight C.
- cutworm (brown or common cutworm) larvae, which have no obvious stripes or markings and are uniformly brown, pink or black.⁴⁹

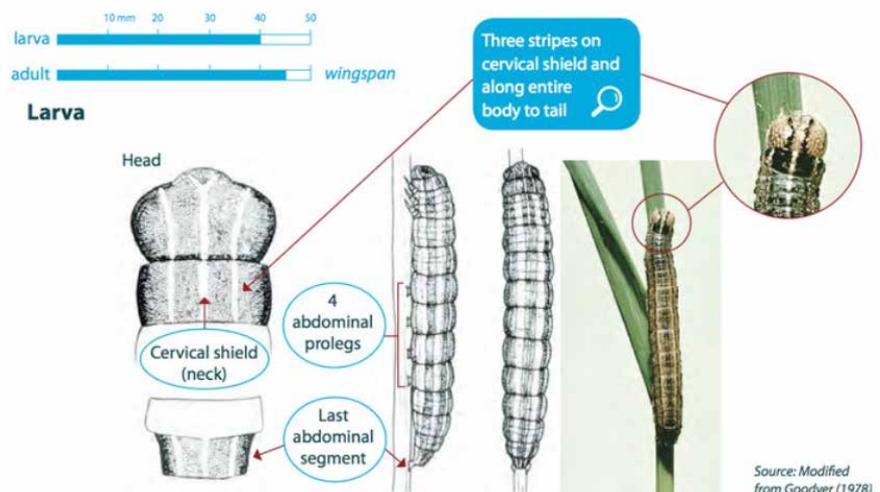


Figure 8: Distinguishing characteristics of the armyworm larva.

Source: cesar

7.6.1 Damage caused by armyworms

Armyworms:

- Prefer lush growth that provides good cover and protection.
- Feed on leaf tissue—leaf margins have a tattered, chewed or scalloped appearance, and in extreme cases whole leaves may be severed at the stem.
- Caterpillars produce green or straw-coloured droppings the size of a match head. These are visible between the rows.
- Bare patches adjacent to barley fields or damage to weeds may indicate armyworm presence before it is evident in crops.⁵⁰

The young larvae feed initially from the leaf surface of pasture grasses and cereals. As the winter and spring progress and the larvae grow, they chew 'scallop' marks from the leaf edges. This becomes increasingly evident by mid to late winter. By the end of winter or early spring, the larvae are reaching full size and maximum food consumption. It is this stage that farmers most frequently notice that complete leaves and tillers may have been consumed or removed from the plant.

Damaging infestations or outbreaks occur in three situations:

⁴⁹ G McDonald (1995) Armyworms. Note AG0412. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/armyworms>

⁵⁰ IPM Guidelines (2016) Armyworm. Queensland Government and GRDC, <http://ipmguidelinesforgrains.com.au/pests/armyworm/>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- In winter, when young tillering cereals are attacked and can be completely defoliated. The caterpillars may come from:
 - the standing stubble from the previous year's cereal crop, in which the eggs had been laid; or
 - neighbouring pastures which have dried out, resulting in the resident armyworms being forced to 'march' into the crop.
- In spring and early summer, when crops commence ripening and seed heads may be lopped.
- In early summer, when grass pastures are cut for hay.

The most damage is caused in ripening crops when the foliage dries off. The armyworms then begin to eat any green areas that remain. In cereals, the last section of the stem to dry out is usually just below the seed head. Armyworms, particularly the older ones, that chew at this vulnerable spot cause lopping of the heads, and they can devastate a crop nearing maturity in one or two nights: one large larva can sever up to seven heads of barley a day (Photo 12),⁵¹ and one larva/m² can cause a loss of 70 kg/ha grain per day. In wheat and barley whole heads are severed, while in oats individual grains are bitten off below the glumes.

The crops affected include all Gramineae crops: cereals, grassy pastures, and maize.



Photo 12: Ragged flag leaf and other leaves on a maturing cereal crop are an indication of the presence of armyworms.

Source: The Beatsheet

7.6.2 Thresholds for control

The economic threshold is estimated at 10 grubs/m² for wheat and triticale, which is higher than for barley because the heads are rarely lopped.⁵²

For winter outbreaks (during tillering), economic thresholds of 8 to 10 larvae per m² provide a guide for spraying decisions. For spring outbreaks (during crop ripening) spraying is recommended when the density of larvae exceeds 1 to 3 larvae per m² although this figure must be interpreted in the light of:

- timing of harvest;

⁵¹ The Beatsheet (2008) Armyworm in wheat. The Beatsheet, <https://thebeatsheet.com.au/armyworm-in-wheat/>

⁵² IPM Guidelines (2016) Armyworm. Queensland Government and GRDC, <http://ipmguidelinesforgrains.com.au/pests/armyworm/>

SECTION 7 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

- green matter available in the crop;
- expected return on the crop; and
- larval development stage (if most are greater than 35–40 mm or pupating, it may not be worth spraying).⁵³

Table 5 shows the value of yield loss incurred by 1 and 2 larva/m² per day, based on approximate values for wheat and an estimated loss of 70 kg/ha per larva. Based on these figures, and the relatively low cost of controlling armyworms, populations in ripening crops in excess of 1 large larva/m² will warrant spraying. This equates to the population of armyworms distributed through the crop causing the loss of 7–15 heads/m² (see Photo 13).

Table 5: *Economic thresholds for control of armyworms.*

Value of grain (\$/t)	Value of yield loss (\$/day)	
	1 larva/m ²	2 larva/m ²
140	9.80	19.60
160	11.20	22.40
180	12.60	25.20
200	14.00	28.00
220	15.40	30.80
250	17.50	35.00
300	21.00	42.00
350	24.50	49.00
400	28.00	56.00



Photo 13: *Armyworms feeding on grain heads.*

Source: [World of Wheat](#)

7.6.3 Managing armyworms

Sampling and detection

Signs of the presence of armyworms include:

⁵³ G McDonald (1995) Armyworms. Note AG0412. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/armyworms>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- Chewing or leaf scalloping along the leaf margins.
- Caterpillar excreta (frass) which collects on leaves or at the base of the plant.
- Cereal heads or oat grains on the ground. Triticale heads may be severed completely, or hang from the plant by a small piece of stalk.

Early recognition of an armyworm problem is vital, as cereal crops can be almost destroyed by armyworms in just a few days, particularly when cereals and pasture seed or hay crops are at the late ripening stage. Although accurate estimates of caterpillar densities require considerable effort, the cost saving is worthwhile.

Check for larvae on the plant and in the soil litter under the plant. The best time to check is late in the day when armyworms are most active. Alternatively, during the day, check around the base of damaged plants where the larvae may be sheltering in the soil.

Sampling can be achieved by using a sweep-net or bucket, or visually searching the ground or crop for caterpillars or signs of damage.

Sweep sampling is particularly useful early in an infestation when the larvae are small and actively feeding in the canopy. The sweep-net or bucket method provides a rapid and approximate estimate of infestation size. The utensil should be swept across the crop in 180° arcs numerous times, preferably 100 times, at different sites in the crop, to give an indication of density and spread. Armyworms are most active at night, so sweeping will be most effective at dusk. Average catches of more than 5–10 per 100 sweeps suggest that further searches on the ground are warranted to determine approximate densities.

When ground sampling, it is necessary to do at least ten spot checks in the crop, counting the number of caterpillars within a square metre.

Most farmers fail to detect armyworms until the larvae are almost fully grown, by which stage 10–20% of the crop may be damaged. The earlier the detection, the less the damage. The young larvae (up to 8 mm) cause very little damage, and are more difficult to find. The critical time to look for armyworms is the last three to four weeks before harvest.⁵⁴

While it is large larvae that do the head lopping, controlling smaller larvae that are still feeding on leaves may be more achievable. Prior to chemical intervention consider how quickly the larvae will reach damaging size and the development stage of the crops. Small larvae take 8–10 days to reach a size capable of head lopping, so if small larvae are found in crops nearing maturity or harvest, no spray may be needed, whereas small larvae in late crops which are still green and at early seed-fill may reach a damaging size in time to significantly reduce crop yield.

Biological control

Around 20 species of predators and parasitoids have been recorded attacking armyworms. The most frequently observed predators are predatory shield bugs, ladybeetles, carabid beetles, lacewings and common brown earwigs. Parasitoids include tachnid flies and a number of wasp species (e.g. *Netelia*, *Lissopimpla* and *Campoletis species*). Viral and fungal diseases are recorded as killing armyworms. Such outbreaks are more common when there are high densities of armyworms.

Cultural control

Control weeds to remove alternative hosts. Armyworm often feed on ryegrass before moving into cereal crops. Standing stubble from previous crops, dead leaves on crops, and grassy weeds are suitable sites for female armyworms to lay eggs.

Larvae may move into cereals if adjacent pastures are chemically fallowed, spray topped or cultivated in spring. Monitor for at least a week after doing any of these things. Damage is generally confined to crop margins.

⁵⁴ G McDonald (1995) Armyworms. Note AG0412. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/armyworms>

Chemical control

To be effective, chemical controls require good coverage to ensure contact with the caterpillars. Control is more difficult in high-yielding crops with thick canopies where larvae rest under leaf litter at the base of plants.

As armyworms are active at night, spray in the late afternoon or early evening to maximise the likelihood of contact.

Be aware of withholding periods when chemical control is used close to harvest.⁵⁵

Refer to the beneficial impact table ([Table 4, Section 7.2 Integrated weed management](#)) from the IPM Guidelines website to identify products least likely to harm beneficials that aren't being targeted.

For up to date information for chemical registrations, see the [APVMA website](#).

7.7 Mites

7.7.1 Brown wheat mite

Brown wheat mite (*Petrobia latens*) damage is only severe in dry seasons, and it is therefore a sporadic pest of winter cereals. It attacks wheat, barley, triticale, oats, cotton and grasses.

The mature wheat mite is about the size of a pinhead, up to 0.6 mm long, globe-shaped and brown (Photo 14), although it can appear to be a deep greenish-brown to black when on a green leaf. Being a mite, it has eight legs, the front legs being significantly longer than the others. It is significantly smaller than the blue oat mite, and has finer legs than, and is also much smaller than the redlegged earth mite, so is unlikely to be mistaken for these two pests.⁵⁶

Adults and nymphs pierce and suck on leaves, giving them a mottled, drought-like appearance. Crops with heavy infestations appear bronzed or yellowish, and seedlings can die.

Monitor for brown wheat mite by checking the crop from planting to the early vegetative stage, particularly in dry seasons. Spray if mottled patches appear throughout the crop and if conditions are dry. Foliar treatments may sometimes be cost-effective. For current chemical control options see [Pest Genie](#) or [APVMA](#).

There are no known natural enemies of the brown earth mite.



Photo 14: *Brown wheat mite, a serious pest of cereals it develops in a dry spring.*

Photo: P Sloderbeck, Kansas State University

⁵⁵ IPM Guidelines (2016) Armyworm. Queensland Government and GRDC, <http://ipmguidelinesforgrains.com.au/pests/armyworm/>

⁵⁶ DAF Queensland (2010) Brown wheat mite. DAF Qld, <https://www.daf.qld.gov.au/business-priorities/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/mites-overview/brown-wheat-mite>

7.7.2 Blue oat mite

The blue oat mites (*Penthaleus spp.*) are important pests of seedling winter cereals, but are generally restricted to cooler grain-growing regions (southern Queensland through eastern New South Wales, Victoria, South Australia and southern Western Australia) (Figure 9).⁵⁷ The blue oat mite (BOM) was introduced from Europe, and first recorded in New South Wales in 1921. Management of these mites in Australia has been complicated by the recent discovery of three distinct species of BOM, which had previously been believed to be a single species. The three species are *Penthaleus major*, *P. falcatus* and *P. tectus*.



Figure 9: The known distribution of blue oat mites in Australia.

Source: cesar

Adult BOM are 1 mm in length and approximately 0.7–0.8 mm wide. They have a blue-black body with a characteristic red mark on the back, and eight reddish-orange legs. (Figure 10). Larvae are approximately 0.3 mm long, oval in shape, and with three pairs of legs. On hatching, BOM are pink–orange in colour, soon becoming brownish and then green.

57 P Umina, S Hangartner (2015) Blue oat mite. cesar, <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Blue-oat-mite>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Figure 10: Distinguishing characteristics of the blue oat mite.

Source: cesar

BOM are often misidentified as redlegged earth mites (RLEM) in the field, which has meant that the damage caused by BOM has been under-represented. Despite having a similar appearance, RLEM and BOM can be readily distinguished from each other: RLEM have a completely black body, and tend to feed in larger groups of up to 30 individuals. BOM have the red mark on their back and are usually found singularly or in very small groups.

The blue oat mite is an important pest of seedling winter cereals and grass pastures, and will also eat pasture legumes and many weeds.⁵⁸ When infestations are severe, the leaf tips wither and eventually the seedlings die.

Eggs laid in the soil hibernate, allowing populations to build up over a number of years. This can cause severe damage if crop rotation is not practised. Check from planting to the early vegetative stage, particularly in dry seasons, monitoring a number of sites throughout the field. Blue oat mites are most easily seen in the cooler part of the day, or when it is cloudy. They shelter on the soil surface when conditions are warm and sunny. If pale green or greyish irregular patches appear in the crop, check for the presence of blue oat mite at the leaf base.⁵⁹

Damage caused by BOM

Mites use adapted mouthparts to lacerate the leaf tissue of plants and suck up the discharged sap. Resulting cell and cuticle destruction promotes desiccation, retards photosynthesis and produces the characteristic silvering that is often mistaken as

i MORE INFORMATION

[PestNotes: Blue oat mite](#)

⁵⁸ DAF Queensland (2010) Blue oat mite. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/mites-overview/blue-oat-mite>

⁵⁹ DAF Queensland (2012) Insect pest management in winter cereals. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals>

frost damage (Photo 15).⁶⁰ BOM are most damaging to newly establishing pastures and emerging crops, greatly reducing seedling survival and retarding development.



Photo 15: Typical blue oat mite damage to leaf.

Source: Agriculture Victoria

Young mites prefer to feed on the sheath leaves or tender shoots near the soil surface, while adults feed on more mature plant tissues. BOM feeding reduces the productivity of established plants, and is directly responsible for reductions in the palatability of pastures to livestock. Even in established pastures, damage from large infestations may significantly affect productivity.

The impact of mite damage is increased when plants are under stress from adverse conditions such as prolonged dry weather or waterlogged soils. Ideal growing conditions for seedlings enable plants to tolerate higher numbers of mites.

There are no economic thresholds established for this pest.

Managing BOM

Though control is not often warranted, it is important to know the critical periods for control (Figure 11). Check from planting to the early vegetative stage, particularly in dry seasons. BOM are most easily seen in the late afternoon when they begin feeding on the leaves.

⁶⁰ Agriculture Victoria (2007) Blue oat mite. Note AG1300. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/blue-oat-mite>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

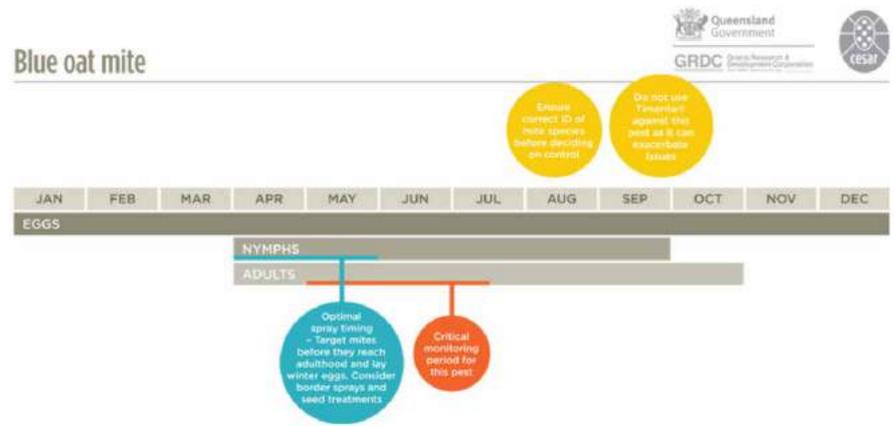


Figure 11: Critical times for managing BOM.

Source: cesar

Biological control

Integrated pest management programs can complement chemical control methods by introducing non-chemical options, such as cultural and biological controls.

Although no systematic survey has been conducted to determine the natural enemies of BOM, a number of predator species are known to attack earth mites in Australia. The most important of these appear to be other mites, although small beetles, spiders and ants may also play a role. The French anystis mite is an effective predator but is limited in distribution. Snout mites will also prey upon BOM, particularly in pastures. Thrips and ladybirds are also natural enemies of BOM. The fungal pathogen, *Neozygites acaracida*, is prevalent in BOM populations during wet winters and could be responsible for observed population crashes.

Preserving natural enemies when using chemicals is often difficult because the pesticides generally used are broad-spectrum and therefore kill beneficial species as well as the pests. Impact on natural enemies can be reduced by using a pesticide that has the least impact and by minimising the number of applications. Although there are few registered alternatives for BOM control, groups such as the chloronicotinyls, which are used in some seed treatments, have a low–moderate impact on many natural enemies.

Cultural control

Cultural controls such as rotating crops or pastures with non-host crops can reduce pest colonisation, reproduction and survival, decreasing the need for chemical control. When *P. major* is the predominant species, canola and lentils are potentially useful rotation crops, while pastures containing predominantly thick-bladed grasses should be carefully monitored and rotated with other crops. In situations where *P. falcatus* is the most abundant mite species, farmers can consider rotating crops with lentils, while rotations that involve canola may be the most effective means of reducing the impact of *P. tectus*.

Many cultural control methods for BOM can also suppress other mite pests, such as RLEM. Cultivation will significantly decrease the number of over-summering eggs, while hot stubble burns can provide a similar effect. Many broad-leaved weeds provide an alternative food source, particularly for juvenile stages. As such, clean fallowing and the control of weeds within crops and around pasture perimeters, especially of bristly ox tongue and cats ear, can help reduce BOM numbers.

Grazing can also reduce mite populations to below damaging thresholds. This may be because shorter pasture results in lower relative humidity, which increases mite mortality and limits food resources. Grazing pastures in spring to less than 2 t/ha feed

on offer (dry weight) can reduce mite numbers to low levels and provide some level of control the following year.⁶¹

Chemical control

Chemicals are the most common method of control against earth mites. Unfortunately, all currently registered pesticides are only effective against the active stages of mites; they do not kill mite eggs.

While a number of chemicals are registered in pastures and crops, differences in tolerance levels between species complicates management of BOM. *P. falcatus* has a high natural tolerance to a range of pesticides registered against earth mites in Australia and is responsible for many control failures involving earth mites. The other BOM species have a lower level of tolerance to pesticides and are generally easier to control with chemicals in the field.

Chemical sprays are commonly applied at the time of infestation, when mites are at high levels and crops already show signs of damage. Control of first generation mites before they can lay eggs is the best way to avoid a second spray. Hence, pesticides used at or after sowing should be applied within three weeks of the first appearance of mites, as adults will then begin laying eggs. While spraying pesticides in spring can greatly reduce the size of RLEM populations the following autumn, this strategy will generally not be as effective for the control of BOM.

Pesticides with persistent residual effects can be used as bare-earth treatments. These treatments can be applied prior to, or at sowing to kill emerging mites and protect the plants throughout their seedling stage.

Systemic pesticides are often applied as seed dressings to maintain the pesticide at toxic levels in the plants as they grow. This can help minimise damage to plants during the sensitive establishment phase, although if mite numbers are high significant damage may still occur before the pesticide has much effect.

To prevent the build-up of resistant populations, spray pesticides only when necessary, and rotate chemical use by selecting pesticides from different chemical classes with different modes of action. To avoid developing multiple pesticide resistance, rotate chemical classes across generations rather than within a generation.⁶²

Information on the registration status, rates of application and warnings related to withholding periods, occupational health and safety (OH&S), residues and off-target effects should be obtained before making decisions on which pesticide to use. This information is available from the chemical standards branch of your state agriculture department, chemical resellers, APVMA, and the pesticide manufacturer. Always consult the label and material safety data sheet (MSDS) before using any pesticide. For current chemical-control options, also refer to [Pest Genie](#) or [APVMA](#).

Refer to the beneficial impact table ([Table 4, Section 1.2 Integrated weed management](#)) from the IPM Guidelines website to identify products least likely to harm beneficials that aren't being targeted.

7.8 *Helicoverpa* species

The name *Helicoverpa* refers to two species of moth, the larvae of which attack field crops in the Northern Region. The two species are *Helicoverpa punctigera* (native budworm) and *H. armigera* (cotton bollworm or corn earworm). Together, they are the most economically damaging insect pests of field crops in Queensland and northern New South Wales.

Helicoverpa armigera is generally regarded as the more serious pest because of its greater capacity to develop resistance to insecticides, its broader host

61 Agriculture Victoria (2007) Blue oat mite. Note AG1300. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/blue-oat-mite>

62 Agriculture Victoria (2007) Blue oat mite. Note AG1300. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/blue-oat-mite>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

range, and the fact that it persists in cropping areas from year to year, whereas *H. punctigera* numbers fluctuate from year to year according to conditions in its inland breeding areas.

Helicoverpa armigera attacks all crops but is less common in wheat, triticale and barley. In contrast, *H. punctigera* only attacks broadleaf crops and is not found on grass or cereal crops such as wheat, barley, sorghum and maize. As it is not unusual to find both *Helicoverpa* larvae and armyworms in cereal crops, correct identification of the species present is important.

Life cycles of *Helicoverpa* spp. take 4–6 weeks from egg to adult in summer, and 8–12 weeks in spring or autumn. The stages are egg, larvae, pupa and adult (moth) (Figure 12);⁶³ the larva goes through several moults as it outgrows its skin, with each stage between moults called an instar.

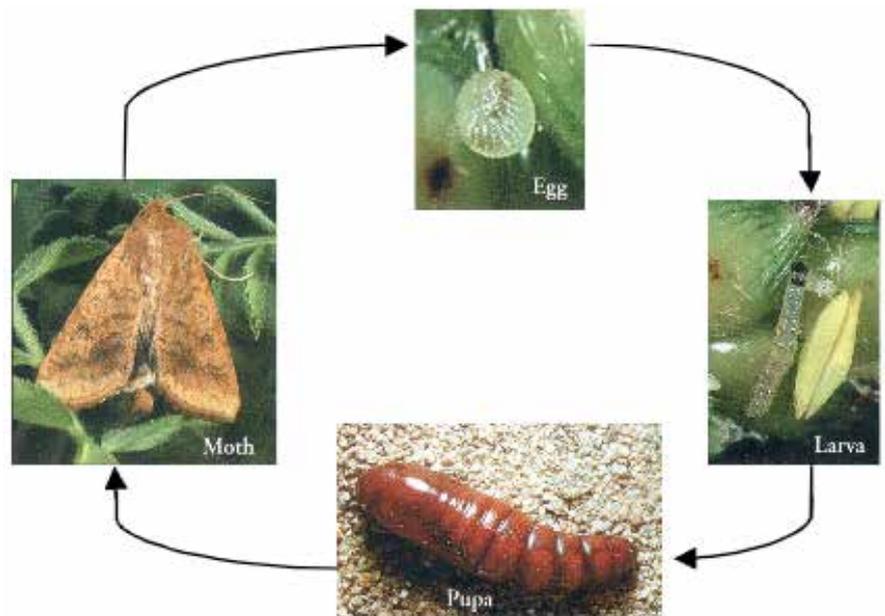


Figure 12: Life cycle of *Helicoverpa* species.

Source: Pulse Australia

Eggs are 0.5 mm in diameter and change from white to brown to having a black head before hatching. Newly hatched larvae are light in colour with tiny dark spots and dark heads. As the larvae develop, they become darker and the darker spots become more obvious. Both species look the same at the egg and small larvae stages (Photo 16).⁶⁴

63 T Bray (2010) Managing native budworm in pulse crops. Southern Pulse Bulletin, http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Pulses-native-budworm.pdf

64 DAF Queensland (2012) *Helicoverpa* species. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/helicoverpa/helicoverpa-species>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 16: Left to right: fresh white, brown ring and black larval head in nearly hatching eggs.

Source: DAF Qld

Medium larvae develop lines and bands running the length of the body and become variable in colour. *H. armigera* larvae have a saddle of darker pigment on the fourth segment and at the back of the head, and dark-coloured legs. *H. punctigera* larvae have no saddle and light-coloured legs.

Large larvae of *H. armigera* have white hairs around the head (Photo 17)⁶⁵; *H. punctigera* have black hairs around the head.



Photo 17: *H. armigera* larvae showing white hairs on head.

Source: CABI

H. armigera pupal tail spines are more widely spaced than those of *H. punctigera*. The pupae of both species are found in soil underneath the crop; healthy pupae wriggle violently when touched.

Moths are a dull light brown with dark markings, and are 35 mm long. *H. armigera* has a pale patch in the dark section of the hindwing (Photo 18) while the dark section is uniform in *H. punctigera*. Forewings are brown in the female and cream in the male.

65 Centre for Agriculture and Biosciences International (2016) *Helicoverpa armigera* (cotton bollworm). CABI, <http://www.cabi.org/isc/datasheet/26757>



Photo 18: Adult moth of *H. armigera*.

Source: CABI

7.8.1 Varietal resistance or tolerance

Virtually all *Helicoverpa* spp. present are *H. armigera*, which has developed resistance to many of the older insecticide groups.⁶⁶

7.8.2 Damage caused by *Helicoverpa* species

Helicoverpa larvae do not cause the typical head-cutting damage of armyworms. As they tend to graze on the exposed tips of a large number of developing grains, rather than totally consuming a low number of whole grains, they increase the potential losses. Most (80–90%) of the feeding and crop damage is done by larger larva in the final two instars.⁶⁷

7.8.3 Thresholds for control

While there are no thresholds developed for *Helicoverpa* larvae in winter cereals, using a consumption rate determined for *Helicoverpa* feeding in sorghum (2.4 g/larva), it can be calculated that one larvae per m² can cause 24 kg grain loss/ha (Table 6).⁶⁸ Based on these figures, a crop worth \$250/tonne will incur a loss of \$6/ha from each *Helicoverpa* larvae. If chemical intervention costs \$30/ha (comprising the chemical and the application costs) the economic threshold or break-even point is 5 larvae/m². These parameters can be varied to suit individual costs, and can incorporate a working benefit:cost ratio. A common benefit:cost ratio of 1.5 means that the projected economic benefit of the spray will be 1.5 times the cost of that spray. Spraying at the break-even point (benefit:cost ratio of 1) is not recommended.⁶⁹

⁶⁶ DAF Queensland (2012) Insect pest management in winter cereals. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals>

⁶⁷ DAF Queensland (2012) Insect pest management in winter cereals. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals>

⁶⁸ DAF Queensland (2012) Insect pest management in winter cereals. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals>

⁶⁹ DAF Queensland (2012) Insect pest management in winter cereals. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals>

Table 6: The value of yield loss incurred at several densities of larvae, using the estimated consumption of 2.4 g/larvae and a range of grain values for wheat. Note that larval damage is irrespective of the crops' yield potential (i.e. each larva will eat its fill whether it is 1 t/ha crop or a 3 t/ha crop).

Cereal price (\$/t)	Value of crop loss (\$/ha)			
	4 larvae/m ²	6 larvae/m ²	8 larvae/m ²	10 larvae/m ²
150	14.4	21.6	28.8	36.0
200	19.2	28.8	38.4	48.0
250	24.0	36.0	48.0	60.0
300	28.8	43.2	57.6	72.0
350	33.6	50.4	67.2	84.0
400	38.4	57.6	76.8	96.0
450	43.2	64.8	86.4	108.0

Source: DAF Qld

7.8.4 Management of *Helicoverpa* species

The best approach to managing *Helicoverpa* is to use a combination of chemical and non-chemical tools. By considering the ecology of *H. armigera* and *H. punctigera*, several key principles emerge that will assist in the successful and sustainable management of these pests.

Chemical control

Presently there are few control options other than the use of chemical insecticides or biopesticides (such as NPV or *Bacillus thuringiensis* var. *kurstaki*, or Bt), for above-threshold populations of larvae in a crop. Spraying should be carried out promptly once the threshold has been exceeded. Controlling *Helicoverpa* effectively with insecticides depends on knowing which species are present in the crop.

Helicoverpa punctigera is easily killed by all registered products, including those to which *H. armigera* is resistant (e.g. synthetic pyrethroids). Because *H. punctigera* moths migrate annually into eastern Australian cropping regions, they lose any resistance they might have developed had they been exposed to insecticides in crops. In contrast, *H. armigera* populations tend to remain local, so their resistance to insecticides is maintained in the population from season to season.⁷⁰

Helicoverpa armigera has historically had high resistance to pyrethroids, so control of medium–large larvae using pyrethroids is not recommended.

Where winter cereals have previously been treated with broad-spectrum insecticides to control aphids, fewer natural enemies may be present to attack *Helicoverpa* larvae, and the survival of caterpillar pests could be greater than in an untreated field.⁷¹

Attract-and-kill technology

Attract-and-kill products consist of a liquid insect lure based on floral volatiles that is mixed with an insecticide. The mixture is then able to be easily applied to large crop areas.

When the adult (and preferably female) moths are attracted to the treated rows, they feed on the mixture, and the insecticide component causes their death before all their eggs are laid. Because the aim is to concentrate the feeding moths in the treated rows, a key advantage of the attract-and-kill approach is that not every row of crop needs to be treated; in some cases, perhaps under 2% of the total crop area.

⁷⁰ DAF Queensland (2012) Key management principles of helicoverpa. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/helicoverpa/helicoverpa-biology-and-ecology/key-management-principles>

⁷¹ DAF Queensland (2012) Insect pest management in winter cereals. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

By reducing the pest moth population, the number of eggs laid into a crop can be significantly reduced. This reduction in egg lay can:

- delay the need for foliar insecticides
- reduce the subsequent pest pressure

Because the insecticide is confined to a small percentage of the crop, another key advantage is that most natural enemies will be unaffected. Research to date suggests that these products generally attract the target pest plus a range of other minor or non-pest moth species.⁷²

For current chemical control options see [Pest Genie](#) or the [APVMA](#).

Spray smart

Timing and coverage are both critical to achieving good control of *Helicoverpa* larvae, whether using a chemical insecticide or a biopesticide.

A poor level of control from inappropriate timing risks crop loss and the costs of re-treating the field. Poor timing also increases the likelihood of insects developing insecticide resistance by exposing larvae to sub-lethal doses of insecticide. Regular scouting of the crop enables the grower to assess both the number of *Helicoverpa* larvae in the crop and the age structure of the population.

Key points:

- Ensure crops are being checked when they are susceptible to *Helicoverpa* damage, as early detection is critical to ensure effective timing of sprays.
- Larvae that are feeding or moving in the open are more easily contacted by spray droplets. Target larvae before they move into protected feeding locations (e.g. flowers, cobs, pods or bolls).
- Ensure larvae are at an appropriate size to be controlled effectively with the intended product.
- Very small (1–3 mm) to small (4–7 mm) larvae are the most susceptible, and a lower dose is needed to kill them. Larvae grow rapidly: if a spray application is delayed more than two days, the crop should be rechecked and reassessed, so as to re-calibrate the amount of chemical needed.
- Assess if the larvae are doing economic damage, and only spray if the value of the crop that will be saved is more than the cost of spraying. Feeding on plants in the vegetative stages generally does not equate to significant yield loss.

Good coverage is increasingly important with the introduction of ingestion-active products because the larvae must eat plant material covered with an adequate dose of the insecticide or biopesticide.

Note that due to the resistance that *Helicoverpa* has developed to major chemical groups, registered chemicals will not necessarily give adequate control in every situation. Local knowledge of which chemicals are work in the area should be sought from consultants and agronomists to ensure that you don't spray unnecessarily or promote the further development of resistance through your choice of insecticide.

Refer to the beneficial impact table ([Table 4, Section 7.2 Integrated weed management](#)) from the IPM Guidelines website to identify products least likely to harm beneficials that aren't being targeted.

For up to date information for chemical registrations, see the [APVMA website](#).

Cultural control

While insecticides are an important tool for controlling and managing *Helicoverpa*, other management tools are also available.

- Pupae busting remains an important non-chemical tool to reduce both the size of overwintering *H. armigera* populations and the carryover of insecticide-resistant

⁷² DAF Queensland (2011) Attract and kill technology for helioverpa management. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/helicoverpa/attract-and-kill>

individuals from season to season. Cultivating to a depth of 10 cm before the end of August will kill a large proportion of overwintering pupae. Check paddocks that had larvae present after mid-March to assess numbers of pupae.

- Weed management in and around crops can prevent the build-up of *Helicoverpa* spp. and other insect pests.
- Spring trap crops have been successfully used as an area-wide management tool for reducing the size of the overall *Helicoverpa* population as it emerges from diapause in spring.
- Be smart with your beneficials. Be aware of the presence of beneficial insects and pathogens in the crop, and factor their likely impact into any management decisions.

Biological control

A variety of predatory and parasitic insects, spiders, birds, bats, rodents and diseases attack *Helicoverpa* at different stages of its life cycle.

Predators

Some predators (e.g. ants) are relatively permanent residents in paddocks, while others migrate from nearby paddocks or other vegetation. Many are opportunity feeders that also feed on other prey. Some predators found commonly in crops will not feed on *Helicoverpa* at all, and some may only feed on certain stages (for example, larvae of a particular size, or only eggs). Knowing what predators eat is important when making management decisions.

The predators of *Helicoverpa* eggs and larvae include the spined predatory shield bug, the glossy shield bug, the damsel bug and the bigeyed bug.

The most common predators of *Helicoverpa* in crops are:

- predatory bugs (e.g. spined predatory shield bug, assassin bug, and damsel bug)
- predatory beetles (e.g. ladybirds, red and blue beetle, carab beetle, and soldier beetle)
- spiders
- green lacewings and brown lacewings
- ants.

Parasitoids

Some wasps and flies attack *Helicoverpa* eggs, larvae and pupae; most of them are parasitoids, which kill their host to complete their development. The parasitoids most active in crops include:

- smaller wasp species such as *Microplitis demolitor*, *Trichogramma* spp. and *Telenomus* spp.
- relatively large parasitoid wasps (*Netelia producta*, *Heteropelma scaposum*, and *Ichneumon promissorius*)
- flies (*Carcelia* spp. and *Chaetophthalmus* spp.).

Parasitoids that attack *Helicoverpa* larvae do not kill their hosts immediately. However, they do stop or slow down caterpillar feeding, which reduces the impact of the pest on the crop. When parasitoids attack late-instar larvae or pupae, they stop moths from developing and going on to produce eggs and larvae (Photo 19).



Photo 19: Normal *Helicoverpa* egg (left) and a black, parasitised egg (right).

Source: DAF Qld

Pathogens

Pathogens are viruses, fungi or bacteria that infect insects. Many naturally occurring diseases infect and kill *Helicoverpa* larvae, among the most common being nucleopolyhedrovirus (NPV) and fungal pathogens (*Metarhizium anisopilae*, *Nomuraea rileyi* and *Beauveria bassiana*). Another disease, ascovirus, stunts larval development, and is spread by wasp parasitoids.

Two pathogens that affect *Helicoverpa* are available commercially as biopesticides:

- Helicoverpa NPV is a highly selective product that infects only *Helicoverpa* larvae and is harmless to humans, wildlife and beneficial insects.
- The bacterial toxin from *Bacillus thuringiensis* (Bt) is available as a selective spray that only kills moth larvae. Genes from the Bt organism have also been used to genetically modify cotton plants so that the toxin is expressed in the plant's tissues. When young *Helicoverpa* larvae feed on a Bt cotton plant, the toxin kills susceptible individuals.

Biopesticides can control small larvae (<7 mm), but are not effective on larger larvae, which are more difficult to control, although NPV is most effective when larvae < 13 mm in length are targeted.

Conserving natural enemies

Natural enemies will rarely eradicate all eggs or larvae, but predators and parasitoids may reduce infestations to below economic threshold if they are not disrupted by broad-spectrum insecticides. The amount of disruption that insecticides cause to natural enemy activity varies depending on which chemicals are used and which natural enemies are active.

Take a whole-farm or regional approach

There is no simple solution to *Helicoverpa* in a farming system that provides a wide range of food sources throughout the year, as the continuous availability of hosts potentially allows successive generations to build up in a cropping region. A whole-farm approach to *Helicoverpa* involves managing the local population by:

- having a good knowledge of pest and life cycle
- checking crops regularly
- being familiar with the economic thresholds for different crops
- basing chemical choices on the latest insect resistance management strategy (IRMS)
- achieving appropriate timing and coverage of sprays
- conserving populations of predatory and parasitic insects

MORE INFORMATION

Important natural enemies of *Helicoverpa*: *Microplitis demolitor* and *ascovirus*

- using trap cropping if appropriate
- cultivating to destroy overwintering pupae
- destroying weed hosts in the crop and surrounding areas.

Area-wide management strategies are designed to manage *Helicoverpa* at a regional level rather than each farmer making *Helicoverpa* control actions in isolation. It requires high levels of communication and cooperation between farmers, consultants, and research and extension personnel.⁷³

7.8.5 *Helicoverpa* and insecticide resistance

Insecticide resistance management strategy

An insecticide resistance management strategy (IRMS) is developed each year in order to contain the increase in resistance of *H. armigera* to insecticides including pyrethroids, carbamates, organophosphates and endosulfan. In its present form it applies mainly to summer crops, especially cotton, but as more insecticides are registered in grain crops the IRMS is being expanded into a farming systems IRMS (FS-IRMS) that considers insecticide use in all broadacre crops throughout the year.

The FS-IRMS aims to ensure that there is a sufficient break, of at least one *Helicoverpa* generation, in the use of each insecticide group, across all crops. For example, there is a recommended end-date for the use of Steward® (indoxacarb) in chickpeas, to allow a break in *Helicoverpa* exposure to indoxacarb before the product is available for use in cotton.

FS-IRMS guidelines

1. Currently there are no restrictions on the number of pyrethroid sprays that can be applied to non-cotton crops, but there are a number of considerations that apply to the use of pyrethroids in the farming systems.
2. It is strongly recommended that pyrethroids not be used on *Helicoverpa armigera*, as they are unreliable.
3. Pyrethroids should be targeted only on small larvae (i.e. < 7 mm long) as application on larger larvae will be ineffective and will increase levels of pyrethroid resistance. (Note: even for insecticide groups for which resistance is not established, small larvae are still more susceptible than larger larvae.)
4. If you are intending to spray a population of *Helicoverpa*, consider where the moths that laid the eggs may have originated. If they are likely to be survivors from a crop that was previously sprayed (e.g. with a pyrethroid), spraying again with the same insecticide will exacerbate resistance.
5. Avoid using broad-spectrum sprays such as organophosphates or pyrethroids early in the season. They reduce the numbers of beneficial insects and increase the chances of aphid, mite and further *Helicoverpa* outbreaks.
6. Be aware that in 2005 there were major changes to the registration for endosulfan. *Endosulfan has been withdrawn from use in grain crops*, with a few exceptions for controlling pests in seedling crops, and can no longer be used in soybeans, sunflowers, mungbeans or other summer grain crops.
7. *Do not use Steward® (indoxacarb) against Helicoverpa on chickpeas after 15 September (central Queensland) or 15 October (southern regions)*. This cut-off date aids resistance management by allowing a full generation of *Helicoverpa* to develop between the last use in chickpeas and the first possible use in cotton.
8. The use of ovicides may be warranted in the event of high egg pressure: use methomyl before the black-head egg stage.
9. Use recommended larval thresholds to minimise pesticide use and reduce resistance selection. Sprays should only be applied if the larvae are doing

⁷³ DAF Queensland (2012) Key management principles of *helicoverpa*. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/helicoverpa/helicoverpa-biology-and-ecology/key-management-principles>

- economic damage (i.e. the value of the crop saved should exceed the cost of spraying).
10. Cultivate chickpeas and other host-crop residues as soon as possible after harvest to destroy pupae. Cultivation must be completed no later than one month after large larvae were observed in the paddock, otherwise the moths will emerge and move elsewhere.
 11. Do not respray an apparent failure with a product of the same chemistry.

Helicoverpa control in an area

Farmers are faced with increasing problems of controlling resistant *Helicoverpa*. In response to this a *Helicoverpa* Regional Management Strategy (HRMS), or area-wide management (AWM) strategy, was formulated by producers, consultants, researchers and extension personnel, and was implemented in two pilot study areas on the Darling Downs in 1998–2001.

The HRMS was designed to manage *Helicoverpa* at a regional level rather than each farmer making *Helicoverpa* control actions in isolation. The HRMS pilot trial resulted in a high level of communication and cooperation between farmers and consultants in an effort to better manage *Helicoverpa*.

The basic principles of the strategy involve year-long cycle of management, and includes tactics that aim to reduce:

- the population of overwintering *Helicoverpa* pupae (March–June)
- the early season build-up of *Helicoverpa* on a regional or district scale (July–November)
- the mid-season population pressure on *Helicoverpa*-sensitive crops (December–March).

Key components of area-wide management include:

- crop checking
- pupae busting
- improved management for commercial chickpea crops
- chickpea trap crops
- using information from pheromone traps
- monitoring the contribution of beneficial insects
- insecticide management.

Many other areas are now implementing similar strategies. In the pilot study areas, many of the original HRMS and AWM groups continue to meet and discuss pest-management issues. Contact your local extension officer, consultant or Queensland [Department of Agriculture and Fisheries](#) IPM Development Extension Officer for information on existing groups in your region, or how to form a group.

Control considerations

Presently there are few control options other than the use of chemical insecticides or NPV for *Helicoverpa* larvae once they are in a crop. Spraying should be carried out promptly once the threshold for each insect has been reached.

Spray small or spray fail

Helicoverpa larvae grow rapidly and a few days' delay in spraying can result in major crop damage and also make them much more difficult to control. If a spray application is delayed for more than two days, the crop should be rechecked and reassessed.

Make sure that crops are checked when they are susceptible to *Helicoverpa* damage, as early detection of an infestation is critical in ensuring the timing of sprays is effective. Also ensure that *Helicoverpa* larvae are at the right size to control effectively with the product you intend to use. Spray only if the larvae are doing economic damage.

i MORE INFORMATION

[Insect monitoring techniques for field crops](#)

Seek professional advice

Seeking professional advice to ensure you are not:

- spraying unnecessarily (i.e. below threshold)
- planning to use an insecticide to which the pest is likely to be resistant
- promoting the further development of resistance through your choice of insecticide.

Common insecticides and registered application rates can be found by individual crop. These are not complete lists of all products registered in winter crops, and it is recommended that you also check [Infopest](#) before applying a chemical. As always, read the label, and follow the instructions on it.

Due to the resistance that *Helicoverpa* has developed to major chemical groups, it is important to remember that registered chemicals will not necessarily give adequate control in each situation. Local knowledge of which chemicals are working should be sought from consultants and agronomists in your area. ⁷⁴

7.8.6 Monitoring

Check for larvae on the plant throughout the growing season; monitoring can be done in conjunction with sampling for armyworms. Using a sweep net, check a number of sites throughout the paddock.

7.9 Lucerne flea

The lucerne flea (*Sminthurus viridis*) is a springtail that is found in both the northern and southern hemispheres but is restricted to areas that have a Mediterranean climate. It is thought to have been introduced to Australia from Europe and has since become a significant agricultural pest of crops and pastures across the southern states. It is not related to the fleas that attack animals and humans.

Lucerne fleas are common pests in New South Wales, Victoria, Tasmania, South Australia and Western Australia (Figure 13). ⁷⁵ Higher numbers are often found in the winter-rainfall areas of southern Australia, including Tasmania, or in irrigation areas where moisture is plentiful. They are generally more problematic on loam and clay soils. Lucerne fleas are often patchily distributed within paddocks and across a region.

⁷⁴ DAF Queensland (2011) Helicoverpa and insecticide resistance. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/helicoverpa/insecticide-resistance>

⁷⁵ G McDonald (2016) Lucerne flea. Updated. cesar, <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-flea>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

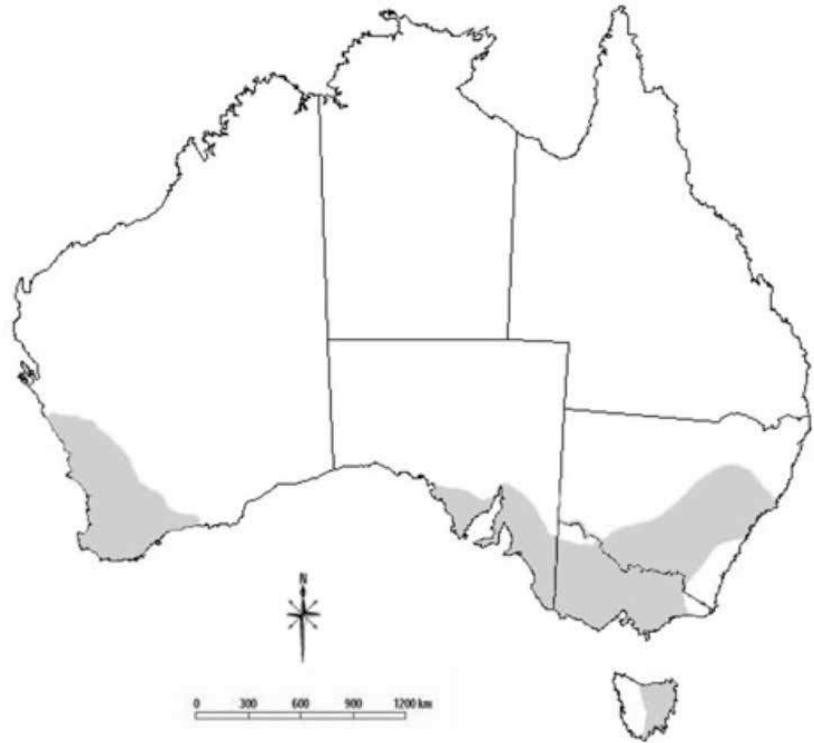


Figure 13: *The known distribution of the lucerne flea in Australia.*

Source: cesar

The springtails are a group of arthropods that have six or fewer, abdominal segments, and a forked tubular appendage or furcula under the abdomen. They are one of the most abundant of all macroscopic insects and are frequently found in leaf litter and other decaying material, where they are primarily detritivores. Very few species, among them the lucerne flea, are regarded as crop pests around the world.

The adult lucerne flea is approximately 3 mm long, light green–yellow in colour and often with mottled darker patches over the body. It is wingless and has an enlarged, globular abdomen (Figure 14). The newly hatched nymph is pale yellow and 0.5–0.75 mm long, and as it grows it resembles an adult, but is smaller.

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

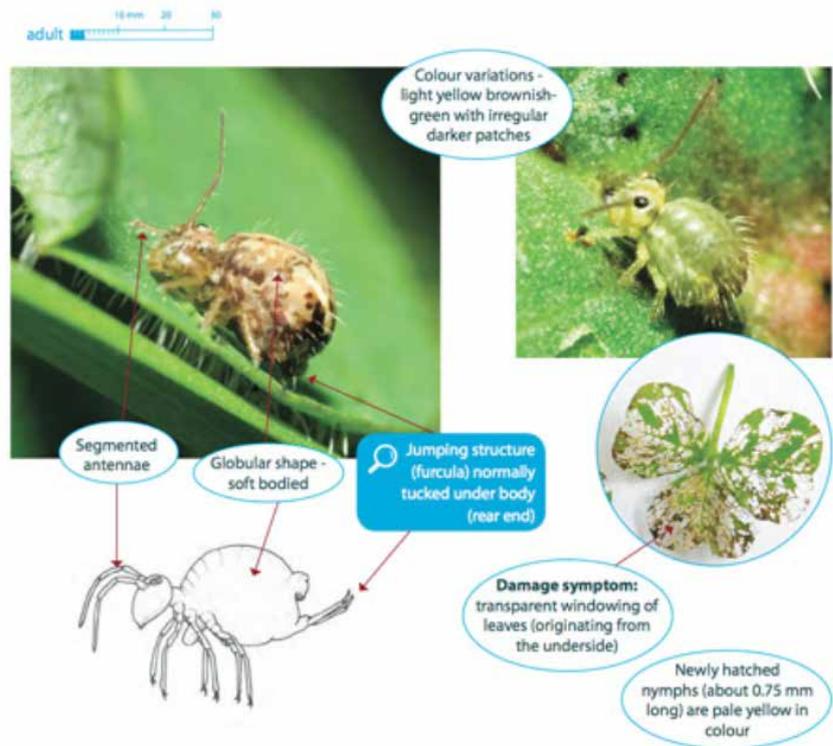


Figure 14: Distinguishing characteristics of the lucerne flea.

Source: cesar

7.9.1 Damage caused by lucerne fleas

Although grasses and cereals are not preferred hosts, lucerne fleas can cause damage to ryegrass, wheat and barley crops. Among the pasture crops, they prefer subterranean clover and lucerne.

Lucerne fleas move up plants from ground level, eating tissue from the underside of foliage. They use a rasping process to consume the succulent green cells of leaves, avoiding the more fibrous veins and leaving behind a layer of leaf membrane. This makes the characteristic small, clean holes in leaves which can appear as numerous tiny 'windows'. In severe infestations this damage can stunt or kill plant seedlings.

7.9.2 Managing lucerne fleas

Monitoring is the key to reducing the impact of lucerne fleas. Crops and pastures grown in areas where lucerne fleas have previously been a problem should be monitored fortnightly for damage from autumn through to spring. Weekly monitoring is better where there have been problems in previous years. Susceptible crops and pastures should also be carefully inspected for the presence of lucerne fleas and evidence of the damage they cause.

It is important to frequently inspect winter crops, particularly canola and pulses, in the first three to five weeks after sowing, as crops are most susceptible to damage immediately following the emergence of seedlings.

Lucerne fleas are often concentrated in localised patches or hot spots, so it is important to have a good spread of monitoring sites in each paddock. Examine foliage for characteristic lucerne flea damage and check the soil surface where insects may be sheltering.

Some sprays must be applied at a particular growth stage, so it is also important to note the growth stage of the population. Spraying immature lucerne fleas before

they have a chance to reproduce can effectively reduce the size of subsequent generations.

Lucerne fleas compete for food and resources with other agricultural pests such as redlegged earth mites and blue oat mites. This means control strategies that target only one species may not reduce the overall pest pressure because other pests can fill the gap. It is therefore important to assess the complex of pests before deciding on the most appropriate control strategy.

Biological control

Several predatory mites, various ground beetles, and spiders prey on lucerne fleas. Snout mites (which have orange bodies and legs) are particularly effective predators of this pest (Photo 20). The pasture snout mite (*Bdellodes lapidaria*) and the spiny snout mite (*Neomulgus capillatus*), have been the focus of biological control efforts against lucerne flea.

The pasture snout mite was originally found in Western Australia but has since moved into eastern Australia, where there are some examples of it successfully reducing lucerne flea numbers. Although rarer, the spiny snout mite can also drastically reduce lucerne flea populations, particularly in autumn.



Photo 20: *Predatory adult snout mite.*

Photo: A. Weeks, cesar

Cultural control

Grazing can reduce lucerne flea populations to below damaging thresholds. This may be because shorter pasture lowers the relative humidity and limits food resources, which increase insect mortality.

Broad-leaved weeds can provide alternative food sources, particularly for juvenile stages. Clean fallowing and the control of weeds, especially capeweed, within crops and around pasture perimeters can therefore help reduce lucerne flea numbers.

Other cultural techniques such as cultivation, trap crops and border crops, and mixed cropping can help reduce overall infestations to below economically damaging levels, particularly when employed in conjunction with other measures. Grasses are less favourable to the lucerne flea and as such can be useful for crop borders and pastures.

In pastures, avoid clover varieties that are more susceptible to lucerne flea damage, and avoid planting susceptible crops such as canola and lucerne into paddocks with a history of lucerne flea damage.⁷⁶

Chemical control

Lucerne fleas are commonly controlled post-emergence, usually after damage is first detected. Control is generally achieved with an organophosphate insecticide. In areas where damage is likely, a border spray may be sufficient to stop invasion from neighbouring pastures or crops. In many cases, spot spraying, rather than blanket spraying, may be all that is required.

If the damage warrants control, treat the infested area with a registered chemical approximately three weeks after lucerne fleas have been observed on a newly emerged crop. This will allow for the further hatching of over-summering eggs but will occur before the lucerne fleas reach maturity and begin to lay winter eggs.

In pastures, a follow-up spray may be needed roughly four weeks after the first spray to control subsequent hatchings, and to kill new insects before they lay more eggs. Grazing the pasture before spraying will help open up the canopy to ensure adequate spray coverage. The second spray is unlikely to be needed if few lucerne fleas are observed at that time.

Crops are most likely to be damaged where they follow a weedy crop or a pasture in which lucerne fleas have not been controlled. Therefore, controlling the fleas in the season prior to the sowing of susceptible crops is recommended.

Caution is advised when selecting an insecticide. Several chemicals registered for redlegged earth mites (i.e. synthetic pyrethroids such as cypermethrin) are known to be ineffective against lucerne fleas. When both lucerne fleas and redlegged earth mites are present, it is recommended that control strategies account for both pests: use a product registered for both at the higher rate of the two, to ensure effective control.

Information on the registration status, rates of application and warnings related to withholding periods, OH&S, residues and off-target effects should be obtained before making decisions on which insecticide to use. This information is available from the chemical standards branch of your state agriculture department, chemical resellers, [APVMA](#) and the pesticide manufacturer. Always consult the label and MSDS before using any insecticide. Also check [PestGenie](#).

Refer to the beneficial impact table ([Table 4, Section 7.2 Integrated weed management](#)) from the IPM Guidelines website to identify products least likely to harm beneficials that aren't being targeted.

7.10 Slugs and snails

Slugs and snails can be a major pest in southern NSW ([Table 7](#)).⁷⁷ Damaging populations of slugs have also been reported in seedling crops in northern NSW and southern Queensland in recent years.

Increased slug and snail activity may be due to the increase in zero- and minimum-till and stubble-retention practices because the amount of organic matter in paddocks increases and gives young slugs and snails a bigger food source. Other risk factors include prolonged wet weather, trash blankets, weedy fallows and a previous history of slugs and snails. Slugs and snails are best controlled before the crop is planted.

⁷⁶ G McDonald (2008) Lucerne flea. Note AG0415. Updated. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/lucerne-flea>

⁷⁷ IPM Guidelines (2016) Slugs and snails. Queensland Government and GRDC, <http://ipmguidelinesforgrains.com.au/pests/slugs-and-snails/>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Table 7: Description of common slugs and snails.

Species	Distinguishing features	Characteristic damage	Seasonal occurrence	Other characteristics
Slugs				
 <p>Grey field or reticulated slug (<i>Deroceras reticulatum</i>) Photo: M. Nash, SARDI</p>	<p>Light grey to fawn with dark brown mottling</p> <p>35–50 mm long</p> <p>Produces a white mucus</p>	<p>Rasping of leaves. (Complete areas of crop may be missing.)</p>	<p>Autumn to spring when conditions are moist, especially when soil moisture is >25%</p>	<p>Resident pest</p> <p>Surface active, but seeks moist refuge in soil macropores</p>
 <p>Black-keeled slug (<i>Milax gagates</i>) Photo: M. Nash, SARDI</p>	<p>Black or brown with a ridge from its saddle all the way down its back to the tip of the tail</p> <p>40–60 mm long.</p>	<p>Rasping of leaves. (Complete areas of crop may be missing.)</p> <p>Hollowed out grains</p>	<p>All year round if conditions are moist, but generally later in the season in colder regions</p>	<p>Burrows, so cereal or maize crops fail to emerge</p> <p>Prefers sandy soil in high rainfall areas (>550 mm), heavier soils in low rainfall areas (<500 mm).</p> <p>Surface active (feeding), but seeks moist refuge in soil macropores</p>
 <p>Brown field slug (<i>Deroceras invadens, D. laeve</i>) Photo: M. Nash, SARDI</p>	<p>Usually brown all over with no distinct markings</p> <p>25–35 mm long</p> <p>Produces a clear mucus</p>	<p>Rasping of leaves</p> <p>Leaves a shredded appearance</p>	<p>All year round if conditions are moist</p>	<p>Prefers warmer conditions and pastures</p> <p>Less damaging than grey field slug and black-keeled slug</p>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Species	Distinguishing features	Characteristic damage	Seasonal occurrence	Other characteristics
Snails				
 <p>Vineyard or common white snail (<i>Cernuella virgate</i>) Photo: M. Nash, SARDI</p>	<p>Coiled white shell with or without a brown band around the spiral</p> <p>Mature shell diameter 12–20 mm</p> <p>Open, circular umbilicus*</p> <p>Under magnification, regular straight scratches or etchings can be seen across the shell</p>	<p>Shredded leaves where populations are high</p> <p>Found up in the crop prior to harvest</p>	<p>Active after autumn rainfall</p> <p>Breeding occurs once conditions are moist (usually late autumn to spring)</p>	<p>Mainly a contaminant of grain</p> <p>Congregates on summer weeds and off the ground on stubble</p>
 <p>White Italian snail (<i>Theba pisana</i>) Photo: M. Nash, SARDI</p>	<p>Mature snails have coiled white shells with broken brown bands running around the spiral</p> <p>Some individuals lack the banding and are white</p> <p>Mature shell diameter 12–20 mm</p> <p>Semi-circular or partly closed umbilicus*</p> <p>Under magnification cross-hatched scratches can be seen on the shell</p>	<p>Shredded leaves where populations are high</p> <p>Found up in the crop prior to harvest</p>	<p>Active after autumn rainfall</p> <p>Breeding occurs once conditions are moist (usually late autumn to spring)</p>	<p>Mainly a contaminant of grain</p> <p>Congregates on summer weeds and off the ground on stubble</p>
 <p>Conical or pointed snail (<i>Cochlicella acuta</i>) Photo: M. Nash, SARDI</p>	<p>Fawn, grey or brown</p> <p>Mature snails have a shell of up to 18 mm long</p> <p>The ratio of the shell length to its diameter at the base is always greater than two</p>	<p>Shredded leaves where populations are high</p> <p>Found up in the crop prior to harvest</p>	<p>Active after autumn rainfall</p> <p>Breeding occurs once conditions are moist (usually winter to spring)</p>	<p>Mainly a contaminant of grain</p> <p>Can be found over summer on and in stubble and at the base of summer weeds</p>

SECTION 7 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Species	Distinguishing features	Characteristic damage	Seasonal occurrence	Other characteristics
 <p>Small pointed snail (<i>Prietocella Barbara</i>) Photo: M. Nash, SARDI</p>	<p>Fawn, grey or brown</p> <p>Mature shell size of 8–10 mm long</p> <p>The ratio of its shell length to its diameter at the base is always two or less</p>	<p>Shredded leaves where populations are high</p> <p>Found up in the crop prior to harvest</p>	<p>Active after autumn rainfall</p> <p>Breeding occurs once conditions are moist (usually winter to spring)</p>	<p>A contaminant of grain, especially hard to screen from canola grain as the same size</p> <p>Mainly found over summer at the base of summer weeds and stubble</p> <p>Similar to slugs will go into soil macropores.</p> <p>Especially difficult to control with bait at current label rates</p>

*Umbilicus: a depression on the bottom (dorsal) side of the shell, where the whorls have moved apart as the snail has grown. The shape and the diameter of the umbilicus is usually species-specific.

Source: IPM Guidelines

7.10.1 Economic thresholds for control

Thresholds (Table 8) can be unreliable due to the interaction between weather, crop growth and snail activity. For example, high populations in the spring do not always relate to the number of slugs and snails harvested. Their movement into the crop canopy is dictated by weather conditions prior to harvest.⁷⁸

Table 8: *Thresholds for controlling snails and slugs in a paddock. If there are more than the number specified per metre for a given pest then actions for controlled the pest should be taken.*

Pest	Number of pest per square metre
Round snails	20
Small pointed snails	40
Grey field slug	5–15
Black-keeled slug	1–2

Source: IPM Guidelines.

7.10.2 Managing slugs and snails

Biological control

Free-living nematodes when carrying bacteria that kill snails and slugs are thought to help reduce populations under certain paddock conditions.

Note that baits containing methiocarb are toxic to a number of other invertebrates and beneficials.

Natural enemies of slugs

Some species of carabid beetles can reduce slug populations, but generally not below established economic thresholds. Many other soil fauna, such as are protozoa, may cause high levels of slug egg mortality under moist, warm conditions. Biological controls alone cannot be solely relied on for slug control.

⁷⁸ IPM Guidelines (2016) Slugs in seedling crops. Queensland Government and GRDC, <http://ipmguidelinesforgrains.com.au/pests/slugs-and-snails/slugs-in-seedling-crops/>

Cultural control

- Hard grazing of stubbles
- Cabling and/or rolling of stubbles when soil temperature is above 35°C
- Burning if numbers are very high and you can ensure hot, even burns
- Cultivation that leaves a fine, consolidated tilth
- Removal of summer weeds and volunteers

Chemical control

Snails

Molluscidal baits containing either metaldehyde or chelated iron are IPM compatible. Apply to the bare soil surface when snails are active after autumn rain, as early as March. Aim to control snails pre-season.

Mature snails over 7 mm in length or diameter will feed on bait while bait is less effective on juveniles. Baiting before egg lay is vital. Try to bait when snails are moving from resting sites after summer rains. Stop baiting eight weeks before harvest to avoid bait contamination in grain. Bait rates need to be at the highest label rate to achieve a greater number of bait points. As the actual number is yet to be determined, label rates may be revised in the future. In cool, moist conditions, snails can move 30 m/week, so treated fields can be re-invaded from fence lines, vegetation and roadsides. Rain at harvest can cause snails to crawl down from crops.

Slugs

Baiting is the only chemical option available to manage slugs. Molluscidal baits containing metaldehyde or chelated iron are IPM compatible. Baits containing methiocarb are also toxic to carabid beetles, one of the few predators of slugs. Different responses to bait can be due to species behaviour. The value of applying bait after a significant rainfall event prior to sowing is still to be tested.

For black-keeled slugs, broadcast baits when dry or place with seed at sowing.

For grey field slugs, broadcast baits.

Do not underestimate slug populations: always use rate that gives 25–30 baits points per metre.

Calibrate bait spreaders to ensure width of spread, evenness of distribution and correct rate. Make sure to bait after/at sowing prior to crop emergence when soil is moist (>20% soil moisture). Re-apply baits to problem areas 3–4 weeks after first application if monitoring indicates slugs are still active.

Note that the number of baits/ha is more important than total weight of bait per hectare. The minimum baits needed for effective control is 250,000 bait points per hectare.

For up to date information for chemical registrations, see the [APVMA website](#).

Monitoring snails

Monitor regularly to establish numbers, types and activity (Table 9), and measure success of controls. Look for snails early morning or in the evening when conditions are cooler and snails are more active.

Key times to monitor:

- 3–4 weeks before harvest to assess need for harvester modifications and cleaning
- after summer rains, check if snails are moving from resting sites
- summer to pre-seeding, check numbers in stubble before and after rolling, slashing or cabling

Monitoring technique:

- sample 30 x 30 cm quadrat at 50 locations across the paddock.

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- if two groups (round and conical) are present, record the number of each group separately
- to determine the age class of round snails, place into a 7 mm sieve box, shake gently to separate into two sizes >7 mm (adults) and <7 mm (juveniles).
- make sieve boxes from two stackable containers, e.g. sandwich boxes, remove the bottom from one and replace by a punch-hole screen with screen size of 7 mm round or hexagonal
- use 5 sampling transects in each paddock, one each at 90 degrees to each fence line and the fifth running across the centre of the paddock, and take five samples (counts), 10 metres apart along each transect

Record the size and number of the snails in each sample. Average the counts for each transect and multiply this figure by 10 to calculate the number of snails per square metre in that area of the paddock.

Table 9: Monitoring snails at different stages of crop development.

Pre-sowing	Seedling–vegetative stages	Grain fill and podding stage	Harvest
<p>High risk:</p> <ul style="list-style-type: none"> • weedy fields • alkaline calcareous soils • retained stubble • wet spring, summer, autumn • history of snails <p>All species congregate at the base of summer weeds or in topsoil. Pointed snails can also be found at the base of or up in stubble as well as inside stubble stems.</p> <p>Appear to build up most rapidly in canola, field peas and beans, but can feed and multiply in all crops and pastures.</p> <p>Most active after rain and when conditions are cool and moist</p> <p>Dormant in late spring and summer</p>	<p>Damage:</p> <ul style="list-style-type: none"> • consume cotyledons, which may resemble crop failure • shredded leaves where populations are high • chewed leaf margins • irregular holes <p>Wide range of sizes indicates snails are breeding in the area. If most snails are the same size, snails are moving in from other areas.</p> <p>Round snails favour resting places off the ground on stubble, vegetation and fence posts</p> <p>Pointed snails are found on the ground in shady places</p>	<p>Can be found up in the crop prior to harvest. Check for snails under weeds or shake mature crops unto tarps.</p>	<p>Predominantly a grain contaminant</p> <p>At harvest, snails move up in the crop and may shelter between grains or under leaves. They can also be found in windrows.</p> <p>The small pointed snail is especially hard to screen from canola grain due to similar size. Buyers will reject grain if:</p> <ul style="list-style-type: none"> • more than half a dead or one live snail is found in 0.5 L of wheat • more than half a dead or one live snail is found in 200 g pulse sample

Source IPM Guidelines

Monitoring slugs

Monitor with surface refuges to provide an estimate of active density (Table 10). Refuges include:

- terracotta paving tiles
- carpet squares or similar

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

MORE INFORMATION

GRDC factsheet, [Slug identification and management](#)

Use a 300 mm by 300 mm refuge when soil moisture is favourable (more than 20%) as slugs require moisture to travel across the soil surface. Slugs are attracted to the refuges from approximately 1 m, so numbers found can be used as numbers per square metre.

Place refuges in areas of previous damage, after rainfall, on damp soil before sowing. Use 10 refuges per 10 hectares.

Check the refuges early in the morning, as slugs seek shelter in the soil as it gets warmer. Alternatively, put out metaldehyde bait strips and check the following morning for dead slugs. Monitor for plant damage.

Slug populations are not evenly distributed in the paddock and are often clumped. Where crop damage is evident inspect the area at night.⁷⁹

Table 10: Monitoring slugs at different stages of crop development.

Pre-sowing	Germination–vegetative stages
<p>High risk:</p> <ul style="list-style-type: none"> high rainfall areas >450 mm a year above-average spring–autumn rainfall cold, wet establishment conditions no-till stubble retained summer volunteers previous paddock history of slugs soils high in clay and organic matter <p>Slugs are nocturnal and shelter during dry conditions and generally not visible</p>	<p>Damage:</p> <ul style="list-style-type: none"> rasping of leaves, leaves have a shredded appearance complete areas of crop may be missing <p>Slugs will eat all plant parts but the seedling stage is most vulnerable and this is when major economic losses can occur</p> <p>Grey and brown field slugs are mainly surface-active but the black-keeled slug burrows and can feed directly on germinating seed</p>

Source: IPM Guidelines

7.11 Wireworms and false wireworms

Wireworms and false wireworms are common, soil-inhabiting pests of newly sown winter and summer crops. Wireworms are the larvae of several species of Australian native beetles which are commonly called click beetles. False wireworms are also the larval form of beetles, some of which are known as pie-dish beetles, which belong to another family, Tenebrionidae, and have distinctively different forms and behaviour.

Both groups inhabit native grassland and improved pastures where they generally cause little damage. However, cultivation and fallowing decimate their food supply, so any new seedlings that grow may be attacked and sometimes destroyed. They attack the pre-emergent and post-emergent seedlings of all oilseeds, grain legumes and cereals, particularly in light, well-draining soils with a high organic content. Crops with fine seedlings, such as canola and linola, are most susceptible.

The incidence of damage caused by wireworms and false wireworms is increasing with increasing use of minimum tillage and short fallow periods.

7.11.1 False wireworms

False wireworms are the larvae of native beetles which normally live in grasslands or pastures and cause little or no damage there. In crops, they are mostly found in paddocks with large amounts of stubble or crop litter, and may affect all winter-sown crops.

There are a large and varied number of species of false wireworms, but all species exhibit some common characteristics. Larvae are cylindrical, hard bodied, fast

⁷⁹ IPM Guidelines (2016) Slugs in seedling crops. Queensland Government and GRDC, <http://ipmguidelinesforgrains.com.au/pests/slugs-and-snails/slugs-in-seedling-crops/>

moving, golden brown to black-brown or grey with pointed, upturned tails or a pair of prominent spines on the last body segment. There are several common groups (genera) of false wireworms found in south-eastern Australia:

- the grey or small false wireworm (*Isopteron punctatissimus* or *Cestrinus punctatissimus*)
- the large or eastern false wireworms (*Pterohelaeus* spp.)
- the southern false wireworms (*Gonocephalum* spp.)⁸⁰

In the grey or small false wireworm, the larvae grow to about 9 mm in length. They are grey-green, have two distinct protrusions from the last abdominal (tail) segment, and tend to have a shiny exterior (Figure 15).⁸¹ Hence, they are most easily recognised in the soil on sunny days when their bodies are reflective. The adults are slender, dark brown and grow to about 8 mm in length. The eggs are less than 1 mm in diameter. There are several species of this pest genus, although *I. punctatissimus* appears to be the one most associated with damage.

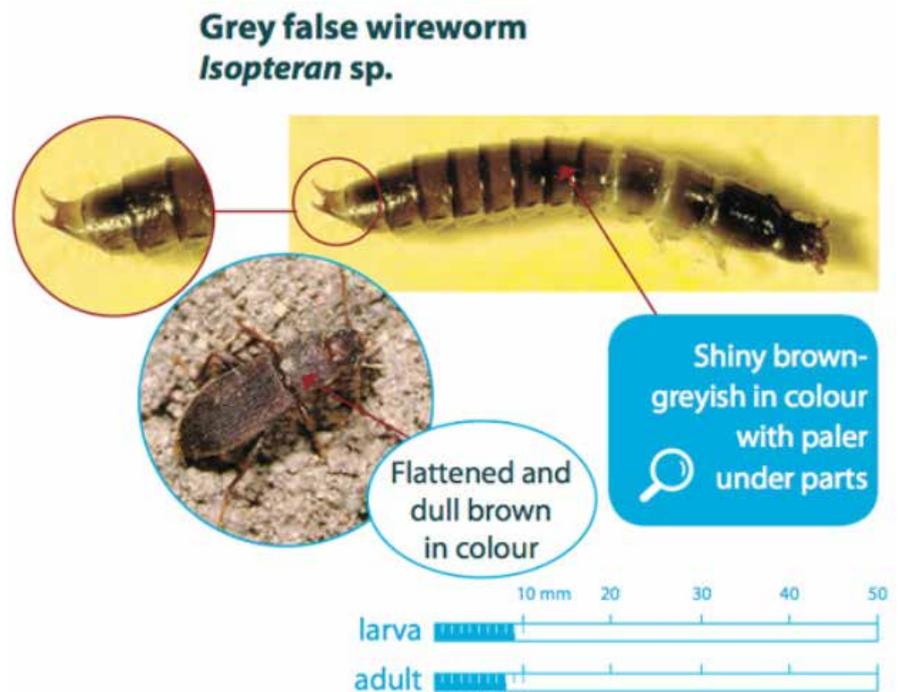


Figure 15: Distinguishing characteristics of the grey false wireworm.

Source: cesar

The large or eastern false wireworms are the largest group of false wireworms. They are the most conspicuous in the soil, and grow up to 50 mm in length. They are light cream to tan in colour, with tan or brown rings around each body segment, giving the appearance of bands around each segment. The last abdominal segment has no obvious protrusions, although, under a microscope, a number of distinct hairs can be seen. Adults are large, conspicuous and often almost ovoid beetles with a black shiny bodies (Photo 21).⁸²

80 G McDonald (1995) Wireworms and false wireworms. Note AG0411. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/wireworms-and-false-wireworms>

81 G McDonald (2016) Grey false wireworm. Updated. cesar, <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Grey-false-wireworm>

82 G McDonald (2016) Eastern false wireworm. Updated. cesar, <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Eastern-false-wireworm>



Photo 21: Eastern false wireworm beetle (left) and larva (right).

Source: cesar

The southern false wireworms grows to about 20 mm in length, and have similar body colours and marking to the large false wireworms. Adults are generally dark brown–grey, oval beetles, which sometimes have a coating of soil on the body (Figure 16).⁸³ The edges of adults’ bodies are flanged, hence the common name pie-dish beetles.

Vegetable beetle
Gonocephalum spp.

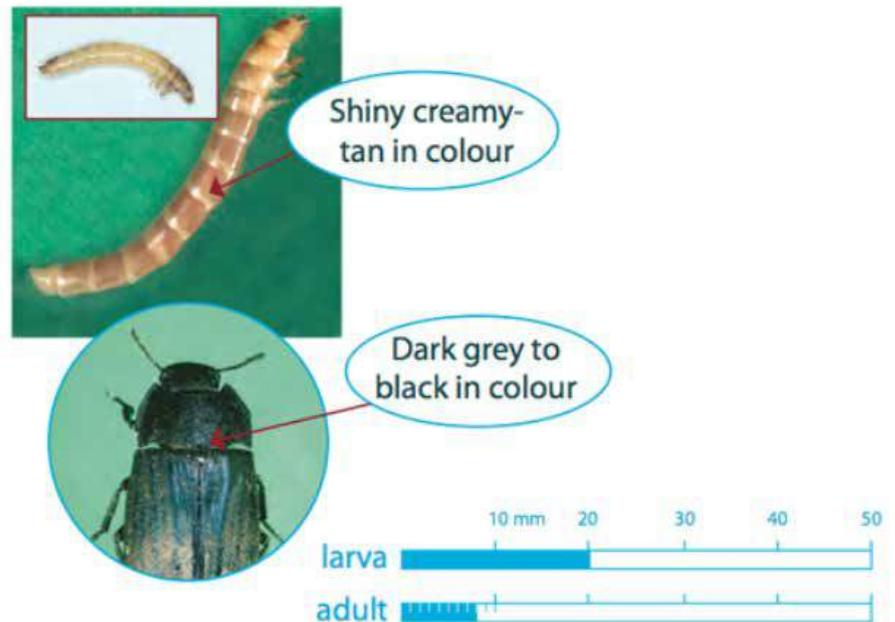


Figure 16: Distinguishing characteristics of the southern false wireworm.

Source: cesar

Biology

Usually only one generation occurs each year. However, some species may take up to 10 years to complete the life cycle. Adults emerge from the soil in December and January, and lay eggs in or just below the soil surface, mostly in stubbles and crop litter. Hence, larvae are most commonly found in paddocks where stubble has been retained.

Larvae of most false wireworm species prefer to feed on decaying stubble and soil organic matter. When the soil is reasonably moist, the larvae are likely to aggregate

⁸³ P Umina, G McDonald (2015) Southern false wireworm. cesar, <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Southern-False-wireworm>

in the top 10–20 mm where the plant litter is amassed. However, when the soil dries, the larvae move down through the soil profile, remaining in or close to the subsoil moisture, and occasionally venturing back to the soil surface to feed. Feeding is often at night when the soil surface is dampened by dew.

Nothing is known about what triggers the false wireworm to change from feeding on organic matter and litter to feeding on plants. However, it is recognised that significant damage to plants is likely to occur when soils remain dry for extensive periods. Larvae are likely to stop feeding on organic matter when it dries out, and when crop plants provide the most accessible source of moisture.

Damage caused by false wireworms

Affected crops may develop bare patches, which could be large enough to require re-sowing (Photo 22).⁸⁴ Damage is usually greatest when crop growth is slow due to cold, wet conditions.



Photo 22: False wireworm damage to pasture.

Source: cesar

Infestations of the small false wireworm can be as high as hundreds of larvae per square meter, although densities as low as five larger false wireworm larvae per square meter can cause damage under dry conditions.

The larvae of the small false wireworm are mostly found damaging fine seedling crops shortly after germination. They feed on the hypocotyl (seedling stem) at or just below the soil surface. This causes the stem to be ring-barked, and eventually the seedling may be lopped off, or it wilts in warm conditions. Larger seedlings (e.g. those of grain legumes) may also be attacked, but the larvae appear to be too small to cause significant damage.

The larger false wireworms can cause damage to most field crops. The larvae can hollow out germinating seed, sever the underground parts of young plants, or attack the above-surface hypocotyl or cotyledons. In summer, adult beetles may also chew off young sunflower seedlings at ground level. Damage is most severe in crops sown into dry seedbeds and when germination is slowed by continued dry weather.

7.11.2 True wireworm

The true wireworms are many species in the family Elateridae. The slow-moving larvae in this family tend to be less common in broadacre cropping regions, although they are always present. They are generally associated with wetter soils than the larvae of false wireworms.

⁸⁴ P Umina, G McDonald (2015) Southern false wireworm. cesar, <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Southern-False-wireworm>

SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Larvae grow to 15–40 mm, are soft-bodied, and flattened, and these characteristics help distinguish them from false wireworms. Their colour ranges from creamy yellow in the most common species to red-brown; their head is dark brown and wedge-shaped. The tail piece is characteristically flattened and has serrated edges. Adults are known as click beetles, due to their habit of springing into the air with a loud click when placed on their backs. The beetles are dark brown, elongated and 9–13 mm long (Figure 17).⁸⁵

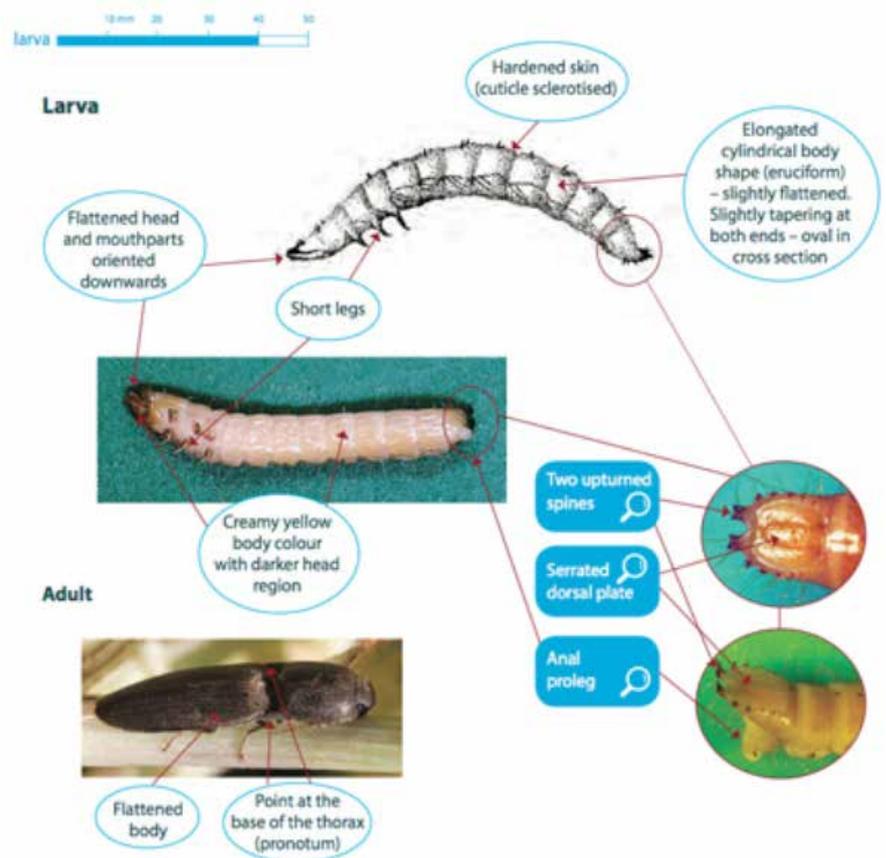


Figure 17: Distinguishing characteristics of true wireworms.

Source: cesar

Biology

There may be one or several generations per year, depending on the species. Wireworms prefer low-lying, poorly drained paddocks and are less common in dry soils. Larvae are reasonably mobile through the soil, and will attack successive seedlings as they emerge. Most damage occurs from April to August. Adults emerge in spring, and are typically found in summer and autumn in bark, under wood stacks or flying around lights.

There is little known of the biology of most species, although one species (*Hapatesus hirtus*) is better understood. It is known as the potato wireworm although it is found in many other crops and pastures, as well as in potatoes. It is very long-lived and probably takes five years or more to pass through all the growth stages before pupating and finally emerging as an adult beetle.

After emerging, adult click beetles mate and lay eggs, and then may spend a winter sheltering under the bark of trees. The connection between trees and adult beetles is probably why damage is often, but not always, most pronounced along tree lines. The wireworms have a long life in the soil and are active all year, even in winter.

85 B Kimber (2015) True wireworm. cesar, <http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/True-wireworm>

Damage

The damage caused by wireworms is similar to that of false wireworms, except that most of it is restricted to below the soil surface. Larvae eat the contents of germinating seeds, and the underground stems of establishing plants, causing wilting and death.

7.11.3 Sampling and detection of wireworms

The principles for detection and control of false and true wireworms are generally similar, although different species may respond slightly differently according to soil conditions.

Sampling

Paddocks should be sampled immediately before sowing. There are two methods, although neither is 100% reliable. This is because larvae change their behaviour according to soil conditions, particularly soil moisture and temperature. The two methods are:

- Soil sampling—take a minimum of five random samples from the soil. Each sample should consist of the top 20 mm of a 0.50 m x 0.50 m area. Carefully inspect the soil for larvae. Calculate the average density per square metre by multiplying the average number of larvae found in the samples by 4. Control should be considered if the average exceeds 10 small false wireworms, or 10 of the larger false wireworms.
- Seed baits—these have been used successfully to sample true and false wireworms in Queensland and overseas. Preliminary work has shown that they can be used to show the species of larvae present, and to give an approximation of density. Take 200–300 g of a large seed (e.g. any grain legume) and soak for 24 hours. Select 5–10 sites in the paddock and place a handful of the soaked seed into a shallow, 50 mm hole, and cover with about 10 mm of soil. Mark each hole with a stake, and excavate each hole after about seven days. Inspect the seed and surrounding soil for false wireworm larvae. This technique is most likely to be successful when there is some moisture in the top 100 mm of soil.

Detection

Larvae of the small false wireworms are relatively difficult, although not impossible, to see in grey and black soils because of their small size and dark colour. However, they can be found in the top 20 mm of dry soil by carefully examining the soil in full sun. Larvae of the other false wireworm species are more prominent because of their relatively pale colour and large size.

7.11.4 Control

Crop residues and weedy summer fallows favour survival of larvae and over-summering beetles. Clean cultivation over summer will starve adults and larvae and expose them to hot, dry conditions, thus preventing population increases. Suitable crop rotations may also limit increases in population numbers.

Seedbeds must be sampled before sowing if control is to be successful. Insecticides may be applied to soil or seed at sowing. Most chemicals registered to control false wireworm are seed treatments, although these may not be consistently reliable. They probably work best when the seedling grows rapidly in relatively moist soils. Adults may also be controlled with insecticide incorporated into baits. If damage occurs after sowing, no treatment is available other than re-sowing bare patches with an insecticide treatment. The critical periods for control of false wireworm are shown in Photo 18.⁸⁶

⁸⁶ G McDonald (1995) Wireworms and false wireworms. Note AG0411. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/wireworms-and-false-wireworms>

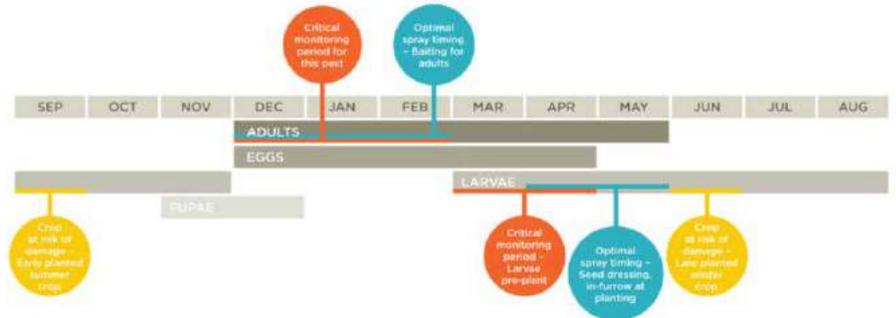
SECTION 7 TRITICALE

TABLE OF CONTENTS

FEEDBACK



False wireworm (*Pterohelaeus, Gonocephalum*)



i MORE INFORMATION

False wire worms in seedling crops

Figure 18: Critical periods for controlling false wireworms.

Source: cesar

For up to date information for chemical registrations, see the [APVMA website](#).

Nematode management

Key messages

- Some varieties of triticale can reduce soil nematodes such as *Pratylenchus neglectus* and *P. thornei* (root-lesion nematodes) and *Heterodera avenae* (cereal cyst nematode).¹
- Some varieties of Triticale have some resistant to *P. neglectus*, and *P. thornei*.
- Some varieties of triticale are thought to be resistant to cereal cyst nematode, a characteristic that is probably inherited from its parent crop, cereal rye.
- Root-lesion nematodes (*P. thornei* and *P. neglectus*) have been detected at potentially damaging levels in nearly 30% of paddocks in the northern part of the Northern Region, and can be common throughout the southern part of the Northern region.
- The most effective way to manage RLN populations and protect yields is to use rotations with resistant and tolerant crops and varieties, and good nutrition and early sowing.
- Soil testing (e.g. with [PreDicta B](#)) is the best way to diagnose nematode infestations and also to inform growers' management decisions.

Nematodes (or roundworms) are one of the most abundant life forms on earth. They are adapted to nearly all environments. In cropping situations they can range from being beneficial to detrimental to plant health.

Successful management of destructive nematodes relies on:

- Farm hygiene to keep paddocks free of root-lesion nematode (RLN).
- Growing tolerant varieties when root-lesion nematodes are present, to maximise yields.
- Rotating with resistant crops to keep root-lesion nematodes at low levels.
- Test soil to monitor population changes between crop rotations and to determine RLN species and population density.
- When rotating crops, avoid planting susceptible crops consecutively, so as to limit the build-up of RLN populations.
- Choose rotation crops with high resistance ratings, so that fewer nematodes remain in the soil to infect the next crop.²

Triticale has some resistance to *P. neglectus*,³ and *P. thornei*.⁴ and some varieties have resistance to cereal cyst nematode⁵, a characteristic that is probably inherited from its parent crop, cereal rye.⁶ Because of this, many growers use it as a disease break in their rotations and value the benefits of triticale for its contribution to soil conservation and reducing parasitic nematode populations in the soil.^{7 8}

1 GRDC (2009) Field Peas: The Ute Guide. GRDC, <https://grdc.com.au/resources-and-publications/apps/field-peas-the-ute-guide>. See also GRDC (2013) Field Peas: The Ute Guide. App. GRDC, <https://grdc.com.au/Resources/Apps>

2 K Owen, J Sheedy, N Seymour (2016) Root-lesion nematode, Queensland. Soilquality.org, <http://www.soilquality.org.au/factsheets/root-lesion-nematode-in-queensland>

3 M Williams (2013) Root out nematodes and get them tested. GRDC, <https://grdc.com.au/Media-Centre/Media-News/West/2013/10/Root-out-nematodes-and-get-them-tested>

4 A Wherrett, V Vanstone (2016) Root lesion nematode. Soilquality.org, <http://soilquality.org.au/factsheets/root-lesion-nematode>

5 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

6 R Asiedu, JM Fisher, CJ Driscoll (1990) Resistance to *Heterodera avenae* in the rye genome of triticale. Theoretical and Applied Genetics, 79 (3), 331–336.

7 Agriculture Victoria (2016) Triticale [download]. In Victorian winter crop summary. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/victorian-winter-crop-summary>

8 KV Cooper, RS Jessop, NL Darvey (2004) Triticale in Australia—Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [GCTV6: Root-lesion nematodes](#)



WATCH: [Understanding root-lesion nematodes](#)



8.1 Root-lesion nematodes

Key points:

- *Pratylenchus neglectus* and *P. thornei* are the main root-lesion nematodes (RLNs) that cause yield loss in the northern agricultural region of Australia. They often occur together.
- Root-lesion nematodes cost Australian growers in excess of \$250 million a year.
- Root-lesion nematodes reduce the development of lateral roots, and this decreases the ability of plants to extract water and nutrients.
- Wheat is the main host of RLN, although varieties vary in their resistance and tolerance. Traditional break crops can also be hosts, and the host range varies for each *Pratylenchus* species.
- Yield losses can be reduced by rotation with resistant and tolerant crops and varieties, good nutrition, sowing early and testing soil.

The root-lesion nematodes are a genus of soil-borne, microscopic plant parasites that are migratory. They are widely distributed in the wheat-growing regions of Australia, the two common species in the Northern Region being *Pratylenchus thornei* (*Pt*) and *P. neglectus* (*Pn*). *P. thornei* is the most damaging species and occurs commonly in the northern part of the Northern region (Photo 1).⁹ *P. neglectus* occurs less frequently in this area, but is common and can be damaging in the southern part of the Northern region.

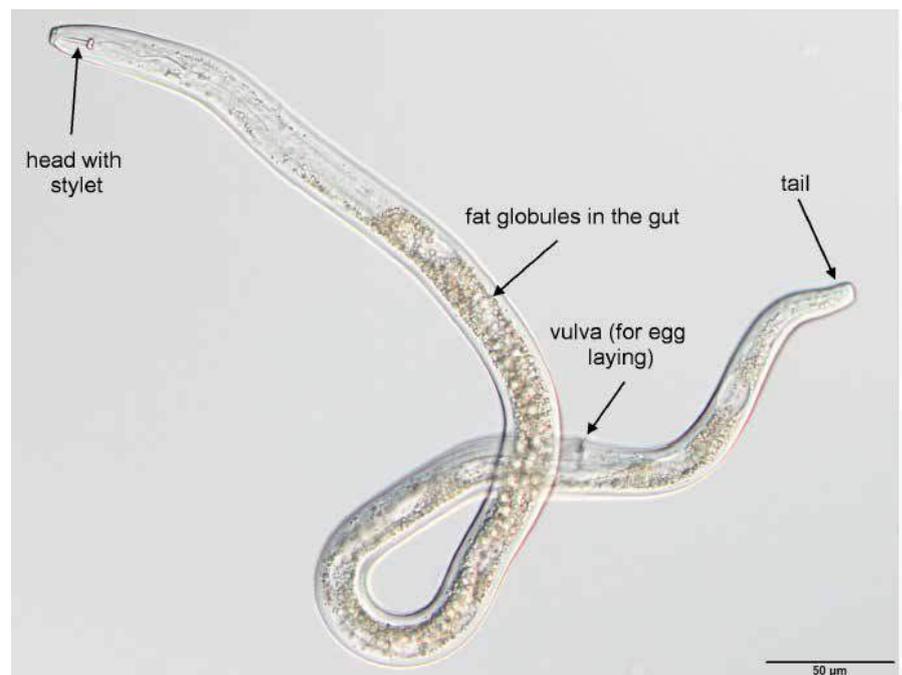


Photo 1: A *Pratylenchus thornei* adult female viewed under the microscope. The nematode is approximately 0.65 mm long.

Source: GRDC

Both species grow to ~0.5–0.75 mm in length and feed and reproduce inside the roots of susceptible crops (and other plants). They penetrate the plant root, digesting the cells' contents and laying eggs within the roots (Photo 2).¹⁰ Nematode multiplication differs both between and within host species.

⁹ GRDC (2015) Root-lesion nematodes, Northern Region. Tips and Tactics. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2015/03/tt-rootlesionnematodes>

¹⁰ J Thompson, K Owen, T Clewett, J Sheedy, R Reen (2009) Management of root-lesion nematodes in the northern grain region. DAF Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/crop-diseases/root-lesion-nematode>

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Pratylenchus thornei occurs throughout the root zone while *P. neglectus*, tends to be concentrated in the top 15 cm of the soil.

Big populations develop quickly following planting, so that the root systems quickly become inefficient in absorbing water and nutrients.¹¹

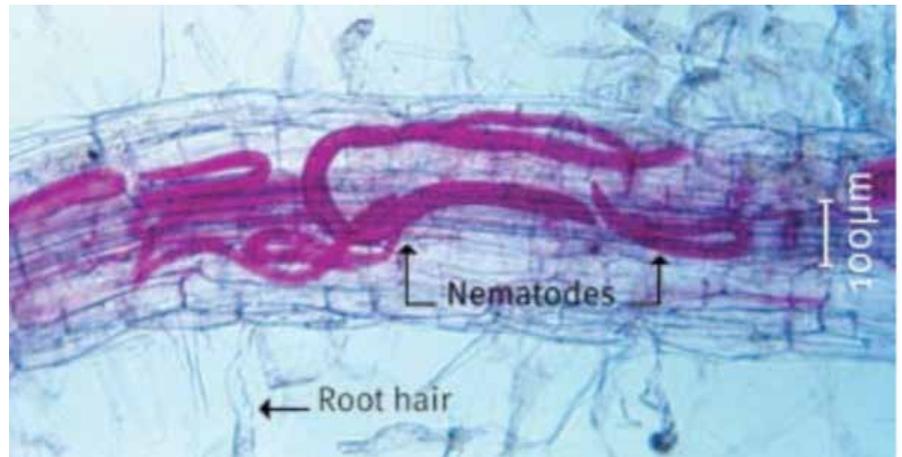


Photo 2: Nematodes (stained to make them easy to see) in a cereal-plant root.

Source: DAF Queensland

P. neglectus has a wide range of hosts, and infects all cereals as well as crops grown in rotation with cereals (e.g. grain legumes, pasture legumes and oilseeds). This species impairs root function, limiting water and nutrient uptake, and leading to poor growth and yield decline. Researchers conducted trials at infested sites to determine the ability of cereal species and varieties to promote the multiplication of the nematode. They also used glasshouse tests to compare nematode multiplication on roots of varieties of triticale, wheat and rye. The roots of triticale contained fewer nematodes than the other cereals.¹²

Triticale is thought to be susceptible to *P. penetrans*, a RLN common in WA, although this information is based on preliminary trials and from observations of samples submitted to AGWEST Plant Laboratories (now called DDLS Seed Testing and Certification). More research is needed before this can be taken as fact.¹³

In 2015, SARDI generated maps of the distribution of *P. thornei* and *P. neglectus* from samples submitted for PreDicta B tests (Figure 1).¹⁴ Results from the autumn samples show that in the northern part of the Northern Region, *P. thornei* (Pt) is more widely distributed and found in greater, more damaging populations than *P. neglectus* (Pn). In this region, paddocks with more than 15 *P. thornei*/g soil or 15,000/kg soil (ascertained by the PreDicta B test) are considered high risk for crops. However, populations of *P. thornei* classified as being of medium risk, that is 2–15/g soil or 2,000–15,000/kg soil, can cause substantial yield loss in intolerant varieties in the warm, wet growing seasons that are conducive to nematode reproduction.¹⁵

¹¹ GRDC (2015) Root-lesion nematodes, Northern Region. Tips and Tactics. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2015/03/rt-rootlesionnematodes>

¹² V Vanstone, M Farsi, T Rathjen, K Cooper (1996) Resistance of triticale to root lesion nematode in South Australia. In *Triticale: Today and Tomorrow*, Springer Netherlands, pp. 557–560.

¹³ A Wherrett, V Vanstone (2016) Root lesion nematode. Soilquality.org, <http://soilquality.org.au/factsheets/root-lesion-nematode>

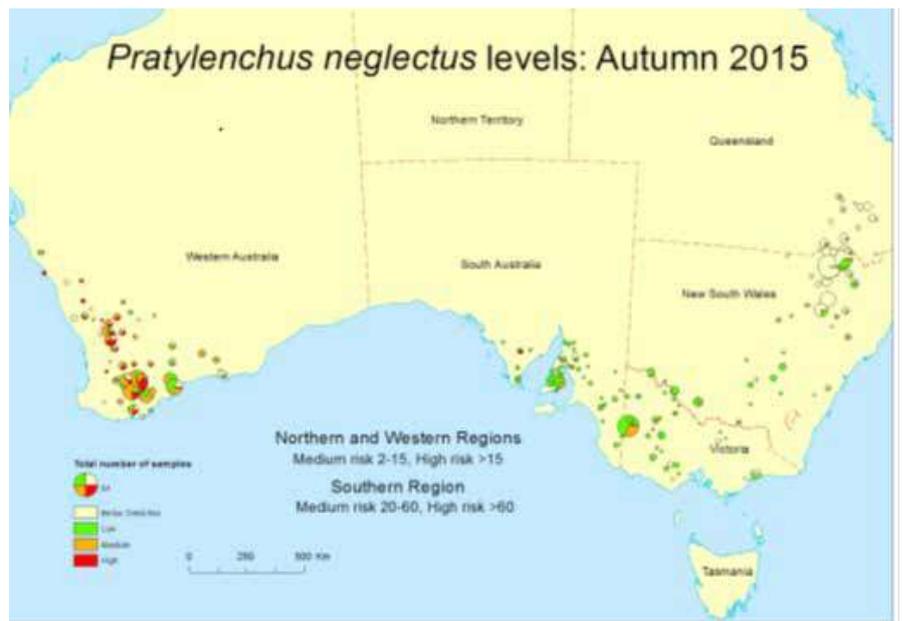
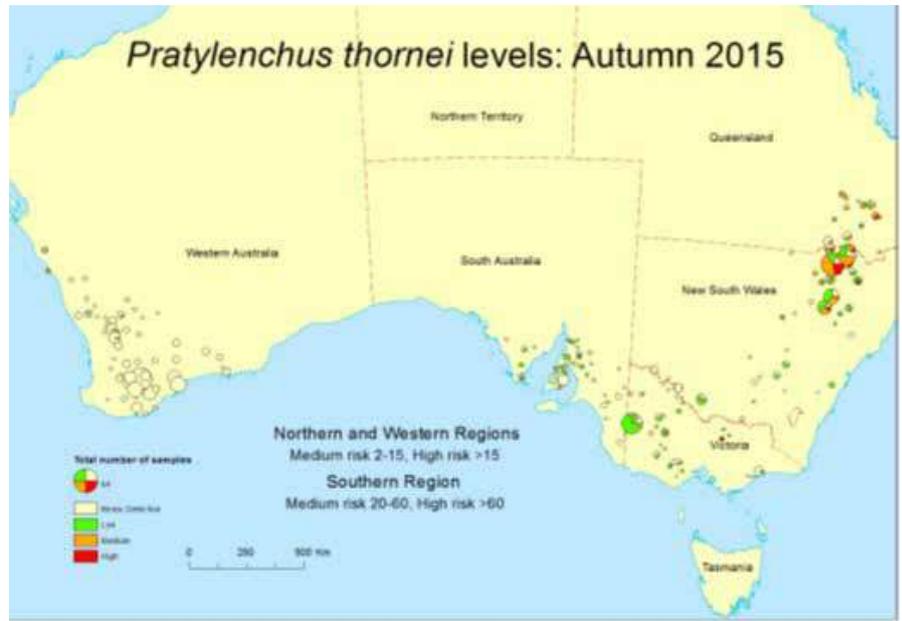
¹⁴ K Owen, T Clewett, J Sheedy, J Thompson (2016) Managing grain crops in nematode fields to minimize loss and optimise profit. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/03/Managing-grain-crops-in-nematode-infested-fields-to-minimise-loss-and-optimise-profit>

¹⁵ K Owen, T Clewett, J Sheedy, J Thompson (2016) Managing grain crops in nematode-infested fields to minimise loss and optimise profit. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/03/Managing-grain-crops-in-nematode-infested-fields-to-minimise-loss-and-optimise-profit>

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK



i MORE INFORMATION

Managing grain crops in nematode infested fields

Figure 1: The distribution of RLNs and risk of yield loss, from samples submitted for PreDicta B tests to SARDI in autumn 2015 for (top) *Pratylenchus thornei* and (bottom) *P. neglectus*.

Source: GRDC

In a survey of soil samples from 596 paddocks in southern Queensland and northern New South Wales cropping areas consistently show *P. thornei* presence in ~60–70% of paddocks. *This nematode is frequently present at concerning levels, detected at over 2 Pt/g soil in ~30–40% of paddocks. In this survey, it was found that 42% of paddocks tested had P. thornei alone, 27% had both species, 6% had P. neglectus alone, and 26% had neither species (Figure 2).*¹⁶

¹⁶ J Thompson, K Owen, T Clewett, J Sheedy, R Reen (2009) Management of root-lesion nematodes in the northern grain region. DAF Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/crop-diseases/root-lesion-nematode>

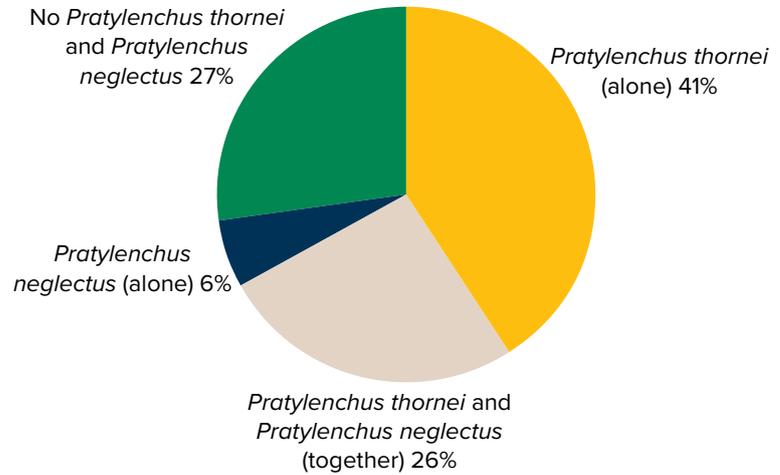


Figure 2: A survey of nematodes in 596 paddocks in the Northern Region revealed that *P. thornei* is the most commonly found root-lesion nematode in the region (prior to recent region boundary changes) and that *P. neglectus* is also present.

Source: DAF Queensland

8.1.1 Symptoms

What to look for in the paddock

- Crops appear patchy with uneven growth, and may appear nutrient-deficient (Photo 3).
- Double-sown and more fertile areas are often less affected.
- There may be stunted growth and 'waviness' across the paddock.



Photo 3: Poor vigour cereal in high-RLN plot (left) compared to a healthy plot with low numbers of RLN (right).

Photo: Grant Hollaway

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK

What to look for in the plant

- Affected plants are stunted and poorly tillered, and can wilt even in moist soil.
- Roots can have indistinct brown lesions or, more often, generalised root browning (Figure 6).
- Badly affected roots are thin and poorly branched, with fewer and shorter laterals.
- Roots may appear withered, with crown roots often less affected than primary roots.
- Roots can assume a 'noodle-like' root thickening.¹⁷
- The roots do not swell or knot and no cysts are produced, occurrences that indicate infection by cereal cyst nematodes.¹⁸
- Note that symptoms may not be as distinct in triticale as it has higher resistance levels to RLNs than wheat of which this symptomology is based upon.



Photo 4: Discolouration and a lack of lateral roots on cereals is caused by root-lesion nematodes.

Photo: Frank Henry

VIDEOS

WATCH: [How to diagnose root-lesion nematode](#)



¹⁷ DAFWA (2016) Diagnosing root lesion nematode in cereals. DAFWA, <https://agric.wa.gov.au/n/2166>

¹⁸ CropPro (2014) Root lesion nematode (RLN). GRDC, http://www.croppro.com.au/crop_disease_manual/ch03s07.php

8.1.2 Varietal resistance or tolerance

Some crops, varieties and plant types have different levels of resistance to different species of the *Pratylenchus* family. Triticale has varying levels of resistance and tolerance to *P. neglectus* and *P. thornei* (Table 1). Triticale is thought to be susceptible to *P. penetrans*, but this needs to be confirmed by research.¹⁹

Table 1: *Triticale variety resistance ratings to nematodes.*

Variety	<i>Pratylenchus neglectus</i> resistance	<i>Pratylenchus thornei</i> resistance
Astute(D)	R–MR	MS
Berkshire(D)	MR	MS
Bison(D)	MR	R–MR
Canobolas(D)	MR	MS–S
Chopper(D)	R	MS–S
Endeavour(D)	MR	S–VS
Fusion(D)	R–MR	MS
Goanna	MR–MS	S–VS
KM10	MR	MSp
Rufus	MS–S	MS–S
Tahara	MR	S
Tobruk(D)	MR	S–VS
Tuckerbox	MR–MS	S
Yowie	MR	MS–S

Disease resistance order from best to worst: R > R–MR > MR > MR–MS > MS > MS–S > S > S–VS > VS
 p = provisional ratings—treat with caution. R = resistant, M = moderately, S = susceptible, V = very
 Source: Agriculture Victoria

8.1.3 What does resistance and tolerance mean?

Resistant varieties will result in fewer nematodes remaining in the soil to infect subsequent crops. Tolerant varieties are able to perform well in the presence of the nematode, but they may allow nematode populations to build up.

Nematode Resistance relates to the effect of the variety on the nematode density present within the paddock (Table 2).

¹⁹ A Wherret, V Vanstone (2016) Root lesion nematode. Soilquality.org, <http://soilquality.org.au/factsheets/root-lesion-nematode>

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Table 2: *Standard disease ratings.*

Uniform rating	Management option description	In the paddock	Management action
Resistant	Growing these varieties will reduce the density of the nematode in question and so reduce yield loss in subsequent intolerant crops.	There will be a reduction in nematode densities when these varieties are grown.	Use these varieties in rotation with non-host crops to reduce nematode infestations. If using R varieties in paddocks with high nematode infestations make sure variety is also tolerant to prevent significant yield loss.
Moderately resistant	Growing these varieties will, to a lesser degree than growing a resistant variety, reduce the density of the nematode in question and, therefore, reduce yield loss in subsequent intolerant crops.	There will be a reduction in nematode densities when these varieties are grown.	These varieties are suitable to be grown in paddocks with high nematode infestations as they reduce nematode densities. They will, however, not reduce nematode densities to the same degree as a resistant variety. Note that if nematode densities are high tolerant to minimise yield loss.
Moderately susceptible	Growing these varieties will result in a small increase in nematode densities during the season.	Growing these varieties will increase the nematode density. However, unless the season is exceptionally favourable, growing these varieties in paddocks with low level nematode densities will only increase densities to moderate levels. If nematode densities are already moderate these varieties may result in high densities that may cause substantial loss in a following intolerant variety.	These varieties are suitable to be grown in paddocks with low nematode densities. They will, however, increase nematode densities which may be a problem for a following intolerant crop.

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Uniform rating	Management option description	In the paddock	Management action
Susceptible	Growing these varieties will increase nematode density which may then cause problems to a following intolerant crop.	Growing these varieties will result in increases in the density of the nematode in question. However, unless the season is exceptionally favourable, growing these varieties in paddocks with a low level will only result in moderate levels. If nematode densities are already moderate these varieties can result in high levels that may cause substantial loss in a following intolerant variety.	These varieties will increase the density of nematodes in a paddock that may be of concern to a following intolerant crop. If nematode densities are high following a susceptible crop, growers should avoid intolerant crops in the following year and select a resistant crop to reduce nematode densities.
Very susceptible	Growing these varieties will support large multiplication rates of the nematode. It may take more than one year of a resistant variety/ non-host crop to reduce the nematode densities to a level that will not affect the yield of an intolerant crop.	These varieties will support large increases in nematode numbers when grown in infested paddocks.	Growers should where possible avoid growing these varieties in infested paddocks. Also avoid growing intolerant varieties after VS varieties due to the potential for significant yield loss. A tolerant non-host crop/resistant variety should be used following VS varieties to reduce nematode densities. If nematode densities are very high it may take more than two years of non-host/resistant varieties to reduce nematode levels to low risk densities.

Source: [NVT Online](#).

Nematode Tolerance relates to yield of the variety in the presence of the nematode (Table 3).

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Table 3: Standard disease ratings.

Uniform rating	Management option description	In the paddock	Management action
Tolerant	Variety will not lose yield in the presence of the nematode, even at high nematode densities.	The crop will not be affected by the presence of the nematode.	No economic management decisions required.
Moderately tolerant	These varieties can generally be sown in paddocks with low to medium levels of nematode infestations without a significant effect on grain yield occurring. These varieties can suffer yield loss (up to 10%) in the presence of high nematode densities.	Minimal yield loss will occur in the presence of the nematode (i.e. < 5%), except when nematode densities are high when up to 10% yield loss may occur.	Do not grow these varieties in paddocks with high nematode densities present. Suggest follow management recommendations to minimise yield loss for the nematode of concern.
Moderately intolerant	These varieties should not be grown in paddocks with medium to high nematode densities. In the presence of high nematode densities in a paddock these varieties will lose up to 30% yield.	In the presence of the nematode and in seasons conducive to disease, these varieties will lose yield and may show symptoms consistent with root damage. The expression of symptoms will be greater in paddocks with higher nematode densities.	These varieties should not be grown in paddocks with medium to high nematode densities. In the presence of high nematode densities in a paddock these varieties can lose up to 30% yield. Suggest follow management recommendations to minimise yield loss for the nematode of concern.
Intolerant	These varieties are prone to yield loss even in the presence of low nematode densities. Such varieties should not be grown in paddocks where nematodes are known to be present. In the presence of high nematode densities yield loss of up to 50% can occur.	In the presence of the nematode symptoms of root disease will often be easily found in the crop.	Do not grow these varieties in paddocks where the nematode is present at medium to high levels. Even paddocks with low nematode densities should be avoided when possible. Suggest follow management recommendations to minimise yield loss for the nematode of concern.

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [GCTV19: Root-lesion nematodes—Resistant cereal varieties have surprising impacts on RLN numbers](#)



Uniform rating	Management option description	In the paddock	Management action
Very intolerant	Do not grow this variety unless the paddock is known to be nematode free or present at very low densities. High nematode densities could cause yield losses of greater than 50% to occur.	Symptoms of nematode damage will be present in these varieties even in the presence of low nematode densities.	Do not grow these varieties in paddocks where the nematode is present, even at low levels. If the variety is to be grown a soil test should be conducted prior to sowing to ensure that the paddock is free from the nematode in question. Suggest follow management recommendations to minimise yield loss for the nematode of concern.

Source: [NVT Online](#)

8.1.4 Damage caused by RLN

Root-lesion nematode numbers build up rapidly when susceptible crops are planted, and the build-up causes decreasing yields over several years. The amount of damage caused will depend on; the numbers of nematodes in the soil at sowing, the tolerance of the variety of crop being grown, and environmental conditions.

Field trials in areas infested with *P. neglectus* have shown yield losses for intolerant wheat ranged from 12–33%.²⁰ In the southern part of the northern region *P. neglectus* can cause major losses to susceptible crops. In southern Australia *P. neglectus* has been known to reduce grain yield by 10–20% and in Western Australia is has been reported to cause losses of up to 15%.²¹

In the northern part of the Northern region, intolerant varieties can lose more than 50% in yield when *P. thornei* populations are high (Figure 3).²²

20 B Burton, R Norton, R Daniel (2015) Root-lesion nematode: importance, impact and management. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Root-lesion-nematodes-importance-impact-and-management>

21 V Vanstone, J Lewis (2009) Plant parasitic nematodes Factsheet. GRDC. <https://grdc.com.au/resources-and-publications/all-publications/bookshop/2010/10/plant-parasitic-nematodes-fact-sheet-southern-western-region>

22 B Burton, R Norton, R Daniel (2015) Root-lesion nematode: importance, impact and management. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Root-lesion-nematodes-importance-impact-and-management>

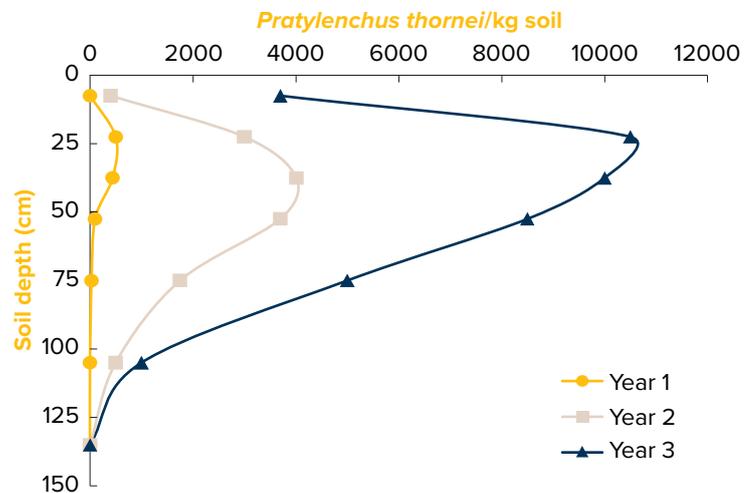


Figure 3: During three years of continuous wheat cropping at Wellcamp (Queensland), numbers of Pt increased from low levels to levels that would reduce yields of intolerant crops. The graph shows numbers in the soil sampled before sowing each year.

Source: DAF Queensland

8.1.5 Conditions favouring development

Root lesion nematodes survive summer as dormant individuals in dry soil and roots, and become active after rain. They can survive several wetting/drying cycles. About three generations of the nematodes are produced each season, with the highest multiplication in spring.

Nematodes can spread through a district in surface water (e.g. floodwater) and can be moved from one area to another in soil that adheres to vehicles and machinery. They can also move via soil adhering to vehicles and farm machinery. In uninfested areas, good hygiene should be adopted. Nematodes can be spread in dust when they are in a dehydrated state over summer.

They have the ability to quickly build up populations in the roots of susceptible crops, and remain in the soil during fallow. As a result, the yield of following crops can be significantly reduced.

IN FOCUS

How long does it take to reduce Pt in soils?

Key points:

- Paddocks that host *P. thornei* populations greater than 40,000 per kg of soil at harvest will require a double break of around 40 months free of a host plant in order to reduce the population.
- Paddocks that host *P. thornei* populations greater than 10,000 per kg at harvest will require a single break of around 30 months free of a host plant in order to reduce the population below the accepted threshold.
- Weeds can be hosts, so fallows must be free of weeds and volunteers.

Researchers explored how long it takes to reduce Pt populations in infected soils. Using wheat cultivars with different levels of tolerance and

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK

resistance, they created a range of nematode populations in the soil. At the harvest of the second wheat crop, the nematode population in each plot was recorded and defined as high (H, >20,000Pt/cm²/1.2 m soil profile), medium (M, >10,000Pt/cm²/1.2 m profile), low (L, >5,000Pt/cm²/1.2 m profile) or very low (VL, <5,000Pt/cm²/1.2 m profile), and calculated as the sum of nematodes across the whole profile. Over the next 30 months soil samples were collected from the plots to monitor the change in nematode populations over time.

The rotation over the 30 months was wheat, followed by a long fallow to sorghum, then a long fallow to wheat. In the fallow that commenced in 2011, no sorghum was sown due to drought.

A paddock with a high initial number of nematodes (80 nematodes per cm³, ~80,000 Pt/kg) took four years to reduce below the threshold. This required two non-host crops such as sorghum and fallows to reduce the population. A paddock with an initially medium level of nematodes (50 nematodes per cm³) took 3.5 years to drop below the threshold (Figure 4),²³ and required the equivalent of a single non-host summer crop and fallows. A low nematode population paddock (20 nematodes per cm³) took 24 months to drop below the threshold.²⁴

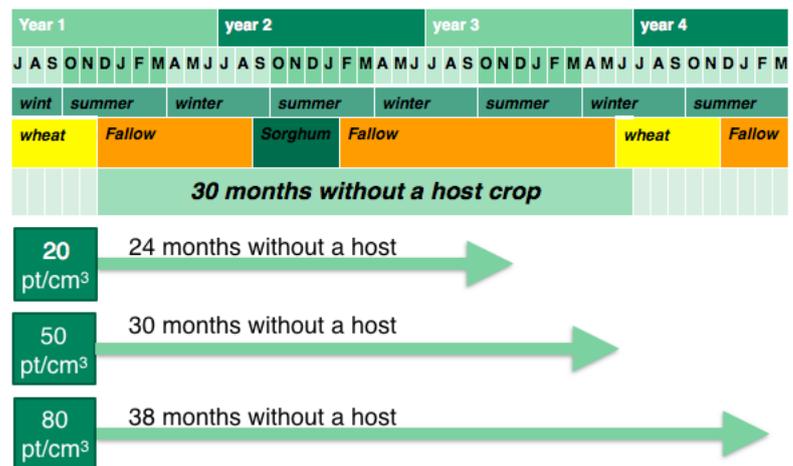


Figure 4: An example of a non-host fallow showing the time required to reduce different starting populations of root-lesion nematode.

Source: GRDC

i MORE INFORMATION

How long does it take to reduce *Pratylenchus thornei* (root lesion nematode) population in the soil?

Impact from *Pratylenchus thornei*, Macalister 2015

8.1.6 Thresholds for control

The damage threshold for both RLNs has been estimated at 2,000 nematodes/kg soil (or 2/g soil). Control is warranted for paddocks with populations over this density.²⁵

In the Northern region, paddocks with more than 15 *P. thornei*/g soil or 15,000/kg soil are considered high risk for crops. However, populations of *P. thornei* classified as being of medium risk, that is 2–15/g soil or 2,000–15,000/kg soil, can cause

23 J Whish, J Thompson (2016) How long does it take to reduce *Pratylenchus thornei* (root lesion nematode) population in the soil? GRDC Update Paper. GRDC, <https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/how-long-does-it-take-to-reduce-pratylenchus-thornei-populations-in-the-soil>

24 J Whish, J Thompson (2016) How long does it take to reduce *Pratylenchus thornei* (root lesion nematode) population in the soil? GRDC Update Paper. GRDC, <https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/how-long-does-it-take-to-reduce-pratylenchus-thornei-populations-in-the-soil>

25 GRDC (2015) Root lesion nematodes. Tips and Tactics. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2015/03/rt-rootlesionnematodes>

substantial yield loss in intolerant varieties in the warm, wet growing seasons that are conducive to nematode reproduction.²⁶

The number of nematodes in the soil can be determined by conducting soil testing, for example with a PreDicta B test.

8.1.7 Management of RLN

Key points:

- Know your enemy—test soil to determine whether RLN are a problem and which species are present.
- Select wheat varieties rated as having a high tolerance to minimise yield losses in RLN-infected paddocks.
- To manage RLN populations, it is important to increase the frequency of RLN-resistant crops in the rotation.
- Multiple resistant crops in a rotation will be necessary for the long-term management of RLN populations.
- There are consistent varietal differences in Pt resistance within wheat and chickpea varieties.
- Avoid crops or varieties that allow the build-up of large populations of RLN in infected paddocks.
- Monitor the impact of your rotation.

There are four key strategies in reducing the risk of root-lesion nematodes:

1. Have soil tested for nematodes in a laboratory (For more information, see [Section 8.1.8 Soil testing](#)).
2. Protect paddocks that are free of nematodes by controlling soil and water run-off and cleaning machinery; plant nematode-free paddocks first.
3. Choose tolerant varieties to maximise yields; [National Variety Trials online](#) is a useful resource. Tolerant varieties grow and yield well when RLN are present.
4. Rotate with resistant crops to prevent increases in root-lesion nematodes (Figure 5²⁷). When high populations of RLN are detected you may need to grow at least two resistant crops consecutively to decrease populations. In addition, ensure that fertiliser is applied at the recommended rate to ensure that the yield potential of tolerant varieties is achieved. Crop rotation with resistant crops such as grain sorghum, millet, sunflower and lupins will reduce the numbers of nematodes in the soil to a level where susceptible varieties can be grown. However, it will not eliminate them completely.²⁸

²⁶ K Owen, T Clewett, J Sheedy, J Thompson (2016) Managing grain crops in nematode-infested fields to minimise loss and optimise profit. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/03/Managing-grain-crops-in-nematode-infested-fields-to-minimise-loss-and-optimise-profit>

²⁷ B Burton, R Norton, R Daniel (2015) Root lesion nematodes: importance, impact and management. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Root-lesion-nematodes-importance-impact-and-management>

²⁸ DAF Qld (2015) Wheat: diseases, physiological disorders and frost. DAF Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases>

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK

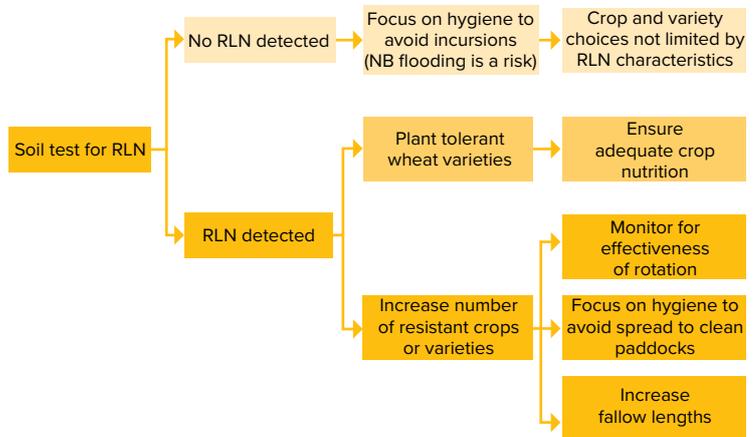


Figure 5: The simplified RLN management flow chart. It highlights the critical first step in the management of RLN is to test soil to determine whether you have a problem to manage. Where RLN are present, growers should focus on both planting tolerant wheat varieties and increasing the number of resistant crops and varieties in the rotation.

Source: GRDC

The first step in management of RLN is to have soil tested to determine whether RLN are present in paddocks. If RLN are detected, the soil test will tell you which of the species is present and the population level in the field. If RLN are not detected, protect those paddocks from contamination by controlling movement of soil and water on the farm. Clean soil from machinery before planting or fertilising, and plant RLN-free paddocks first.

When RLN are detected, rotations and variety choice are central to successfully reducing RLN populations. Only non-host crops or resistant varieties will minimise the build-up of RLN (Tables 4 and 5). Aim to reduce populations to less than 2/g soil. Re-testing of soil after growing resistant crops is recommended, so that crop sequences can be adjusted if populations are still at damaging levels. Avoid very susceptible crops and varieties.²⁹ Consider re-testing in five years, particularly if there has been flooding, because RLN can move in floodwaters and in soil.

Table 4: Susceptibility of some non-cereal crop and pasture species to root lesion nematode infection.

RLN species	Susceptible crops	Moderately susceptible crops	Resistant crops
<i>Pratylenchus neglectus</i>	Canola, chickpeas, mustard	Common vetch, lentils	Field peas, narrow leaf lupins, faba beans, triticale, safflower, cereal rye, medic, clover
<i>Pratylenchus thornei</i>	Chickpeas, vetch, faba beans	Canola, mustard, field peas*, lentils	Field peas*, lupins

* New field pea varieties are more susceptible to *P. Thornei* than older varieties, so check the classification of each variety.

Source: GRDC

29 GRDC (2015) Root-lesion nematodes, Northern Region. Tips and Tactics. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2015/03/rt-rootlesionnematodes>

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Table 5: Comparison of the risk of build-up of *Pratylenchus thornei* and *P. neglectus* in crops.

Crop	<i>P. thornei</i>	<i>P. neglectus</i>
Cereals		
Barley	Medium to high	Low to medium
Canary seed	Low	Low
Maize	Low	Low
Millet	Low	Low
Oats	Low	NT
Sorghum (grain)	Low	Medium to high
Triticale	Medium to high	Low
Wheat	Low, medium to high	Low, medium to high
Legumes		
Blackgram	High	Medium (p)
Chickpeas	Medium to high	Low to medium
Cowpeas	High	NT
Faba beans	Medium to high	Low
Field peas	Low to medium	NT
Navy beans	High	NT
Pigeon peas	Low	NT
Oilseeds		
Canola, mustard	Low to medium	Medium to high
Cotton	Low	Low
Linseed	Low	Low
Soybeans	High	Low
Sunflowers	Low	Low
Pastures, forage		
Brassica (forage)	Low to medium (p)	NT
Lablab	Low	NT
Sorghum (forage)	Low	Medium to high

Source: GRDC

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [Root lesion nematodes part 3: What can I do?](#)



WATCH: [Crop variety effect on nematodes](#)



MORE INFORMATION

[National Variety Trials](#)

GRDC Tips and Tactics, [Root-lesion nematodes, Northern Region](#)

Fallow

RLN populations will generally decrease during a ‘clean’ fallow but the process is slow and expensive in lost potential income. Additionally, long fallows may decrease arbuscular mycorrhizae (AM) levels and create more cropping problems than they solve.

Weed control

Weeds can play an important role in the increase or persistence of nematodes in cropping soils. Thus, poor control of susceptible weeds compromises the use of crop rotations for RLN management. Wild oat, barley grass, brome grass and wild radish are susceptible to *P. neglectus*. When a pasture is included in the cropping rotation, weeds strongly influence nematode populations at the end of the pasture phase. Manage volunteer susceptible crop plants that can harbour nematodes.³⁰

Nutrition

Damage from RLN reduces the ability of cereal roots to access nutrients and soil moisture, and can induce nutrient deficiencies. Although under-fertilising is likely to exacerbate the impact of RLN-affected yields, over-fertilising is unlikely to *compensate* for a poor variety choice.

Adequate nutrition (especially nitrogen, phosphorus and zinc) normally allows plants to better tolerate plant parasitic nematodes, although this does not necessarily lead to lower nematode reproduction.

Field trials in areas infested with *P. neglectus* have shown yield losses for intolerant wheat ranged from 12–33% when minimal levels of phosphorus were applied but losses were reduced to only 5% with a high (50 kg/ha) rate of phosphorus.

Nematicides (control in a drum)

There are no nematicides registered for use against RLN in broadacre cropping in Australia. Screening of potential candidates continues to be conducted, but RLN are very difficult to target because populations are frequently deep in the soil profile.³¹

Natural enemies

Biological suppression is a potential method of reducing populations of *P. thornei* and *P. neglectus*. Recent research has identified that Northern Region soils are capable of suppressing root-lesion nematodes, especially in the top layer (0–15 cm), and this capacity can be enhanced by increasing the biological activity of that soil, mainly through carbon inputs and minimising soil disturbance.

Several organisms that prey on nematodes have been found in northern soils that have the potential to reduce root-lesion nematode populations. They include the *Pasteuria* bacteria that infect and eventually kill *Pratylenchus* spp. Several species of fungi, including some that trap nematodes, and predatory nematodes have also been found.

Research is continuing to develop methods of increasing biological activity to enhance natural suppression of nematodes deeper in the soil profile.

³⁰ V Vanstone, J Lewis (2009) Plant parasitic nematodes Factsheet. GRDC. <https://grdc.com.au/resources-and-publications/all-publications/bookshop/2010/10/plant-parasitic-nematodes-fact-sheet-southern-western-region>

³¹ B Burton, R Norton, R Daniel (2015) Root-lesion nematode: importance, impact and management. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Root-lesion-nematodes-importance-impact-and-management>

IN FOCUS

Biological suppression of RLN in northern soils

Key points:

- In one study, biological suppression occurred in most soils tested in the northern grain-growing region, showing that populations of *RLN* are reduced by parasites and predators.
- Suppression was found to be greater in the top 10 cm of soil than at deeper layers (e.g. 30–45 cm). Practices such as zero tillage with stubble retention enhanced suppression. In the absence of these, it is estimated that RLN multiplication would be significantly greater, especially in topsoils, and that this would result in much greater losses in the productivity of susceptible crops.
- Several antagonists of *Pratylenchus* spp. were found in northern grain-growing soils that enhance the plant's resistance to nematodes: nematode-trapping fungi, predatory nematodes, parasitic bacteria, and root-colonising fungi. Further research is focussing on these organisms as they are likely to contribute to the ability of natural subsoil systems to suppress RLN.

Actively enhancing the ability of soils to suppress root-lesion nematodes is a control option that deserves some consideration. In regard to RLN, disease suppression can be defined as the ability of a soil and its organisms to suppress the incidence or severity of disease even in the presence of the pathogen, host plants and favourable environmental conditions. The vast array of organisms in the soil can provide a degree of biological buffering against pathogens. Disease reduction results from the combined effects of many antagonists acting collectively and mediated through inputs of organic matter (general suppression) and direct antagonism by a limited number of organisms (specific suppression).

A recent GRDC-funded project aimed to better understand the suppressive nature of grain-growing soil environments and provide growers with methods to enhance the soils' ability to suppress root-lesion nematodes.

Over four years, researchers sampled 24 sites to test the suppressive nature of the soils. The sites were located in several farmers' paddocks and three long-term farm-management trial sites. The soils were given several fertiliser or tillage treatments. Also, seven of the sites were comparisons of cropped/pasture or native/scrub remnant soils that were close by to gain an understanding of the impact cropping may have on any natural ability of soils to suppress RLNs.

Repeated studies over four years of multiple soils from northern NSW and southern Queensland consistently showed that some soil environments have a natural ability to suppress root-lesion nematodes. In glasshouse tests, the researchers also found that a 10% addition of suppressive field soil to a sterilised soil (heated at 60°C for 45 mins) is sufficient to reduce RLN multiplication by 60–90%, showing that the suppressive effect was biological and could be transferred or added to a less suppressive soil.

Implications:

- Suppression does occur in most of the soils tested, as populations of *P. thornei* were reduced due to biological activity. Suppression was greater in the top 10 cm of soil than at deeper layers, and practices such as zero tillage with stubble retention enhanced the effect.
- Maintenance of a healthy topsoil through diverse organic matter inputs will preserve the potential of soils to naturally suppress RLNs.

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK

MORE INFORMATION

[Biological suppression of RLN in northern region](#)

- Heavy rates of stubble (up to 20 t/ha) increased general suppression of RLN in the short term. This coincided with high levels of microbial activity.
- The presence of a crop for longer periods of time and the associated input of root exudates may have provided a better environment for sustained microbial activity and, hence, suppression of RLN.
- Growers using no-till, stubble-retention practices and cropping when soil moisture allows are probably doing a great deal toward enhancing the suppressive ability of their topsoils. Without these practices, RLN multiplication would probably be significantly greater, especially in topsoils, and therefore lead to much greater losses in productivity of susceptible crops.

More work is required to confirm the biological-control agents found to be present in grain-growing soils can have a significant impact on RLN populations on a broad scale.³²

8.1.8 Soil testing

Soil testing is the best way to diagnose nematode infestations and also to inform growers' management decisions. It is important to know whether nematodes are on your farm and which species are present. This is important because varietal tolerance information for *P. thornei* does not hold true for *P. neglectus*, so proper species identification can help minimise losses that arise from planting intolerant varieties in nematode-infested land.

RLN populations can persist in the soil for a long time, so it is important to know the size of the population at the end of each season. Once a population increases, non-host, resistant crops or fallows are required to reduce the population below the damage threshold. Planting susceptible or tolerant crops within this period will enable the rapid increase in populations to higher levels.³³

There are two services available to test for RLNs.

Leslie Research Centre tests

The Leslie Research Centre of the Department of Agriculture and Fisheries Queensland offers a commercial test for their the presence of nematodes in soil.

Since nematodes may not be evenly spread across a paddock, particularly when there are new infestations, it is important to take samples from several locations within a paddock. It is suggested that growers take nine cores in groups of three.

Nematodes are often more numerous in the subsoil than in the topsoil. Although you can have soil to a depth of 120 cm analysed, this isn't necessary. As long as soil is sampled in two layers, topsoil at 0–15 cm and subsoil at 15–30 cm, a useful result can be achieved. Use a hand corer (or a mattock if no corer is available). Topsoil-only samples can give inaccurate results and should always be accompanied by a subsoil sample. If deeper samples are already being taken for other analysis (e.g. nitrate), a nematode assessment can be made from the depths 0–30 cm, 30–60 cm and 60–90 cm.

³² N Seymour, G Stirling, J Li (2016) Biological suppression of RLN in northern grain growing soils. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/03/Biological-suppression-of-root-lesion-nematodes-in-northern-grain-growing-soils>

³³ J Whish, J Thompson (2016) How long does it take to reduce *Pratylenchus thornei* (root lesion nematode) population in the soil? GRDC Update Paper. GRDC, <https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/how-long-does-it-take-to-reduce-pratylenchus-thornei-populations-in-the-soil>

SECTION 8 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

MORE INFORMATION

Leslie Research Centre, [Test your farm for nematodes](#)

Send samples to: Soil Microbiology Section
Leslie Research Centre
PO Box 2282 Toowoomba, QLD 4350
13 Holberton Street v
Toowoomba
Phone: (07) 4639 8888
Fax: (07) 4639 8800

MORE INFORMATION:

Leslie Research Centre, [Test your farm for nematodes](#)

PreDicta B tests

PreDicta B is a DNA-based soil-testing service that was developed by the South Australian Research and Development Institute (SARDI) (The B in the name stands for broadacre). The test identifies which soil-borne pathogens pose a significant risk to broadacre crops before paddocks are planted (Photo 5).³⁴

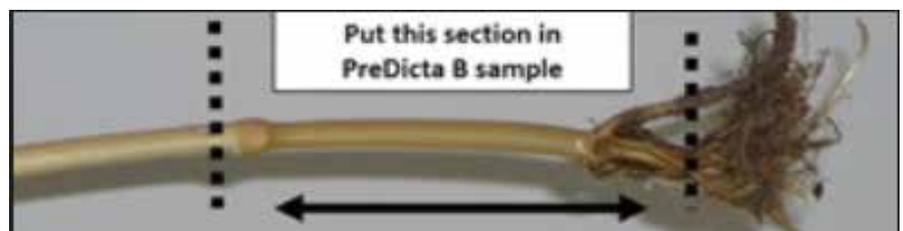


Photo 5: It is important to follow the PreDicta B sampling instructions closely.

Source: GRDC

PreDicta B can be used to test for:

- Root-lesion nematodes including *P. neglectus* and *P. thornei*
- take-all (*Gaeumannomyces graminis* var. *tritici* (Ggt) and *G. graminis* var. *avenae* (Gga)).
- Rhizoctonia root rot (*Rhizoctonia solani* AG8).
- crown rot (*Fusarium pseudograminearum* and *F. culmorum*).
- blackspot of peas (*Mycosphaerella pinodes*, *P. medicaginis* var. *pinodella* and *P. koolunga*).

Testing service

You can access PreDicta B diagnostic testing services through a SARDI accredited agronomist, who will interpret the results and give you advice on management options to reduce your risk of yield loss.

Samples are processed weekly between February and mid-May (prior to crops being sown).

PreDicta B is not intended for in-crop diagnosis.

8.2 Cereal cyst nematode

Key points:

- Cereal cyst nematode (CCN) can cause major yield loss to crops in the southern part of the Northern growing region. CCN is rarely found in northern NSW and Queensland
- Some varieties of triticale are thought to be resistant to cereal cyst nematode, a characteristic that is probably inherited from its parent crop, cereal rye.
- CCN is most damaging in low rainfall districts and seasons, especially with late breaks.

³⁴ D Lush (2014) PreDicta B sampling strategy. GRDC, <https://grdc.com.au/Media-Centre/Media-News/South/2014/04/PreDicta-B-sampling-strategy>

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- Rotations using break crops minimise the carryover of CCN host species (e.g. canola, lupins, chickpeas) as non-host crops are more effective than resistant cereals in reducing levels of CCN.
- Be aware of and try to minimise consecutive cereal hosts in rotations. CCN levels can become damaging after growing a susceptible crop for only one or two seasons.
- Grow resistant cereal cultivars to limit levels of CCN in the soil.
- Control volunteer cereal hosts and grass weeds during late summer and early autumn and in break crops.
- Sow early where possible to ensure better root development.
- Maintain optimum soil fertility to help crops get ahead of CCN infections.

Cereal cyst nematode is a pest of graminaceous crops worldwide. It is a significant problem across south-eastern Australia, including the southern part of the Northern region. CCN becomes more problematic in areas where intensive cereal cropping occurs.

There have been isolated reports of cereal cyst nematode (*Heterodera avenae*) near Tamworth and Dubbo on lighter-textured soils and friable black soils. If growers suspect CCN they should contact a local agronomist.³⁵

Cereal cyst nematode only infects, feeds on and develops on cereals and other grasses (particularly wild oats). Non-cereal crops do not host the nematode, so are useful in rotations to limit damage caused to cereals.

CCN usually occurs early in the season and can occur on heavy or light soils.

The nematodes hatch over a period of several weeks, with the peak hatch occurring about six weeks after the autumn break. The eggs are contained in cysts that remain from previous seasons and hatch in response to lower temperatures and autumn rains. Hatching is delayed by late breaks or dry autumns, and this increases the risk of crop damage. Once hatched, the young nematodes seek out the roots of host plants. While the male nematodes remain free-living in the soil, the females penetrate the roots and begin feeding. Therefore, to prevent CCN multiplying, it is necessary to control host plants within 10 weeks of crop germination.

Following mating, the female produces eggs within its body. As the season progresses she remains feeding at the same infection site, and begins to swell into a characteristic white sphere. This process takes 6–9 weeks, and the CCN female remains like this until the host plant begins to senesce. The female dies and its cuticle hardens and turns brown to form a cyst. The cysts are particularly hardy, and remain in the soil over summer until temperatures fall and the autumn rains begin. Temperatures below 15°C and moist soil stimulate the hatching of the next generation. Cereal cyst nematodes have only one life cycle a year (Figure 6).³⁶ However, each cyst contains several hundred eggs, so populations can increase rapidly on susceptible cereals.³⁷

35 GRDC (2009) Plant parasitic nematodes, Northern Region. Factsheet. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/bookshop/2010/10/plant-parasitic-nematodes-fact-sheet-northern-region>

36 G Hollaway (2013) Cereal root diseases. Note AG0562. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-root-diseases>

37 A Wherrett, V Vanstone (2016) Cereal cyst nematode. Soilquality.org, <http://www.soilquality.org.au/factsheets/cereal-cyst-nematode>

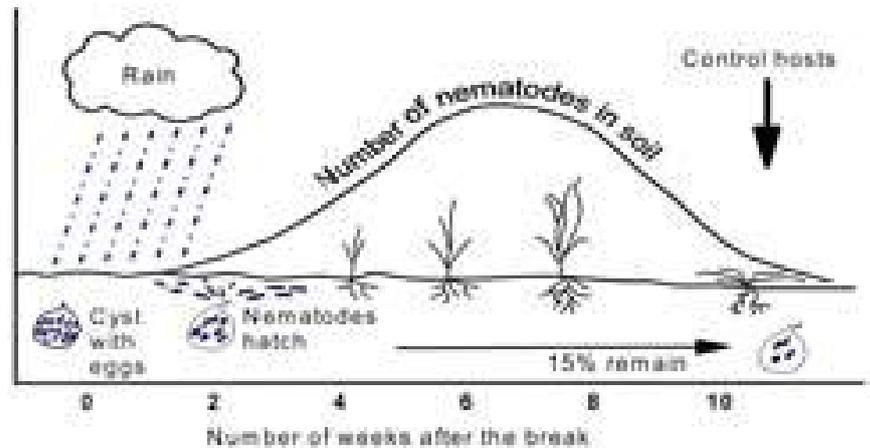


Figure 6: Life cycle of the cereal cyst nematode.

Source: Agriculture Victoria

Each year approximately 80% of nematodes hatch from cysts after the autumn break, while the remaining 20% stay dormant until the following season. This is why it will take at least two years with break crops to control CCN. However, under dry conditions or drought up to 50% of nematodes remain dormant, and an extra year of break crop is advisable.³⁸

8.2.1 Symptoms and detection

The symptoms of CCN infection can be readily recognised. Above ground, patches of yellowed and stunted plants that fail to thrive can be observed (Photo 6).³⁹ Planting a susceptible crop in successive years will result in these patches becoming larger.

Below ground, close examination of the roots will reveal symptoms that are typical of CCN. Below ground, cereal roots can appear knotted (Photo 7), and 'ropey' or swollen (Photo 8).⁴⁰ Development of the root systems is retarded and shallow. In spring, characteristic white cysts about the size of a pin head can be seen with the naked eye if roots are carefully dug out and washed free of soil. These are the swollen bodies of the female CCN, each containing several hundred eggs.⁴¹

³⁸ G Hollaway, F Henry (2013) Cereal root diseases. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-root-diseases>

³⁹ A Wherrett, V Vanstone (2016) Cereal cyst nematode. Soilquality.org. <http://www.soilquality.org.au/factsheets/cereal-cyst-nematode>

⁴⁰ CropPro (2014) Cereal cyst nematode (CCN). GRDC, http://www.croppro.com.au/crop_disease_manual/ch03s03.php

⁴¹ A Wherrett, V Vanstone (2016) Cereal cyst nematode. Soilquality.org. <http://www.soilquality.org.au/factsheets/cereal-cyst-nematode>

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 6: CCN will cause distinct patches of yellowed and stunted plants. Note the likeness of symptoms to poor nutrition or water stress.

Photo: Vivien Vanstone. Source: Soilquality.org



Photo 7: CCN produce knotting of cereal roots.

Photo: Vivien Vanstone. Source: Soilquality.org

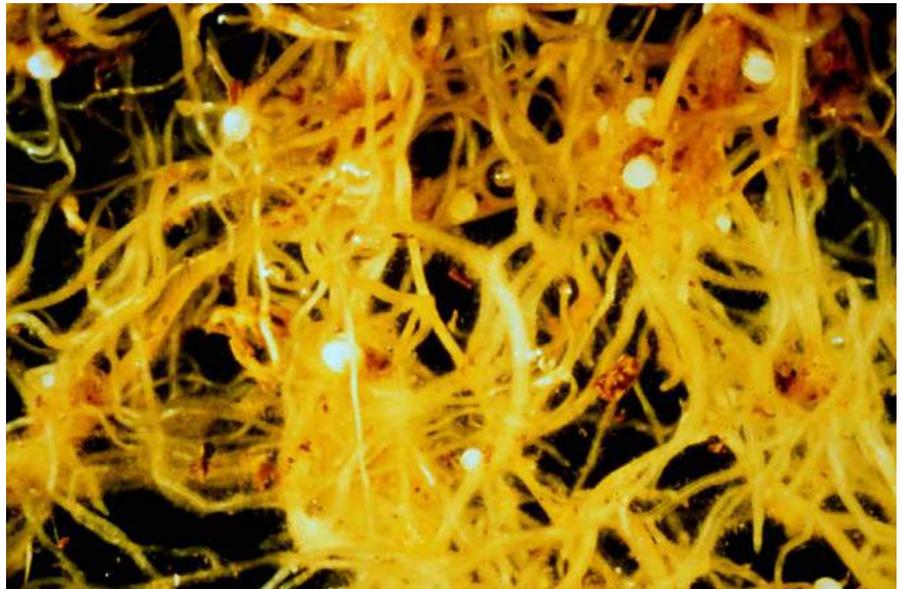


Photo 8: Cereal roots infected with CCN appear 'ropy' and swollen.

Source: CropPro

8.2.2 Varietal resistance or tolerance

Some varieties of triticale are thought to be resistant to cereal cyst nematode (Table 6) a characteristic that is probably inherited from its parent crop, cereal rye. Good resistance can be found in varieties such as Chopper(D), Endeavour(D), and Tuckerbox, however some varieties such as KM10 are susceptible to the nematode.

Table 6: Triticale variety resistance ratings to nematodes.

Variety	CCN resistance
Astute(D)	R
Berkshire(D)	–
Bison(D)	R
Canobolas(D)	–
Chopper(D)	R
Endeavour(D)	R
Fusion(D)	R
Goanna	R
KM10	S
Rufus	R
Tahara	R
Tobruk(D)	–
Tuckerbox	R
Yowie	R

Disease resistance order from best to worst: R > R–MR > MR > MR–MS > MS > MS–S > S > S–VS > VS
Source: Agriculture Victoria

8.2.3 Damage caused by CCN

In serious outbreaks of CCN, it may be important to avoid cereals for two years to ensure an adequate reduction in the population. Just two CCN eggs per of gram soil can cause significant economic loss to intolerant cereal crops. Levels of 1–5 eggs/g soil can reduce yield of intolerant cultivars by up to 20% (Photo 9).⁴²



Photo 9: Yield loss in a cereal crop due to CCN.

Photo: Vivien Vanstone. Source: Soilquality.org

8.2.4 Management

As with other nematodes, there is no effective or economically feasible means of controlling CCN through the application of chemicals. Chemical nematicides are expensive to use and toxic to humans, and the success of applications is highly variable.

Cereal cyst nematode is best controlled through effective rotation management. Only 70–80% of eggs hatch each season, regardless of the crop host. As a result, it can take several years for high CCN levels to be reduced by rotation with resistant or non-host crops. The use of a break crop (e.g. canola, lupins, chickpeas) ensures a large proportion of the CCN population is removed. In serious outbreaks of CCN, it may be important to avoid cereals for two years to ensure an adequate reduction in the population.

Ryegrass, wild oats and other grass are also good hosts for CCN, although reproduction rates may be lower than on the cropping species. For this reason, during a pasture phase in a rotation, it is important to control cereal weeds in the crop so as to contain the development of a CCN population. Likewise, any grasses present following summer rains or around paddock borders, it provides a carryover for the nematode population.

Maintaining optimum soil fertility also helps to minimise the effects of CCN. Allowing the emerging crop access to adequate nutrition allows the root systems to establish and get ahead of potential nematode infections. Although this does not decrease the nematode population, losses associated with CCN infections will be minimised.

Finally, in paddocks where there is a known population of cereal cyst nematode and the planting of a cereal cannot be avoided, it is important to choose cultivars that have CCN resistance.⁴³

42 A Wherrett, V Vanstone (2016) Cereal cyst nematode. Soilquality.org, <http://www.soilquality.org.au/factsheets/cereal-cyst-nematode>

43 A Wherrett, V Vanstone (2016) Cereal cyst nematode. Soilquality.org, <http://www.soilquality.org.au/factsheets/cereal-cyst-nematode>

Disease breaks for CCN

The best disease breaks against CCN are:

- grass-free pulse and oilseed crops or legume pasture;
- resistant cereals; and
- chemical fallow prepared early in the season before nematodes have produced viable eggs.⁴⁴

8.3 Nematodes and crown rot

While all winter cereals host the crown rot fungus, the degree of yield loss due to infection varies with the cereal type. The approximate order of increasing yield loss is cereal rye, oats, barley, bread wheat, triticale and durum wheat.⁴⁵

Many trials concentrate on crown rot alone, but in the Northern Region, it is becoming more important to build a picture of the interaction of crown rot with other factors, especially in combination with *Pt* levels. As well as reducing yield, *Pt* reduces grain quality and nitrogen-use efficiency, and increases the severity of crown-rot infections.⁴⁶

The Northern Grower Alliance has been involved in numerous field trials since 2007, and in collaboration with NSW DPI, has evaluated the impact of crown rot on a range of winter-cereal crop types and varieties.

This work has greatly improved understanding of the impact of crown rot and of variety tolerance, and has also indicated that growers may be suffering significant yield losses from another ‘disease’ that often goes unnoticed. This appears to be *Pt*. Although the trials had not been designed to focus on nematodes, a convincing trend was apparent after 2008 that *P. thornei* was having a frequent and large impact on wheat variety yield.⁴⁷

Where *Pt* combines with high levels of crown rot, a common scenario, yield losses can be exacerbated if varieties are susceptible to *Pt*. Instead of a 10% yield loss in a susceptible variety from *Pt* alone, losses could amount to 30–50% if crown rot is combined with a *Pt*-intolerant variety (Photo 10). The research has shown that *Pt* numbers can increase much faster than in an area in which tolerant varieties are growing. These increased *Pt* numbers can lead to even greater damage in future crops.⁴⁸

44 CropPro. Cereal cyst nematode. GRDC, http://www.croppro.com.au/crop_disease_manual/ch03s03.php

45 GRDC (2016) Crown rot in winter cereals—Southern region. Tips and Tactics. GRDC, <https://grdc.com.au/Resources/Factsheets/2016/02/Crown-rot-in-winter-cereals>

46 T Dixon (2013) Balancing crown rot and nematodes in wheat. Ground Cover. Issue 104, May–June 2013. GRDC, <https://grdc.com.au/resources-and-publications/groundcover/gc104/balancing-crown-rot-and-nematodes-in-wheat>

47 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Managing-root-lesion-nematodes-how-important-are-crop-and-variety-choice>

48 B Freebairn (2011) Nematodes and crown rot: a costly union. Ground Cover. Issue 91, March–April 2011. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-91-March-April-2011/Nematodes-and-crown-rot-a-costly-union>

SECTION 8 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [GCTV9: Crown rot and root-lesion nematodes](#)



WATCH: [Over the Fence North: Drew Penberthy](#)



Photo 10: Grass plant showing both parasitic nematode damage to roots and crown rot in above-ground tissues.

Source: North Carolina State University

8.3.1 Management

Variety choice is the key management option when it comes to managing Pt risk. However, when it comes to crown rot management, although varieties have some impact, rotation and stubble management are by far our most important management tools.⁴⁹

Soil testing

Crown Analytical Services has the first Australian commercial test for crown rot. It is based on five years of laboratory research.

Crown rot causes significant yield losses. The frequency of the disease has increased in recent years due to continuous cropping of wheat. Some of the current strategies for managing it are to control grass hosts prior to cropping, rotate susceptible cereals with non-host break crops, burn infected stubble, and grow tolerant wheat varieties. Therefore, it is very important for crown-rot testing to be carried out on a paddock. It allows for growers and consultants to determine if it is present and how severe it is. An informed decision can then be made regarding crop choice and farming system.

Testing involves carrying out a visual assessment on stubble followed by a precise plating test. This is the only way of accurately testing for the disease. Results are provided to the grower and consultant within approximately four weeks of receiving the sample.

[Crown Analytical Services](#) provides sample bags and postage paid packs. Go to service's [protocol web page](#) to better understand the process.

For more on crown rot, see [Section 9. Diseases](#).

⁴⁹ B Freebairn (2011) Nematodes and crown rot: a costly union. Ground Cover. Issue 91, March–April 2011. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-91-March-April-2011/Nematodes-and-crown-rot-a-costly-union>

Varietal choice

Research into varietal tolerance to crown rot and nematodes has revealed that choosing a variety is difficult. Determining the relative tolerance of varieties to crown rot is complex, as it can be significantly influenced by background inoculum levels, RLN populations, differential variety tolerance to *Pn* and *Pt*, and varietal interaction with the expression of crown rot. Other soil-borne pathogens such as *Bipolaris sorokiniana*, which causes common root rot, also need to be accounted for in the interaction between crown rot and varieties. Other factors that influence the expression of crown rot in different varieties are starting soil water, rain while the crop is growing, relative biomass production, sowing date and how moisture or temperature stress affect the variety during grainfill.

Growers should consider switching to varieties that can tolerate crown rot. Growers still need to be aware that significant yield loss can occur in the more tolerant varieties when infection levels are high, particularly when plants suffer serious moisture or temperature stressed during grainfill. Current levels of tolerance in varieties are still not a complete solution to crown rot.⁵⁰

50 S Sumpfendorfer, M Gardner, G Brooke, L Jenkins (2014) Crown rot and nematodes. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Crown-rot-and-nematodes>

Diseases

Key messages

- Triticale can be less susceptible to the common fungal diseases of cereals, which makes it suitable for use in rotations where stubble is retained.
- Some varieties have good resistance to stem, leaf and stripe rusts, mildew and *Septoria tritici* blotch as well as both resistance and tolerance to cereal cyst nematode (CCN).
- Soil and stubble testing is essential for diagnosing many cereal diseases.
- Integrated Disease Management strategies are recommended to reduce disease risk and minimise the likelihood of resistance to controls methods.
- Keeping consistent paddock records and implemented crop rotations are some of the most important and simple strategies in fighting crop diseases.

In the early years of triticale in Australia, the crop was relatively free of disease compared with other winter cereals. As the crop expanded in the 1980s, a range of diseases became more important and began to require active management. The main diseases have been the three rusts (leaf, stem and stripe rust), crown rot, Barley yellow dwarf virus (BYDV). Breeders have had to be careful to avoid the release of susceptibility to diseases when releasing new varieties.¹ The potential arrival of stem rust Ug99 plus new races of stem rust has major implications for triticale production, since the genetics of rust resistance is less well documented in triticale than wheat.²

Triticale can be sensitive to BYDV, downy mildew, loose smut, yellow leaf spot, scald, rhizoctonia, ergot and some strains of stripe rust. These diseases may cause yield loss in triticale and crops should be monitored closely during seasons when conditions may favour the development of these diseases.

Nevertheless, triticale generally has better disease resistance than its wheat parent, courtesy of the rye component of its genetic make-up, and many growers use it as a disease break in their rotations and value the benefits of triticale for its contribution to soil conservation. Though triticale can have better resistance to some diseases than wheat, it can be a host for disease, so growers should monitor crops carefully and choose rotations based on disease risk.

Triticale has some resistance to take-all (lower susceptibility than wheat) and *Septoria tritici* blotch.

Triticale also assists in maintaining soil health by helping reduce nematodes, such as *Pratylenchus neglectus* and *P. thornei* (root-lesion nematodes) and *Heterodera avenae* (cereal cyst nematode), and a range of fungi and bacteria that build up in the soil and reduce yields when the same crop species is grown repeatedly.

Table 1 shows the reaction to diseases by different varieties of triticale.³

1 B McIntosh (1999) Cereal rust corner. Ground Cover. Issue 25. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-25/CEREAL-RUST-CORNER-with-Bob-McIntosh>

2 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_pdf

3 Agriculture Victoria (2016) Triticale [download]. In Victorian winter crop summary. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/victorian-winter-crop-summary>

SECTION 9 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 1: *Triticale variety agronomic guide and disease reaction.*

Variety	Grazing production	Straw strength	Maturity	Resistances					
				Stem rust	Leaf rust	Tobruk pathotype	Stripe rust Yr 17–27 pathotype	Cereal cyst nematode	RLN <i>P. neglectus</i>
Dual-purpose									
Breakwell▲	quick–early	very good	mid–late	R	R	S–VS	MR	R	–
Cartwheel	quick–early	very good	mid–late	R	R	–	R	–	–
Crackerjack ▲	quick–early	moderate	mid	R	MR–MS	MS ^a	R–MR	–	–
Endeavour	quick–early	very good	late	R	R	R–MR	R–MR	R	–
Tobruk▲	quick–early	very good	mid–late	R	R	MS–S ^a	MR	–	–
Tuckerbox	quick–early	–	mid	MR	R	MR–MS	MR	R	–
Grain only									
Astute#	NR	very good	early–mid	R–MR	R–MR	–	R–MR	–	–
Berkshire▲	NR	good	early–mid	R	R	MS	MR–MS	–	–
Bison#	NR	good	early–mid	R–MR	R–MR	–	R	R	R
Bogong▲	NR	very good	early–mid	R–MR	R–MR	MS	MR–MS	–	–
Canobolas▲	NR	good	early–mid	R	R	MS–S	MR–MS	–	–
Chopper▲	NR	very good–good	very early	MR	R	MS–S	MR–MS	R	MR
Fusion	NR	medium–good	mid	R	R	MR ^b	R–MR	R	R
Goanna#	NR	good	early–mid	R	R	MR–MS	R–MR	R	–
Hawkeye	NR	good	mid	R–MR	R	MR, MS–S ^b	MR, MS ^b	R	R
Jaywick	NR	good	early–mid	MR–MS	R	MR, MS–MS ^b	R–MR, MS ^b	R	R
KM10#	NR	good	very early	R	MR–MS	–	R	S	–
Rufus▲	NR	good	early–mid	R	R	MS	MR–MS	R	R–MR
Tahara▲	NR	moderate	early–mid	R	R	MS	MR–MS	R	R
Yowie#	NR	good	mid	R	R	MR–MS, MS ^b	MR	R	–
Yukuri	NR	good	mid–late	R	R	R–MR	R–MR	S	–

NR = Not recommended, R = Resistant, R–MR = Resistant to Moderately resistant, MR = Moderately resistant, MR–MS = Moderately resistant to Moderately susceptible, MS = Moderately susceptible, MS–S = Moderately susceptible to Susceptible, S = Susceptible, S–VS = Susceptible to Very susceptible, VS = Very susceptible. V. Tol = Very tolerant, pOutclassed. ^a Susceptible to head infection. ^b mixed population, some plants are more susceptible to stripe rust. Where ratings are separated by '&' the first is correct for the majority of situations, but different pathotypes are known to exist at a low level and the latter rating reflects the response to these pathotypes.—Unknown or no data. # Limited data available on Astute⁽ⁱ⁾, Bison⁽ⁱ⁾, Goanna, KM10 and Yowie in NSW.

Source: NSW DPI

MORE INFORMATION

[GrowNotes Alert™](#)

9.1.1 GrowNotes Alert™

GrowNotes Alert is a free nationwide system for delivering urgent, actionable and economically important pest, disease weed and biosecurity issues directly to you, the grower, adviser and industry body, the way you want. Real-time information from experts across Australia, to help growers increase profitability.

A GrowNotes Alert notification can be delivered via SMS, email, web portal or via the iOS App. There are also three by dedicated regional Twitter handles—@GNAAlertNorth, @GNAAlertSouth and @GNAAlertWest—that can also be followed.

The urgency with which alerts are delivered can help reduce the impact of disease, pest and weed costs. GrowNotes Alert improves the relevance, reliability, speed

and coverage of notifications on the incidence, prevalence and distribution of these issues within all Australian grain growing regions.

9.2 General disease-management strategies

- Use resistant or partially resistant varieties.
- Use disease-free seed.
- Use fungicidal seed treatments to kill fungi carried on the seed coat or in the seed.
- Have a planned crop fungicide regime.
- Conduct disease audits of the crop to determine the severity of the disease. This can also be used as a tool to determine what crop is grown in what paddock the following year.
- Conduct disease audits of fallowed paddocks to determine the severity of the disease, e.g. yellow leaf spot and crown rot. This can also be used as a tool to determine what crop is grown in what paddock the following year.
- Send plant or stubble samples away for analysis (e.g. [Plant Science Consulting](#)) to determine the pathogen or strain you are dealing with or the severity of the disease.
- Keep the farm free of weeds, which may carry over some diseases. This includes cereals over summer that may act as a green bridge.
- Rotate crops. ⁴

9.2.1 Integrated disease management tactics in triticale

Key points:

- Destroy volunteer triticale plants by February, as they can provide a green bridge for rust carryover.
- Community efforts are required to eradicate volunteers from roadsides, railway lines, bridges, paddocks and around silos.
- Crop rotation is very important in the case of yellow leaf spot.
- Growing resistant varieties is an economical and environmentally friendly way of disease reduction.
- Seed or fertiliser treatment can control stripe rust up to four weeks after sowing, and suppress it thereafter.
- During the growing season active crop monitoring is very important for an early detection of diseases.
- Correct disease identification is very important; you can consult the department's fact sheets, charts, website and experts.
- When deciding if a fungicide spray is needed, consider crop stage and potential yield loss.
- Select a recommended and cost-effective fungicide.
- For effective coverage, the use of the right spray equipment and nozzles is very important.
- Read the label, wear protective gear, be safe to yourself and environment.
- Avoid repeated use of fungicides with the same active ingredient in the same season.
- Always check for withholding periods before grazing and harvesting a crop applied with any fungicide.

⁴ DAF Qld (2015) Wheat:diseases, physiological disorders and frost. DAF Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases>

 MORE INFORMATION[Ute Guides Online](#)[GRDC, Cereal root and crown diseases: Back pocket guide](#)[Field Crop Diseases Manual online](#)

- If you suspect any severe disease outbreak, especially on resistant varieties, your agronomist or the local representatives of the state agricultural department.⁵

9.2.2 Tools for diagnosing cereal diseases

Foliar diseases—the Ute guide

GRDC UteGuides App is a mobile information resource for farmers and agronomists working in the Australian Grains Industry. It provides searchable library topics with extensive high resolution images on subjects relevant to grain-growers. It compliments and extends GRDC's paper-based Ute Guide series by linking all resources under a single App.

The GRDC [Foliar diseases Ute Guide](#) provides disease descriptions and images relevant to each crop.

Crop Disease Au app

The app [Crop Disease Au](#), developed by the National Variety Trials, allows the user to quickly:

- Identify crop diseases.
- Compare disease-resistance ratings for cereal, pulse and oilseed varieties.
- Potentially, facilitate the early detection of exotic crop diseases.

The app brings together disease-resistance ratings, disease information and also features an extensive library of quality images that make it easier for growers to diagnose crop diseases and implement timely management strategies. Live feeds from the Australian National Variety Trials (NVT) database means the apps is always up to date with the latest varieties.

If a disease cannot be identified there is also a function that allows the user to take a photo of their crop and email it to a friend or an adviser.

The precursor for this app was the Victorian Department of Economic Development, Jobs, Transport and Resources (DEDJTR) Crop Disease app developed by a team of grains pathologists. Crop Disease Au functions similarly to the old app, but provides information for all Australian grain-growing regions.

9.3 Rusts

In Australia, there are three rust diseases of triticale and wheat:

- stripe rust
- stem rust
- leaf rust

They are caused by three closely related fungi all belonging to the genus *Puccinia*. The rusts are so named because the powdery mass of spores which erupt through the plant's epidermis have the appearance of rusty metal. The spores can be spread over considerable distances by wind, and may also spread via clothing and equipment.

Rusts have a number of features in common. They can only infect a limited number of specific host plants (mostly volunteer triticale, wheat and barley) and can only survive on green, growing plant tissue. Biotrophic pathogens (including stem rust, stripe rust and leaf rust) require a living plant host and, since they cannot survive on soil, seed or dead tissue, need a 'green bridge', grassy weeds or overlapping crops to persist. (Plants that facilitate the survival of rust fungi through the summer are components of what is known as the 'green bridge'.)⁶

5 DAF Qld (2015) Integrated disease management of wheat rusts and yellow leaf spot. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/wheat-rusts>

6 DAF Qld (2015) Wheat: diseases, physiological disorders and frost. DAF Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases>

i MORE INFORMATION

[Stripe rust pathotype 'Jackie Yr27' detected for the first time](#)

[The Rust Bust](#)

[Cereal rust situation, September 2016](#)

Given favourable conditions rust can cause large losses in susceptible varieties. However, growers have shown that by planning to manage this disease they can effectively minimise its effects.

During the early 1980s a number of short, early triticales (e.g., Coorong and Satu) became susceptible to a new stem rust pathotype that evolved in southern Australia and moved northwards. As a result of heavy losses, triticale virtually disappeared from northern NSW and Queensland. The resistant varieties, such as Tahara, Muir, Bejon and Abacus, that replaced the older ones are too late for northern areas, and now triticale tends to be a crop for the southern zone, especially in areas with acid soils.

The early-maturing triticales have only six pairs of rye chromosomes, one pair being replaced by an additional pair from bread wheat. It turns out that the most effective genes for stem-rust resistance are located in the rye chromosome that was removed. That chromosome also carries a gene for day-length sensitivity that delays flowering.

In 2007, a new pathotype of stripe rust was detected in many triticale cultivars. Despite dry conditions, stripe rust infections swept through triticale crops, in particular Jackie. The pathotype was virulent on most triticale varieties. The Jackie pathotype, unlike most new pathotypes, was widespread and affected most triticale cultivars.⁷ The Jackie pathotype also had major impacts on the wheat industry.

Stripe rust reached epidemic levels in eastern Australia during 2009, resulting in widespread fungicidal spraying.

The University of Sydney's September 2016 Cereal rust report warned growers to monitor crops carefully. Reports on leaf rust and stripe rust in the eastern states suggested that these diseases are starting to gain momentum in crops. Monitoring of crops for all cereal rusts is advised and samples of all rusts observed in cereal crops should be submitted for pathotype analysis to the Australian Cereal Rust Survey.⁸

In the September 2016 cereal rust report, samples of leaf rust off Sunzell were received from the Queensland areas of Millmerran in mid August and Mirabookain in late August. Pathotype identifications for these two samples were under way in September. Later samples were also received from Warwick, Gatton, and Emerald.

The Rust Bust is an initiative of the Australian Cereal Rust Control Program (ACRCP) Consultative Committee, with support from the GRDC. The Rust Bust aims to raise awareness of rust-management strategies that reduces risk of disease outbreak.

9.3.1 Varietal resistance or tolerance

Some triticale varieties have good resistance to stem, leaf and stripe rusts (Table 2).⁹

7 NSW DPI (2007). New triticale stripe rust pathotype. NSW DPI. <http://www.dpi.nsw.gov.au/content/archive/agriculture-today-stories/ag-today-archives/december-2007/triticale-stripe-rust-pathotype>

8 W Cuddy, R Park, D Singh (2016) Cereal rust situation, September 2016. Cereal Rust Report (14) 7. University of Sydney. https://sydney.edu.au/content/dam/corporate/documents/sydney-institute-of-agriculture/research/plant-breeding-and-production/cereal_rust_report_2016_14_7.pdf

9 Agriculture Victoria (2016) Triticale [download]. In Victorian winter crop summary. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/victorian-winter-crop-summary>

SECTION 9 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 2: *Triticale resistance ratings to Rust diseases.*

Variety	Resistances			
	Stem rust	Leaf rust	Tobruk pathotype	Stripe rust Yr 17–27 pathotype
Dual-purpose				
Breakwell▲	R	R	S–VS	MR
Cartwheel	R	R	–	R
Crackerjack▲	R	MR–MS	MS ^a	R–MR
Endeavour	R	R	R–MR	R–MR
Tobruk▲	R	R	MS–S ^a	MR
Tuckerbox	MR	R	MR–MS	MR
Grain only				
Astute#	R–MR	R–MR	–	R–MR
Berkshire▲	R	R	MS	MR–MS
Bison#	R–MR	R–MR	–	R
Bogong▲	R–MR	R–MR	MS	MR–MS
Canobolas▲	R	R	MS–S	MR–MS
Chopper▲	MR	R	MS–S	MR–MS
Fusion	R	R	MR ^b	R–MR
Goanna#	R	R	MR–MS	R–MR
Hawkeye	R–MR	R	MR, MS–S ^b	MR, MS ^b
Jaywick	MR–MS	R	MR, MS–MS ^b	R–MR, MS ^b
KM10#	R	MR–MS	–	R
Rufus▲	R	R	MS	MR–MS
Tahara▲	R	R	MS	MR–MS
Yowie#	R	R	MR–MS, MS ^b	MR
Yukuri	R	R	R–MR	R–MR

NR = Not recommended, R = Resistant, R–MR= Resistant to Moderately resistant, MR = Moderately resistant, MR–MS= Moderately resistant to Moderately susceptible, MS = Moderately susceptible, MS–S= Moderately susceptible to Susceptible, S = Susceptible, S– VS= Susceptible to Very susceptible, VS=Very susceptible. V. Tol = Very tolerant, pOutclassed. a Susceptible to head infection. b mixed population, some plants are more susceptible to stripe rust. Where ratings are separated by '&' the first is correct for the majority of situations, but different pathotypes are known to exist at a low level and the latter rating reflects the response to these pathotypes.—Unknown or no data. # Limited data available on Astute(), Bison(), Goanna, KM10 and Yowie in NSW.

Source: NSW DPI).

9.3.2 Symptoms

Table 3 outlines the symptoms of common diseases of cereals.¹⁰

Table 3: Diagnosing leaf diseases in cereals.

Disease	Spore colour	Symptoms	Plant part affected
Stripe rust	Yellow-orange	Small closely packed circular pustules during the vegetative stage, becoming stripes along leaves of older plants	Upper surface of leaf, leaf sheaths, awns and inside glumes
Leaf rust	Reddish-orange	Random, circular to oval pustules	Upper surface of leaf and leaf sheaths
Stem rust	Reddish-brown	Random, oblong pustules with torn margins	Both sides of leaf, leaf sheaths, stems and outside of head
Yellow leaf spot	small tan (yellowish-brown) oval spots surrounded by a yellow margin	Spots up to 10 mm, varied shapes and may coalesce	Both sides of leaf, leaf sheaths, stems and outside of head

Source: DAF Qld

9.3.3 Stripe rust

Stripe rust has become more important in recent years owing to new races arriving in eastern Australia.

Stripe rust is caused by the fungus *Puccinia striiformis*. It is easily distinguished from other rusts by the yellow-orange spores, which produce small, closely packed pustules that develop into stripes along the length of the leaf veins. The spores occur on the upper surface of the leaves, the leaf sheaths, awns and inside of the glumes (Photo 1).¹¹

¹⁰ DAF Qld (2015) Integrated disease management of wheat rusts and yellow leaf spot. DAF Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/wheat-rusts>

¹¹ DAF Qld (2015) Integrated disease management of wheat rusts and yellow leaf spot. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/wheat-rusts>

SECTION 9 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

VIDEOS

WATCH: [GCTV1: Cereal rust](#)



MORE INFORMATION

[Stripe rust](#)



Photo 1: *Stripe rust in a cereal plant.*

Source: DAF Qld

Stripe rust requires cool and wet conditions to infect the crop. Free moisture on the leaves and an optimal temperature of 10–15°C are required for infection. Pustules erupt 10–14 days after infection.

If the weather is conducive to stripe rust, the disease can cause up to 25% yield loss on varieties scoring moderately susceptible = 5 (MR–MS) or lower. This is provided there is inoculum from a neglected green bridge or from an infected crop.

There are several fungicides recommended for the control of stripe rust. Fungicides can be incorporated with the fertiliser or applied as seed dressings to delay the onset of disease. Later on if the ‘money’ leaves require protection and stripe rust is present in the district, recommended foliar fungicides can be applied for the control of stripe rust (see [Tables 4 and 5 in Section 9.3.6: Managing cereal rusts](#)).

Managing stripe rust

Stripe rust may be a problem in triticale. The key to stripe rust management is variety choice. Avoid growing highly susceptible varieties, and use moderately or highly resistant varieties instead. Growers should check to ensure their current variety has adequate field resistance to both the Jackie and Tobruk(D) pathotypes of stripe rust or consider using foliar fungicides to control the disease in the crop if required.

There are now options available to treat seed to provide seedling protection against the disease.¹² Seed treatment should be considered for controlling seedling stripe rust in susceptible varieties, especially those sown early for grazing.¹³ Fertiliser can also be treated with fungicides to help aid with rust control.

Newer varieties generally have improved stripe-rust resistance. Varieties with at least an MR–MS (moderately resistant–moderately susceptible) should be used. Usually changing to a more resistant variety also gives a yield advantage. For example, changing from Jackie to Endeavour(D) makes good sense. Endeavour(D) offers a 15% yield increase over Jackie, has excellent dry-matter production for early grazing, and is resistant to all current strains of stripe rust.

¹² Agriculture Victoria (2012) Growing triticale. Note AG0497. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>

¹³ P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI, <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>

Seek local advice on managing stripe rust in triticale. Remember that just because a variety is rust resistant does not mean it will be completely free of stripe rust.

Under very high disease pressure, isolated leaves of resistant varieties can be infected. This does not automatically mean the resistance has broken down or that the crop needs spraying.¹⁴ In these cases rust samples should be sent to:

[Australian Cereal Rust Survey](#)
 Plant Breeding Institute
 Private Bag 4011
 Narellan, NSW 2567

9.3.4 Stem rust

Triticale has good resistance to stem rust.¹⁵ All the present commercial varieties have been screened for the current races of stem rust and they have adequate levels of resistance, although if new races arrive varieties will require screening for them as the levels of resistance to new races are unknown.¹⁶

Stem rust is caused by the fungus *Puccinia graminis* f. sp. *tritici*. In addition to triticale it can also attack wheat, barley and cereal rye. It produces reddish-brown spore masses in oval, elongated or spindle-shaped pustules on the stems and leaves. Unlike leaf rust, pustules erupt through both sides of the leaves (Photo 2).¹⁷ Ruptured pustules release masses of stem rust spores, which are disseminated by wind and other carriers.



Photo 2: Stem rust in a cereal plant.

Source: DAF Qld

Stem rust develops at higher temperatures than the other rusts, within a range of 18–30°C. Spores require free moisture (i.e. dew, rain or irrigation) and take up to six hours to infect the plant. Pustules can be seen 10–20 days after infection.

¹⁴ Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

¹⁵ KN Adhikar, RA McIntosh (1998). Inheritance of wheat stem rust resistance in triticale. *Plant Breeding*, 117 (6), 505–513.

¹⁶ RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report.pdf

¹⁷ DAF Qld (2015) Integrated disease management of wheat rusts and yellow leaf spot. DAF Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/wheat-rusts>

SECTION 9 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

VIDEOS

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MORE INFORMATION

[Stem rust](#)

[Leaf rust](#)

[GRDC Foliar Diseases—Ute Guide](#)

Inoculum must be present for the disease to develop. Practicing crop hygiene by removing volunteer cereals, which forms a green bridge for the fungus through the summer, can eliminate or delay the onset of stem rust.

Foliar fungicides to control stem rust are presented in [Tables 4 and 5 in Section 9.3.6: Managing cereal rusts](#).

9.3.5 Leaf rust

Triticale response to leaf rust varies from moderately susceptible to resistant, depending on the variety.

Leaf rust is caused by the fungus *Puccinia triticina* (previously called *Puccinia recondite* f. sp. *tritici*). The disease can infect triticale, rye and wheat. It produces reddish-orange spores which occur in small, 1.5 mm, circular to oval-shaped pustules. These are found on the top surface of the leaves, distinguishing leaf rust from stem rust (Photo 3).¹⁸



Photo 3: Leaf rust in a cereal plant.

Source: DAF Qld

The spores require temperatures of 15–20°C and free moisture (i.e. dew rain, irrigation) on the leaves to successfully infect cereal. The first signs of the disease, sporulation, occur 10–14 days after infection. Removal of volunteer cereal plants, which form a green bridge for the fungus through the summer, can eliminate or delay the onset of leaf rust.

Foliar fungicides to control leaf rust are presented in [Tables 4 and 5 in Section 9.3.6: Managing cereal rusts](#).

9.3.6 Managing cereal rusts

Rust diseases of cereals can be eliminated or significantly reduced by removing the green bridge. This should be done well before the new crop is sown, allowing time for any herbicide to work and for the fungus to stop producing spores.

Wherever possible, sow resistant varieties rated MR (moderately resistant = 6) and above.

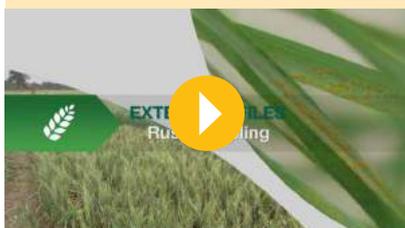
¹⁸ DAF Qld (2015) Integrated disease management of wheat rusts and yellow leaf spot. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/wheat-rusts>

SECTION 9 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

VIDEOS

WATCH: [GCTV Extension files: rust sampling](#)



MORE INFORMATION

CSIRO, [Cereal rusts](#)

[The Rust Bust](#)

Rust fungi change continuously, producing new pathotypes. They are detected when disease is found on a previously resistant variety. Even if a resistant variety has been sown, the crop should be monitored on a regular basis, starting no later than growth stage (GS) 32, the second-node stage on the main stem, and continue to at least GS 39, the flag leaf. This is because the flag leaf and the two leaves below it are the main factories contributing to yield and quality. It is very important that these leaves are protected from diseases.¹⁹

Always read product labels carefully and stay up to date with the [APVMA](#) website.

There are a number of fungicides recommended for the control of foliar diseases of cereals (Table 4 and Table 5).²⁰

Table 4: Fungicides recommended for seed and fertiliser treatment.

Diseases	Fungicides	
	Fluquinconazole (167 g/L)	Flutriafol (250 g/L)
Stripe rust (yellow rust)	Rate of product formulation: 450 mL/100 kg seed	Rate of product formulation: 200 or 400 mL/ha fertiliser
Leaf rust (brown rust)	Rate of product formulation: 450 mL/100 kg seed	
Stem rust (black rust)		
Withholding periods	12 weeks for grazing and harvest	4 weeks for grazing and harvest

Source: DAF Qld

Table 5: Rate of fungicide (product formulation) recommended as foliar sprays for the control of rust diseases of cereals.

Diseases	Foliar fungicides							
	Epoxi-conazole (125 g/L)	Flutriafol (250 g/L)	Propi-conazole (250 g/L)	Triadime-fon (125 g/L)	Tebuco-nazole (430 g/L)	Prothioconazole (210 g/L) + Tebuconazole (210 g/L)	Azoxystrobin (200 g/L) + Cyproconazole (80 g/L)	Propiconazole (250 g/L) + Cyproconazole (80 g/L)
Stripe rust (yellow rust)	250–500 mL/ha	250–500 mL/ha	250–500 mL/ha	500 or 1000 mL/ha	145 or 290 mL/ha	150–300 mL/ha + Hasten 1% v/v	400 or 800 mL/ha	250–500 mL/ha
Leaf rust (brown rust)	500 mL/ha	250–500 mL/ha	150–500 mL/ha		145 or 290 mL/ha	150–300 mL/ha + Hasten 1% v/v	400 or 800 mL/ha	150–500 mL/ha
Stem rust (black rust)			500 mL/ha		145 or 290 mL/ha	150–300 mL/ha + Hasten 1% v/v		500 mL/ha
Yellow leaf spot (tan spot)			250–500 mL/ha		145 or 290 mL/ha	150–300 mL/ha	400 or 800 mL/ha	250–500 mL/ha
Withholding periods	6 weeks for grazing and harvest	7 weeks for grazing and harvest	4 weeks for harvest, 7 days for grazing	4 weeks for grazing and harvest	5 weeks for harvest, 14 days for grazing	5 weeks for harvest, 14 days for grazing	6 weeks for harvest, 21 days for grazing	6 weeks for harvest, 21 days for grazing

Source: DAF Qld, Last updated 24 April 2015

¹⁹ DAF Qld (2015) Wheat:diseases, physiological disorders and frost. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases>

²⁰ DAF Qld (2015) Integrated disease management of wheat rusts and yellow leaf spot. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/wheat-rusts>

SECTION 9 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [GCTV18: Adult plant resistance—fungicide](#)



WATCH: [GCTV9: Cereal rust—adult plant resistance](#)



WATCH: [GCTV18: Triple rust resistance](#)



IN FOCUS

Breeding cereals for rust resistance in Australia

Rust diseases have caused significant losses to Australian cereal crops, and continue to pose a serious threat. Because Australian cereal-crop yields are generally low, genetic resistance remains the most economical means of controlling rust. Resistant cultivars also contribute significantly to reducing over-summer rust survival.

The Australian Cereal Rust Control Program conducts annual pathogenicity surveys for all cereal rust pathogens, undertakes genetic research to identify and characterise new sources of resistance, and provides a germplasm screening and enhancement service to all Australian cereal-breeding groups. These three activities are interdependent and are closely integrated, with particular emphasis on linking pathology and genetics to develop more resistant varieties. Recent changes in the rust pathogens, including the development of virulences for the resistance genes Yr17, Lr24, Lr37 and Sr38, and the introduction of a new pathotype of the stripe rust pathogen, have provided new and significant challenges for rust resistance breeding. Similar challenges exist in breeding barley and oats for rust resistance. In future, as more markers linked to durable rust resistance sources become available, it is likely that the use of marker-assisted selection will become more common-place in rust resistance breeding.²¹

9.4 Yellow leaf spot (tan spot)

Yellow leaf spot, has become a widespread and important disease of cereals in Australia (Photo 4).²² Its expansion has been supported by stubble retention, intense cereal production in the rotation and widespread cultivation of susceptible varieties.²³

21 RF Park (2008) Breeding cereals for rust resistance in Australia. *Plant Pathology*, 57 (4), 591–602.

22 DAF Qld (2015) Integrated disease management of wheat rusts and yellow leaf spot. DAF Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/wheat-rusts>

23 G Holloway (2014) Yellow leaf spot of wheat. Note AG1114. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/yellow-leaf-spot-of-wheat>



Photo 4: Yellow leaf spot in cereal crop.

Source: DAF Qld

Yellow leaf spot is caused by the fungus *Pyrenophora tritici-repentis*. It survives in wheat and, occasionally, triticale stubble. In rare cases, the fungus may survive in barley stubble. Wet spores (ascospores) develop in fungal fruiting bodies on stubble, and spread during wet conditions to infect growing plants.

As the crop develops, masses of a second type of spore (conidia) are produced on old lesions and dead tissues. Conidia result in rapid development of the epidemic within a crop and spread of the disease to other crops and areas. Again, wet conditions are necessary for spore production and infection. Strong winds are needed to spread the disease any great distance.²⁴

9.4.1 Varietal resistance or tolerance

Most triticale cultivars have moderate resistance to yellow leaf spot (Table 6).²⁵ Yellow leaf spot, however, it can still carryover the disease into following years.²⁶

VIDEOS

WATCH: [GCTV2: Yellow or tan spot](#)



²⁴ DAF Qld (2015) Wheat: diseases, physiological disorders and frost. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases>

²⁵ Agriculture Victoria (2016) Triticale [download]. In Victorian winter crop summary. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/victorian-winter-crop-summary>

²⁶ Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, <http://www.farmtrials.com.au/trial/13801>

Table 6: *Triticale variety disease guide for yellow leaf spot.*

Variety	Resistance to yellow leaf spot
Astute(D)	MR–MS
Berkshire(D)	MR
Bison(D)	MR
Canobolas(D)	MR
Chopper(D)	MR
Endeavour(D)	MR
Fusion(D)	MR–MS
Goanna	MR
KM10	MR–MS
Rufus	MR
Tahara	MR
Tobruk(D)	MR
Tuckerbox	MR
Yowie	MR

Maturity: E = early, M = mid-season, L = late, VL = very late Height: M = medium, T = tall Colour: W = white, Br = brown Disease resistance order from best to worst: R > R–MR > MR > MR–MS > MS > MS–S > S > S–VS > VS *p* = provisional ratings—treat with caution, R = resistant, M = moderately, S = susceptible, V = very # Varieties marked may be more susceptible if alternative strains are present

Source: Agriculture Victoria

9.4.2 Damage caused by disease

Yellow leaf spot is most often observed in seedlings, but when conditions are suitable it can progress up the plant where it causes significant yield loss.²⁷ Grain yield can be substantially reduced and losses of more than 50% may occur in extreme situations. Pink grain with reduced value is also a frequent result of severe yellow leaf spot epidemics. Where cereal follows cereal and some stubble is left on the soil surface, losses may be around 10–15%, and up to 30% in wet seasons.

9.4.3 Symptoms

Yellow leaf spot is characterised by tan-brown flecks turn into yellow-brown oval-shaped spots or lesions surrounded by yellow margins. They may expand to 10–12 mm in diameter. Large lesions coalesce, and develop dark brown centres or cause the tips of leaves to die. Spots develop on both sides of leaves (Photos 5 and 6). Severe yellow leaf spot may result in short, spindly plants with reduced tillering and root development. Where conditions are favourable to the disease, plants may be fully defoliated soon after flowering.²⁸

²⁷ G Holloway (2014) Yellow leaf spot of wheat. Note AG1114. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/yellow-leaf-spot-of-wheat>

²⁸ DAF Qld (2015) Wheat: diseases, physiological disorders and frost. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases>



Photo 5: *Yellow leaf spot in triticale.*

Source: Thomas County Ag



Photo 6: *Yellow spot lesions may coalesce, causing the tip of the leaf to die.*

Source: Thomas County Ag

i MORE INFORMATION

[GRDC Foliar Diseases—Ute Guide](#)

9.4.4 Conditions favouring development

Yellow leaf spot is likely to develop in wet years in paddocks where triticale residues remain on the soil surface. Temperatures of 15–28°C, with up to 12 hours of leaf wetness, are the optimal condition for infection.²⁹

²⁹ GRDC (2011) Management to reduce the risk of yellow leaf spot. Factsheet. GRDC, <https://grdc.com.au/Resources/Factsheets/2011/08/Yellow-Leaf-Spot-Fact-Sheet>

9.4.5 Management of disease

The impact of the disease can be reduced by:

- Planting partially resistant varieties.
- Rotating with resistant crops such as barley, oats or chickpeas.
- Incorporating the stubble into the soil.
- Grazing or burning the stubble late in the fallow period.

Incorporation or burning of stubble is not recommended unless infestation levels are very high. The correct identification of the yellow leaf spot fungus in infected stubble should be carried out before the stubble is removed. Varieties partially resistant to yellow leaf spot offer the only long-term solution and should be considered for planting where yellow leaf spot could be a problem.³⁰

If you do not want to be concerned by yellow leaf spot (including at seedling stages) then:

- Do not sow cereal-on-cereal.
- If you are going to sow cereal-on-cereal consider:
 - A late (autumn) stubble burn; and/or
 - Selecting a triticale variety with some level of resistance to yellow leaf spot (and also note tolerance or resistance to other diseases).
- Primary management decisions for yellow leaf spot need to be made before and/or at sowing. Fungicides are a poor last resort for controlling yellow leaf spot as they have reduced efficacy.³¹

MORE INFORMATION

Management of yellow leaf spot in wheat: decide before you sow

In-crop fungicides and timing

Fungicides used against yellow leaf spot in Australia include:

- propiconazole
- tebuconazole
- azoxystrobin + cyproconazole
- propiconazole + cyproconazole

The timing of application of the chosen fungicide is crucial. The most effective time is at 90% flag leaf emergence, with disease levels of less than 10% on the flag leaf (Table 7).³²

Table 7: Rate of fungicide (product formulation) recommended as foliar sprays for the control of yellow leaf spot in cereals.

Disease	Foliar fungicides							
	Epoxi-conazole (125 g/L)	Flutriafol (250 g/L)	Propi-conazole (250 g/L)	Triadimefon (125 g/L)	Tebuconazole (430 g/L)	Prothioconazole (210 g/L) + Tebuconazole (210 g/L)	Azoxystrobin (200 g/L) + Cyproconazole (80 g/L)	Propiconazole (250 g/L) + Cyproconazole (80 g/L)
Yellow leaf spot (tan spot)			250–500 mL/ha		145 or 290 mL/ha	150–300 mL/ha	400 or 800 mL/ha	250–500 mL/ha
Withholding periods	6 weeks for grazing and harvest	7 weeks for grazing and harvest	4 weeks for harvest, 7 days for grazing	4 weeks for grazing and harvest	5 weeks for harvest, 14 days for grazing	5 weeks for harvest, 14 days for grazing	6 weeks for harvest, 21 days for grazing	6 weeks for harvest, 21 days for grazing

Source: DAF Qld

³⁰ DAF Qld (2015) Wheat:diseases, physiological disorders and frost. DAF Qld, <https://www.dafqld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases>

³¹ S Simpfendorfer (2013) Management of yellow leaf spot in wheat: decide before you sow. GRDC Update Paper, GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Management-of-yellow-spot-in-wheat-decide-before-you-sow>

³² DAF Qld (2015) Integrated disease management of wheat rusts and yellow leaf spot. DAF Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/wheat-rusts>

i MORE INFORMATION

[Yellow leaf spot: is it worth spraying?](#)

GRDC factsheet, [Yellow leaf spot](#)

[The economics and risks of early sprays for yellow leaf spot](#)

🔊 PODCAST

GRDC Radio (Northern Update), [Crown rot and take-all warning](#)

The higher rate of application has been shown to provide longer protection under periods of high disease pressure. Fungicide effectiveness is greater on susceptible varieties and is reduced with increasing levels of resistance.

Information on fungicide effectiveness has been gathered from irrigated field trials and does not confirm the economic viability of such applications during the extreme pressure of large-scale epidemics.³³

Check the Australian Pesticides and Veterinary Medicines Authority ([APVMA](#)) website for fungicide updates.

9.5 Take-all

Key points:

- Take-all is a fungal disease of the roots of cereals.
- Though triticale is less susceptible to take-all than wheat, it can still carryover the disease into following years.³⁴ Early sowing increases the risk.³⁵
- In early field experiments conducted over six years with a wide range of severity of take-all disease, triticale was intermediate in resistance to take-all, between wheat (susceptible) and rye (resistant).³⁶
- Grass-free pastures and break crops minimise *G. graminis* survival, e.g. pulses and canola.
- Monitor rainfall patterns (when and how much?), and adjust sowing times where possible.
- Control weeds during late summer and early autumn.
- Ammonium-based nitrogenous fertilisers decrease take-all incidence through improved crop nutrition.
- In severe take-all outbreaks, grass free cropping may be a management strategy.

Take-all is a soil-borne disease of cereal crops and is most severe on crops in southern Australia, particularly in the high-rainfall southern cropping regions and areas closer to the coast. The disease is caused by two variations of the fungus *Gaeumannomyces graminis*: *G. graminis* var. *tritici* (Ggt) and *G. graminis* var. *avenae* (Gga). Control of take-all is predominantly cultural and relies on practices which minimise carry-over of the disease from one cereal crop to the next.³⁷

9.5.1 Symptoms

Initial indications of take-all in a crop are the appearance of indistinct patches of poor growth in the crop; these may be from a few metres across to significant areas of crop. Closer inspection of individual plants will show discolouration of the crown, roots and stem base. Blackening of the centre of the roots (stele) is symptomatic of an early take-all infection. Severely infected plants will have a blackened crown and stem base and be easy to pull from the soil, with no attached root system. Any remaining roots are brittle and break off with a square end.

The appearance of whiteheads later in the season is another indicator of a take-all (although frost and micronutrient deficiencies can also cause whiteheads), with severe infections causing the crop to hay-off early. Infected plants will produce pinched grain, with severe infections yielding little harvestable seed in the head (hence take-all) and in some cases infected areas may not be worth harvesting.³⁸

33 DAF Qld (2015) Wheat: diseases, physiological disorders and frost. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases>

34 Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, <http://www.farmtrials.com.au/trial/13801>

35 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI, <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>

36 TW Hollins, PR Scott, RS Gregory (1986). The relative resistance of wheat, rye and triticale to take all caused by *Gaeumannomyces graminis*. Plant Pathology, 35 (1), 93–100.

37 Soilquality.org (2016) Take-all disease, NSW. Factsheet. Soilquality.org, <http://www.soilquality.org.au/factsheets/take-all-disease-nsw>

38 Soilquality.org (2016) Take-all disease, NSW. Factsheet. Soilquality.org, <http://www.soilquality.org.au/factsheets/take-all-disease-nsw>

What to look for in the paddock

- Patches (up to several metres in diameter and with indistinct and irregular edges) of white-coloured tillers and heads containing shrivelled or no grain (Photo 7).³⁹
- Affected plants can be individuals scattered among healthy plants or entire populations of plants over a large area.



Photo 7: Patches with irregular edges of white coloured tillers and heads containing shrivelled or no grain.

Source: DAFWA

What to look for in the plant

- First obvious signs of infection are seen after flowering, with the development of whiteheads.
- Roots of affected plants are blackened and brittle, and break easily. They are black to the core, not just on outer surface (Photo 8).
- Severely affected plants can also have blackened crowns and lower stems.

³⁹ DAFWA (2015) Diagnosing take-all in cereals. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-take-all-cereals>

i MORE INFORMATION

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Photo 8: Roots of affected plants are blackened, brittle, break easily, and are black to the core (left). Severely affected plants can have blackened crowns and lower stems (right).

Source: DAFWA

9.5.2 Conditions favouring development

Gaeumannomyces graminis survives the Australian summer in the residue of the previous season's grass host (Figure 1).⁴⁰ The arrival of cooler temperatures and rainfall in the autumn encourages the fungus into action, and it is in this period that it infects the roots of the emerging crop. Higher rainfall in winter is likely to increase take-all disease pressure. For this reason, the southern regions of New South Wales are most likely to suffer yield loss in cereal crops due to take-all. While lower soil moisture will decrease the chance of a severe outbreak of take-all, plants that are already infected will find it difficult to cope due to water stress.

Soil at field capacity (fully wet) encourages early season infection of seedlings by both *G. graminis* var. *tritici* and *G. graminis* var. *avenae*. Greatest yield loss occurs on infected plants when moisture is limited post-anthesis.

40 Soilquality.org (2016) Take-all disease, NSW. Factsheet, Soilquality.org, <http://www.soilquality.org.au/factsheets/take-all-disease-nsw>

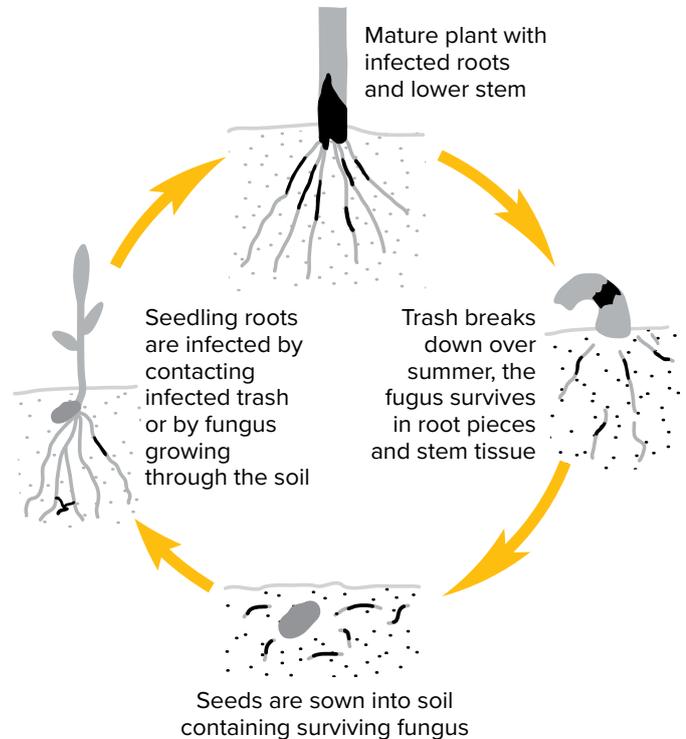


Figure 1: Common life cycle of the take-all fungus.

Source: Soilquality.org

Hosts

All annual grasses can be infected by *G. graminis*, although some species are more susceptible than others. While triticale, wheat and barley are the most susceptible crops to take-all, barley grass is also an effective host to the disease. Brome grass, silver grass and ryegrass are all viable host species for take-all, too. Oats is the only cereal crop to offer resistance, although evidence of *G. graminis* strains capable of causing yield loss has been reported in areas where continual oat cropping occurs. The non-cereal crops (e.g. lupins, canola and clover) do not host take-all.⁴¹

9.5.3 Managing take-all

Key points:

- By far the most effective method of reducing take-all is to remove grasses in the year before the crop with a grass-free pasture or break crop.
- Seed, fertiliser or in-furrow applied fungicides are registered for take-all control.
- Acidifying fertilisers can slightly reduce disease severity; conversely, the severity of take-all may increase following liming.
- Control volunteer grasses and cereals.
- Delay sowing following the opening rains by implementing a short chemical fallow.⁴²

The most effective management strategy for take-all is to deny the fungus the ability to survive in the paddock, through the elimination of hosts. This is most effectively done through the use of a non-cereal break crop (i.e. lupin, canola, field peas,

41 Soilquality.org (2016) Take-all disease, NSW. Factsheet, Soilquality.org, <http://www.soilquality.org.au/factsheets/take-all-disease-nsw>

42 DAFWA (2015) Diagnosing take-all in cereals. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-take-all-cereals>

SECTION 9 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

MORE INFORMATION

[PreDicta B](#)

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faba beans, chickpeas) and effective grass-weed control during autumn. Pastures containing low levels of grass species will also have reduced take-all carryover the following season. Where minimum tillage is practiced, the time taken for residues to breakdown is increased, and this allows the disease to stay viable for longer. The use of break crops and activities to hasten residue breakdown may be beneficial. While burning does decrease the amount of surface residue infected with the fungus, it is generally not hot enough to affect the infected material below ground.

Fungicides, applied as either fertiliser or seed treatments, are registered for use against take-all, but are generally only economically viable where severe outbreaks have occurred. Registered fungicides provide useful protection in paddocks with low to medium disease risk. In many cases it is more practical to sow non-cereal crops or pasture to reduce take-all carryover.

Competition from other soil organisms decreases the survival of *G. graminis* in the soil. Summer rains or an early break in the season allows for such conditions. The effect of this can be negated by poor weed control during this period. This has a double effect:

- Cereal weeds become infected, thus enabling *G. graminis* to survive until crop establishment.
- Rapid drying of the topsoil due to weeds decreases the survival of competitive soil organisms, therefore slowing *G. graminis* decline.

Soil testing

The DNA-based soil test PreDicta B can be used to detect take-all in the paddock. Soil samples that include plant residues should be tested early in late summer to allow results to be returned before seeding. This test is particularly useful when sowing susceptible varieties, and for assessing the risk after a non-cereal crop.⁴³

PreDicta B samples are processed weekly from February to mid-May (prior to crops being sown) to assist with planning the cropping program. The test is not intended for in-crop diagnosis. That is best achieved by sending samples of affected plants to your local plant pathology laboratory. In order to get an accurate result, it is important to follow the PreDicta B sampling protocol precisely.⁴⁴

Take-all decline

Take-all decline is the apparent waning of the incidence of take-all following many years of continuous cereal cropping. It has been shown to occur in South Australia. Decline has been attributed to the build-up of antagonistic micro-organisms in the soil. This occurrence is unlikely to be something growers can rely on, as the economic losses incurred during the build-up appear to be unacceptable.

There have, however, been examples of a reduction in the incidence of take-all due to gradual acidification of soil; this decline is reversed when lime is applied to increase soil pH.⁴⁵

9.6 Crown rot

Key points:

- Triticale is susceptible to crown rot.⁴⁶
- Crown rot survives on infected stubble, from where it is passed onto the following crop.
- Use non-host crops (i.e. pulses, oilseeds and broadleaf pasture species) in rotation sequences to reduce inoculum levels.

43 Soilquality.org (2016) Crown rot, Queensland. Factsheet, Soilquality.org, <http://www.soilquality.org.au/factsheets/crown-rot-queensland>

44 D Lush (2014) PreDicta B sampling strategy. GRDC, <https://grdc.com.au/Media-Centre/Media-News/South/2014/04/PreDicta-B-sampling-strategy>

45 Soilquality.org (2016) Take-all disease, NSW. Factsheet, Soilquality.org, <http://www.soilquality.org.au/factsheets/take-all-disease-nsw>

46 Matthews P, McCaffery D, Jenkins L. (2016). Winter crop variety sowing guide 2016. NSW DPI, <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>

SECTION 9 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- Control grass-weed hosts to reduce opportunities for *Fusarium* spp. to survive fallow or non-host rotations.
- Sow varieties with partial resistance or improved tolerance where available.

Information concerning the resistances of triticale varieties to *Fusarium* diseases is very limited. For crown rot (*Fusarium psuedograminearum*) most research has been completed in wheat, but data from 2007 included one triticale (Everest). Inoculation with the crown-rot fungus caused the greatest reduction in yield in durum wheat (average of 58%) with less but similar reduction in five wheat varieties (25%) and one triticale (23%). Within the wheat varieties the reductions were in a 10% range and it is likely that a similar position would occur within triticale varieties. This emphasises the importance of crop rotational strategy, e.g. the use of disease break crops such as canola and mustard, within the cropping system.⁴⁷

The crown rot fungus may increase in wet years as rain splash distributes the fungus from lower stem nodes into grain heads.

While all winter cereals host the crown-rot fungus, yield loss due to infection varies with cereal type. The approximate order of increasing yield loss is cereal rye, oats, barley, bread wheat, triticale and durum wheat.⁴⁸ Crown rot is a priority cereal disease in the Northern Region.⁴⁹

Crown rot becomes apparent after flowering expressed as whiteheads following periods of moisture and/or heat stress. Crown rot is sometimes first seen in patches or in wheel tracks, but is often not obvious until after heading. Then it becomes obvious with the appearance of dead heads that contain shrivelled or no grain are called whiteheads, although it is important to note that yield loss can occur even without the formation of whiteheads.

Update on the latest research

Key points:

- Managing the impact of crown rot on yield and quality means managing the balance between inoculum levels and the amount of soil water.
- The amount of soil water is the biggest factor in the impact of crown rot on profitability, yet most management strategies focus on combating inoculum, sometimes even to the detriment of soil water. It is more important to maintain good levels of soil water so that triticale is not temperature or water stressed during grainfill.
- For crown rot, cultivation, even shallow cultivation, distributes infected residue more evenly across paddocks and into the infection zones below the ground for crown rot. This is not good!
- Some of the newer varieties appear promising in that they provide improved tolerance to crown rot.
- PreDicta B is a good tool for identifying the level of risk for crown rot (and other soil-borne pathogens) prior to sowing. However, it requires a dedicated sampling strategy and is not a simple add-on to a soil nutrition test.

Crown rot is a significant disease of winter cereals. Infection is characterised by a light honey-brown to dark brown discolouration of the base of infected tillers, and the crown rot-induced production of whiteheads that causes major yield loss is related to the presence of the fungus and moisture stress after flowering. It is critical that growers understand that there are three distinct and separate phases of crown rot, namely survival, infection and expression. Management strategies are different for each phase.

47 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Rethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

48 GRDC (2016) Crown rot in winter cereals: Northern Region. Tips and Tactics. GRDC, <https://grdc.com.au/Resources/Factsheets/2016/02/Crown-rot-in-winter-cereals>

49 T Dixon (2013) Balancing crown rot and nematodes in wheat. Ground Cover. Issue 104, May–June 2013. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-104-May-June-2013/Balancing-crown-rot-and-nematodes-in-wheat>

- Survival—the crown-rot fungus survives as mycelium (cottony growth) inside winter cereal and grass-weed residues, which it has infected. The fungus will survive as inoculum inside the stubble for as long as the plant material remains intact, which varies greatly with soil and weather conditions as decomposition is a very slow process.
- Infection—given some level of soil moisture, the crown-rot fungus grows out of stubble residues and infects new winter cereal plants through the coleoptile, sub-crown internode or crown tissue, which are all below the soil surface. The fungus can also infect plants on the soil surface through the outer leaf sheaths. However, whatever the points of infection, direct contact with the previously infected residues is required. Infections can occur throughout the whole season, given the necessary moisture. Hence, wet seasons favour greater infection by the crown-rot fungus, especially when combined with the production of greater stubble loads, which significantly build up inoculum levels.
- Expression—yield loss is related to moisture and temperature stress around flowering and through grainfill. This stress is believed to trigger the crown rot fungus to proliferate in the base of infected tillers, restricting water movement from the roots through the stems, and producing whiteheads. The expression of whiteheads in plants infected with crown rot (i.e. they will still have basal browning) is restricted in wet seasons and increases greatly with increasing moisture and temperature stress during grainfill. Focus attention to crops around trees in a paddock or along tree lines. Even in good years, whiteheads associated with crown-rot infection are likely to be seen around trees. This is due to the extra competition for water.

9.6.1 Damage caused by crown rot

The presence of crown rot in the plant stem limits water movement, which can result in premature death of the tiller and the presence of whiteheads (or deadheads) (Photo 9). Crown rot survives from one season to the next on infected stubble, from where it is passed onto the following crop. The impact of a bad crown-rot season can make or break a crop, with bread-wheat yield losses of up to 55% possible at high inoculum levels, and losses in durum up to 90%.

Triticale can see similar yield losses from crown rot as wheat (average yield loss).



Photo 9: Scattered whiteheads in cereal crop.

Source: DAFWA

9.6.2 Symptoms of crown rot

If the leaf bases are removed from the crowns of diseased plants, a honey-brown to dark-brown discolouration will be seen. In moist weather, a pinkish-purple fungal growth forms inside the lower leaf sheaths and on the lower nodes.

The infection of plants with crown rot occurs at the base of the plant and spreads up the stem during the growing season. The onset of crown rot is often not obvious until after heading, when whiteheads appear with the onset of water stress. Plants infected with crown rot display a number of symptoms, including:

- Brown tiller bases, often extending up 2–4 nodes (Photo 10).⁵⁰ This is the most reliable indicator of crown rot, with browning often becoming more pronounced from mid to late grainfilling through to harvest.
- Whitehead formation, particularly in seasons with a wet start and dry finish (Photo 11). These are usually scattered throughout the crop, and do not appear in distinct patches. These may first appear in wheel tracks where crop-available moisture is more limited.
- A cottony fungal growth that may be found around the inside of tillers, and a pinkish fungal growth that may form on the lower nodes, especially during moist weather (Photo 12).
- Pinched grain at harvest.⁵¹



Photo 10: Honey-brown discolouration of stem bases.

Source: DAFWA

⁵⁰ DAFWA (2016) Diagnosing crown rot of cereals. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-crown-rot-cereals>

⁵¹ Soilquality.org (2016) Crown rot, Queensland. Factsheet, Soilquality.org, <http://www.soilquality.org.au/factsheets/crown-rot-queensland>

SECTION 9 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 11: Scattered single tillers and whiteheads.

Source: DAFWA



Photo 12: Pinkish-purple discoloration often forms around or in the crown or under leaf sheaths.

Source: DAFWA

9.6.3 Conditions favouring development

The effects of crown rot on yield tend to be most severe when there are good crop conditions in the first part of the season followed by a dry finish. This is because the moist conditions at the beginning of the season enable the fungus to grow from infected stubble to an adjacent seedling, while the dry conditions during flowering and grainfilling cause moisture stress, allowing rapid growth of the pathogen within the plant. A wet finish to the season can reduce the damage caused by crown rot, but will not prevent yield loss in all cases.⁵²

Cultivation can also have a huge impact. Crown rot is a stubble-borne disease and for a plant to become infected it must come into contact with inoculum from previous winter cereal crops. So by cultivating soil, growers are actually helping to spread the crown rot inoculum to next year's crop. The best thing a grower can do with infected stubble is leave it alone.⁵³

Interaction with root-lesion nematodes

Root-lesion nematodes (RLNs) are also a widespread constraint to cereal production across the region. RLNs feed inside the root systems of susceptible winter cereals and create lesions that reduce lateral branching. This reduces the efficacy of the root system to extract soil water and nutrients, which can subsequently exacerbate the expression of crown rot. Varieties with reduced tolerance to *Pratylenchus thornei* can suffer significantly greater yield loss from crown rot if both of these pathogens are present within a paddock.

See [Section 8.3 Nematodes and crown rot](#) in Section 8: Nematodes for more information.

9.6.4 Management

Key points:

- Rotate crops—this is the most important management tool. A grass-free break from winter cereals is the best way to lower crown-rot inoculum levels.
- Test—a pre-sowing PreDicta B soil test will identify paddocks at risk of crown rot.
- Sow winter cereals into paddocks where the risk is lowest.
- Choose more resistant crop varieties, but variety choice needs to be combined with effective management.
- Observe—check plants for browning at the base of infected tillers as this is the most reliable indicator of crown rot. Don't rely solely on whiteheads as an indicator (Figure 2).
- Keep crown rot inoculum at low levels is the most effective way to reduce yield loss from this disease.⁵⁴

52 Soilquality.org (2016) Crown rot: Qld. Factsheet, Soilquality.org, <http://www.soilquality.org.au/factsheets/crown-rot-queensland>

53 T Dixon (2013) Balancing crown rot and nematodes in wheat. Ground Cover. No. 104, May–June 2013. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-104-May-June-2013/Balancing-crown-rot-and-nematodes-in-wheat>

54 GRDC (2016) Crown rot in winter cereals, southern region. Tips and Tactics. GRDC, <https://grdc.com.au/Resources/Factsheets/2016/02/Crown-rot-in-winter-cereals>



Figure 2: The GRDC's 'Stop the crown rot' campaign.

Source: GRDC

Crown rot may be controlled through planting more resistant varieties and by using crop rotation. If the disease is severe, rotation to a non-susceptible crop for at least two and preferably three years is recommended. A winter crop such as chickpea, oats or any summer crop may be used as a disease-free rotation crop.⁵⁵

Crop rotation

The most effective way to reduce crown rot inoculum is to include non-susceptible crops in the rotation sequence. The crown rot fungus can survive for two to three years in stubble and soil. Growing a non-host crop for at least two seasons is recommended to reduce inoculum levels. This allows time for decomposition of winter cereal residues that host the crown rot fungus. Stubble decomposition varies with the type of break crop grown: canopy density and rate of the canopy closure as well as row spacing, the amount of soil water they use and seasonal rainfall.

Because crown rot survives from one season to the next on infected stubble, the use of break crops can give stubble a chance to decompose and thus reduce soil inoculum levels. The use of break crops with dense canopies, such as canola, can be particularly effective, as these help to maintain a moist soil surface, which further promotes the breakdown of cereal residues.

The number of break crops required to sufficiently reduce crown rot levels will vary, depending on rainfall in the break year. In dry years, when residue breakdown is

⁵⁵ DAF Qld (2015) Wheat: diseases, physiological disorders and frost. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases>

slower, a two-year break crop may be required to reduce crown rot to acceptable levels. In wetter seasons, a one-year break may be sufficient.

It should be noted that incorporating plant residues into the soil by cultivation during the break period can increase the rate of decay of residue. However, it also spreads infected residue, which may increase plant infection rates in following crops, thus counteracting any benefits from increased rate of breakdown.

Baling, grazing and/or burning crop residues are not effective solutions for the removal of crown rot, either. The majority of the crown rot inoculum is below ground and in the bottom 7 cm of the stem. Thus, the crown rot fungus can survive in below-ground tissue even if above-ground material is removed.

Variety selection

All winter cereal crops host the crown-rot fungus. Yield loss varies between crops and the approximate order of increasing loss is oats, barley, triticale, bread wheat and durum.

Where growers are aware their paddocks are infected with crown rot, tolerant varieties can be used to limit yield losses (Figure 3). Growers need to be aware of the levels of crown rot disease in their paddocks, as even the most tolerant crops can suffer yield loss under high levels of the disease. At intermediate levels of disease, the grower can take a calculated risk about returns versus yield loss by growing only tolerant varieties. However, where high levels of disease are present even tolerant varieties may be affected, and a break crop may be required.

VIDEOS

WATCH: GRDC, [Grains research updates: Crown rot tolerance in new cereal cultivars](#)

Crown rot tolerance in new cultivars: Is there enough to base varietal decisions on? With Rob Long

MORE INFORMATION

[Tips and Tactics: Crown rot in winter cereals, southern region](#)

[Understanding crown rot underpins effective management, southern and western regions](#)

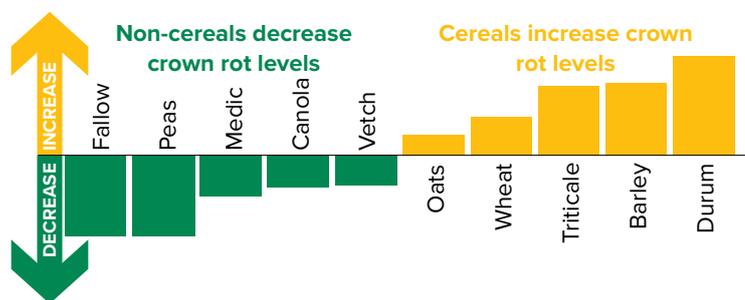


Figure 3: Rotation effects on crown rot levels in the soil in the following year.

Source: GRDC.

NSW DPI trials at 23 sites in 2013–14 indicate that susceptibility can represent a yield benefit of around 0.50 t/ha in the presence of high levels of crown rot infection. However, variety choice is NOT a solution to crown rot with even the best variety still suffering up to 40% yield loss from crown rot under high infection levels and a dry/hot seasonal finish.⁵⁶

Crop management

Stressed plants are most susceptible to the effects of crown rot. Thus the use of management practices to optimise soil water and ensure good crop nutrition can help reduce the impacts of crown rot. Effective strategies include:

- Reducing moisture stress in plants through good fallow management and avoiding excessively high sowing rates.
- Matching nitrogen fertiliser inputs to available soil water to avoid excessive early crop growth.
- Ensuring good crop nutrition. Zinc nutrition can be particularly important as the expression of whiteheads can be more severe in zinc-deficient crops.

⁵⁶ S Simpfendorfer (2015) Crown rot: an update on latest research. GRDC Update Paper, GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Crown-rot-an-update-on-latest-research>

Cultivation

The effect of cultivation on crown rot is complex, as it potentially impacts on all three phases of the disease cycle.

- **Survival**—stubble decomposition is a microbial process driven by temperature and moisture. In theory, cultivating stubble increases the rate of decomposition as it reduces particle size of stubble, buries the particles in the soil where microbial activity is greater, and puts the stubble below the soil surface, where it is maintained in better moisture and temperature conditions than at the surface or above ground. However, this is generally not sufficient: cultivating also dries out the soil in the cultivation layer, which immediately slows down decomposition. Full decomposition of cereal stubbles is a slow process that requires adequate moisture for an extended time. One summer fallow, even if extremely wet and stubble has been ploughed in, is *not* long enough!
- **Infection**—the cultivation of winter cereal stubble harbouring the crown-rot fungus breaks the inoculum into smaller pieces and spreads them more evenly through the cultivation layer across the paddock. Consequently, the fungus has a much greater chance of coming into contact with seedlings when the next winter cereal crop germinates and starts to grow. In a no-till system the crown-rot fungus becomes confined to the previous cereal rows and is more reliant on infection through the outer leaf sheaths at the soil surface, thus greatly reducing infection. Cultivating or harrowing negates the option of inter-row sowing as a crown rot management strategy.
- **Expression**—extensive research has shown that cultivation dries out the soil to the depth of cultivation and reduces the water infiltration rate due to the loss of structure (e.g. macropores). The lack of cereal stubble cover can also increase soil evaporation. With poorer infiltration and higher evaporation, fallow efficiency is reduced for cultivated systems compared to a no-till stubble retention system. Greater moisture availability has the potential to provide buffering against the expression of crown rot late in the season.

Stubble burning

Stubble burning removes the above-ground portion of crown rot inoculum but the fungus will still survive in infected crown tissue below ground, burning is **not** a 'quick fix' for high-inoculum situations. The removal of stubble by burning increases evaporation from the soil surface and makes fallow less efficient. A cooler autumn burn is preferable to an earlier hotter burn as it minimises the loss of soil moisture while still reducing inoculum levels.

Reducing water loss

Inoculum level is important in limiting the potential for yield loss from crown rot, but the factor that most dictates the extent of yield loss is moisture and temperature stress during grainfill. Any management strategy that limits the storage of soil water or creates constraints that reduce the ability of roots to access this water will increase the probability and/or severity of moisture stress during grainfill and exacerbate the impact of crown rot.

Grass-weed management

Grass weeds should be controlled in fallows and in crops, especially in break crops, as they host the crown-rot fungus and can also significantly reduce soil-moisture storage. In pasture situations, grasses need to be cleaned out well in advance of a following cereal crop as they serve as a host for the crown-rot fungus.

Sowing time

Earlier sowing within the recommended window for a given variety and region can bring the grainfill period forward and reduce the probability of moisture and temperature stress during grainfill. Earlier sowing can increase root length and depth and provide greater access to deeper soil water later in the season, which buffers against the expression of crown rot. This has been shown in NSW DPI research

across seasons to reduce yield loss from crown rot. However, earlier sowing can place a crop at risk of frost damage during its most susceptible time.

Sowing time is a balancing act between the risk of frost and heat stress. However, when it comes to crown rot, increased disease expression with delayed sowing can have just as big an impact on yield as frost. The big difference from NSW DPI trial work is the additional detrimental impact of later sowing on grain size in the presence of crown rot infection.

IN FOCUS

The incidence of crown rot on cultivars sown on two dates in northern NSW

Researchers assessed 13 bread-wheat cultivars, a durum wheat, a barley, and a triticale cultivar in the paddock for their reaction to crown rot, based on the incidence of basal browning. Plots were sown in May and again in July at two sites in northern New South Wales where the incidence of crown rot had been high in the previous year. The incidence of infected plants and the incidence of plants with basal browning tended to be higher in all cultivars when sown in May. There was a mean loss in potential yield at one site of 35%, and at the other site of 18%. However, the mean loss in potential yield was unaffected by sowing date.⁵⁷

Row placement

In a no-till system, the crown rot fungus becomes confined to the previous cereal rows and is more reliant on infection through the outer leaf sheaths at the soil surface. This is why inter-row sowing with GPS guidance has been shown to provide around a 50% reduction in the number of plants infected with crown rot when used in a no-till cropping system.

Research conducted by NSW DPI has also demonstrated the benefits of row placement in combination with crop rotation and the placement of break crop rows and winter cereal rows in the sequence to limit disease and maximise yield. Sowing break crops between standing cereal rows, which are kept intact, then sowing the following crop directly over the row of the previous year's break crop, ensures four years between cereal rows being sown in the same row space. This substantially reduces the incidence of crown rot in crops, improves establishment of break crops (especially canola), and chickpeas will benefit from reduced incidence of virus in standing cereal stubble.

Soil type

The soil type does not directly affect the survival or infection phases of crown rot. However, the water-holding capacity of each soil type does affect the expression of crown rot by the degree to which it buffers triticale plants against moisture stress late in the season. Hence, yield loss can be worse on red soils than black soils due to the generally lower water-holding capacity of red soils. On top of this, other sub-soil constraints, e.g. sodicity, salinity or shallower soil depth, can also reduce the level of plant-available water, which can increase the expression of crown rot.

⁵⁷ TA Klein, LW Burgess, FW Ellison (1989) The incidence of crown rot in wheat, barley and triticale when sown on two dates. *Animal Production Science*, 29 (4), 559–563.

i MORE INFORMATION

[PreDicta B](#)

GRDC Tips and Tactics, [Crown rot in winter cereals: Northern Region](#)

▶ VIDEOS

WATCH: GRDC, [Grains research updates: Improving PreDicta B](#)



WATCH: [Over the Fence North: Drew Penberthy](#)



WATCH: GRDC, [Grains research updates: crown rot tolerance in new cereal cultivars](#)



Interaction with root-lesion nematodes

Root-lesion nematodes (RLNs) are also a widespread constraint to cereal production across the region. RLNs feed inside the root systems of susceptible winter cereals and create lesions that reduce lateral branching. This reduces the efficacy of the root system to extract soil water and nutrients, which can subsequently exacerbate the expression of crown rot. Varieties with reduced tolerance to Pt can suffer significantly greater yield loss from crown rot if both of these pathogens are present within a paddock.

Soil testing

In addition to visual symptoms, the DNA-based soil test PreDicta B can be used to assess the level of crown rot in the paddock. Soil samples that include plant residues should be tested early in late summer to allow results to be returned before seeding. This test is particularly useful when sowing susceptible varieties, and for assessing the risk after a non-cereal crop.⁵⁸

The test is not intended for in-crop diagnosis. In order to get an accurate result, it is important to follow the PreDicta B sampling protocol precisely (Photo 13).⁵⁹

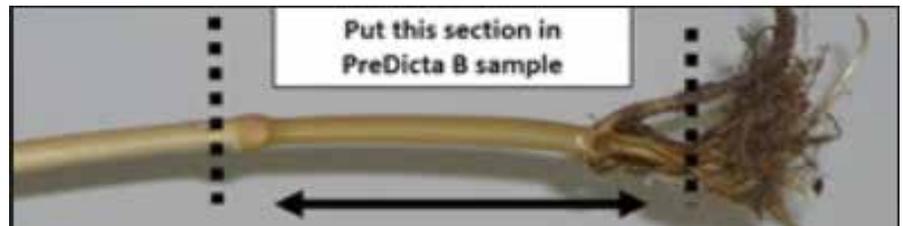


Photo 13: It is important to follow the PreDicta B sampling protocol precisely.

Source: GRDC.

Crown Analytical Services has the first Australian commercial test for crown rot. It is based on five years of laboratory research.

Testing involves carrying out a visual assessment on stubble, followed by a precise plating test. This is the only way of accurately testing for the disease. Results are provided to the grower and consultant within approximately four weeks of receiving the sample.

[Crown Analytical Services](#) provides sample bags and postage-paid packs. Go to the service's [Protocol web page](#) to better understand the process.

9.7 Common root rot

Common root rot (*Bipolaris* spp.) is a soil-borne fungal disease which attacks cereals. It survives from one season to the next through fungal spores that remain in the cultivated layer of the soil. The disease increases in severity with continuous cereal sequences. The symptoms of common root rot are:

- a dark-brown to black discolouration of the stem just below the soil surface
- black streaks on the base of stems
- slight root rotting

9.7.1 Damage caused by disease

Common root rot can cause yield losses of between 10–15% in susceptible wheat varieties.

58 Soilquality.org (2016) Crown rot, Queensland. Factsheet, Soilquality.org, <http://www.soilquality.org.au/factsheets/crown-rot-queensland>

59 D Lush (2014) PreDicta B sampling strategy. GRDC, <https://grdc.com.au/Media-Centre/Media-News/South/2014/04/PreDicta-B-sampling-strategy>

9.7.2 Symptoms

What to look for in the paddock

- Affected plants tend to be scattered over a paddock, and they may be slightly stunted, have fewer tillers and produce smaller heads.

What to look for in the plant

- Browning of roots and sub-crown internode (the piece of stem emerging from the seed to the crown) (Photo 14).⁶⁰
- Blackening of sub-crown internode in extreme cases.



Photo 14: *Blackening of sub-crown internode in an extreme case of common root rot.*

Source: DAFWA

9.7.3 Conditions favouring development

The disease can occur from tillering onwards, but is most obvious after flowering.

There are no distinct paddock symptoms, although the crop may lack vigour. Severe infections can lead to stunting of plants.

Common root rot appears to be more prevalent in paddocks that are N deficient. When N is not limiting, yield loss occurs through a reduction in tillering due to poor N use efficiency.

Affected plants are usually scattered through the crop. The disease is widespread through the grain belt, and is often found in association with crown rot.

⁶⁰ DAFWA (2015) Diagnosing common root rot of cereals. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-common-root-rot-cereals>

The fungus that causes common root rot survives on the roots of grasses and as dormant spores in the soil. It can build up to damaging levels in continuous cereal rotations.⁶¹

Infection is favoured by high soil moisture for six to eight weeks after planting.

9.7.4 Management

The disease may be controlled by planting the more resistant varieties and by crop rotation. Where the disease is severe, rotation to non-susceptible crops for at least two years is recommended. Summer crops such as sorghum, sunflower, or white French millet can be used for this purpose.⁶² It is important to:

- Reduce levels of the fungus in your paddocks by rotating with crops such as field peas, faba beans, canola, mustard, mungbeans, sorghum or sunflower.
- Keep susceptible crops and pasture grass-free.
- Sow more resistant varieties.
- If moisture permits, reduce sowing depth to limit the length of the sub-crown internode (SCI).
- Ensure adequate nutrition, especially of phosphorus, which reduces severity.
- Reconsider stubble burning, as it does not decrease spore levels in the soil.⁶³

9.8 Smut and bunt

Triticale is not usually prone to infection from smuts and bunt. However, it is good insurance for better yields to apply a seed dressing to the grain when it is being graded.⁶⁴

9.8.1 Bunt or stinking smut

Bunt or stinking smut (*Tilletia* spp.) affects ears of mature triticale, durum and wheat. A mass of black fungal spores replaces the interior of a grain with what is known as a bunt ball. Compared with healthy plants, infected plants are shorter and have darker green ears and gaping glumes (Photo 15).⁶⁵ Bunt is usually only noticed at harvest when bunt balls and fragments are seen in the grain. It is important to manage this disease, as receival sites will not accept grain deliveries with traces of bunt balls.

61 K Moore, B Manning, S Simpfendorfer, A Verrell (n.d.) Root and crown diseases of wheat and barley in northern NSW. NSW DPI. http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0019/159031/root-crown-rot-diseases.pdf

62 DAF Qld (2015) Wheat: diseases, physiological disorders and frost. DAF Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases>

63 K Moore, B Manning, S Simpfendorfer, A Verrell (n.d.) NSW DPI. Root and crown diseases of wheat and barley in northern NSW. NSW DPI, http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0019/159031/root-crown-rot-diseases.pdf

64 Agriculture Victoria (2012) Growing triticale. Note AG0497. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale>

65 DAFWA (2016) Smut and bunt diseases of cereal: biology, identification and management. DAFWA, <https://www.agric.wa.gov.au/autumn/smut-and-bunt-diseases-cereal-biology-identification-and-management?page=01>

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Photo 15: Common bunt in cereal head showing glumes containing bunt balls.

Source: DAFWA

The spores germinate with the seed when it is planted, and infect the young seedling. The fungus then grows inside the developing plant, finally replacing each normal grain with a mass of spores. If a bunt ball is crushed, a putrid, fishy odour is released. Spores released during harvest will contaminate sound grain.

Managing bunt

- Seed that is sown to provide the following season’s seed should be treated with a fungicidal seed dressing.
- Seed obtained from plants grown from untreated seed should be treated with a fungicidal seed dressing before planting.
- All seed should be treated with a fungicidal seed dressing which will control bunt.
- Grain from a crop with bunt should not be used for seed.
- On farms where a crop has been affected by bunt, all seed should be treated with fungicidal seed dressing for at least six years.

These recommendations could be adopted in one of two ways:

- Treat all seed with a fungicidal seed dressing every second year.
- Treat a small quantity of seed of each variety with a fungicidal seed dressing every year, and use only the grain from this seed as planting seed in the following year.⁶⁶

9.8.2 Loose smut

Triticale is susceptible to loose smut,⁶⁷ though it does not usually occur to a degree where control is warranted.

⁶⁶ DAF Qld (2015) Wheat: diseases, physiological disorders and frost. DAF Qld, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases>

⁶⁷ P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI, <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>

Loose smut is a fungal disease that becomes evident at head emergence. A loose, powdery mass of fungal spores is formed in the head; these are readily blown away leaving a bare, ragged stalk (Photo 16).⁶⁸



Photo 16: Barley heads affected by loose smut.

Source: DAFWA

If the spores settle on healthy flowers, they may germinate and infect the embryo of the developing seed. When the seed is planted, the smut grows inside the plant until flowering, when the disease appears. Because loose smut is carried inside the seed, systemic seed dressings are needed to control it. These are more expensive than the others and should be used only when a high incidence of loose smut is expected.⁶⁹

Managing smut

The disease is controlled by pickling seed in a systemic fungicide which penetrates the developing seedling to kill the internal infection. Seed-dressing fungicides for cereals differ in their efficacy for smut management with trial research demonstrating that some seed dressings can reduce the incidence of loose smut in heavily infected seed to nearly zero. The correct application of seed dressings is critical to ensuring adequate control. In-furrow and foliar fungicide applications are not effective.⁷⁰

9.9 Rhizoctonia root rot

Key points:

- The presence of *Rhizoctonia* fungal disease is most evident as bare patches in a young crop. Close inspection of infected seedlings shows brown discolouration or rotting of the roots and evidence of 'spear tips'.
- In cereals, oat is most tolerant, followed by triticale, wheat and then barley, which is the most intolerant.⁷¹

68 DAFWA (2016) Smut and bunt diseases of cereal: biology, identification and management. DAFWA, https://www.agric.wa.gov.au/autumn/smut-and-bunt-diseases-cereal-biology-identification-and-management?page=0_1

69 DAF Qld (2015) Wheat: diseases, physiological disorders and frost. DAF Queensland, <https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases>

70 DAFWA (2016) Smut and bunt diseases for cereal. DAFWA, <https://www.agric.wa.gov.au/autumn/smut-and-bunt-diseases-cereal-biology-identification-and-management?page=0%2C0>

71 GRDC (2008) What is Rhizoctonia bare patch? Factsheet. GRDC, https://grdc.com.au/_data/assets/pdf_file/0014/222143/rhizoctonia-factsheet.pdf.pdf

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- Adequate nutrition during crop emergence gives the crop a better chance of getting ahead of the disease.
- Fast-growing roots will push past the infected topsoil before *Rhizoctonia* infects the root tip.
- Poor weed management prior to seeding allows *Rhizoctonia solani* to 'prime' itself for infection of the upcoming crop.
- In severe paddock infections cultivation following late summer–early autumn rains can help to reduce infection by the fungus.

Rhizoctonia root rot is a fungal disease caused by *Rhizoctonia solani* AG8. It affects a wide range of crops and has become more prevalent in light soils in recent years following the introduction of minimum tillage. The traditional practice of tilling prior to planting encouraged the breakdown of the fungus in the soil before seedlings emerged. Minimum tillage decreases the rate of organic-matter breakdown, thereby providing a habitat for *Rhizoctonia solani* over summer. The disease affects most major crops to varying degrees, with barley being most susceptible and oat crops are least susceptible. Bare patch and root rot of cereals, and damping off and hypocotyl rot of oilseeds and legumes are all caused by different strains of *R. solani*.⁷²

Yield losses in crops affected by Rhizoctonia can be over 50% and crops with uneven growth may lose up to 20%. The disease fungus grows on crop residues and soil organic matter and is adapted to dry conditions and lower fertility soils. The fungus causes crop damage by pruning newly emerged roots (spear-tipped roots) which can occur from emergence to crop maturity. The infection results in water and nutrient stress to the plant, as the roots have been compromised in their ability to translocate both moisture and nutrients.

Key factors influencing Rhizoctonia occurrence and severity

While *Rhizoctonia solani* AG8 fungus is likely to be present in many soils, it is not necessarily going to cause a problem. One reason for this is that beneficial soil micro-organisms and high microbial activity have been shown to suppress the expression of the disease and reduce the level of disease. In cereals, *R. solani* AG8 inoculum builds up from sowing to crop maturity and generally peaks at crop maturity, while rain post-maturity of a crop and over the summer fallow causes a decline in inoculum (Figure 4).

72 Soilquality.org (2016) Rhizoctonia, NSW. Factsheet, Soilquality.org, <http://www.soilquality.org.au/factsheets/rhizoctonia-nsw>

i MORE INFORMATION

[Karoonda break crops trials: soil biology and rhizoctonia diseasev](#)

▶ VIDEOS

WATCH: [Over the Fence: improving soil health helps fight against Rhizoctonia](#)

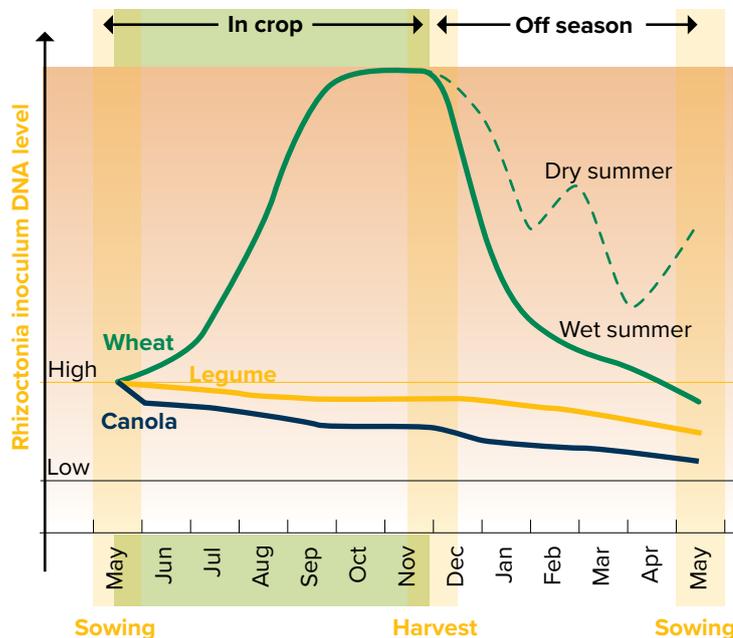


Figure 4: *R. solani* AG8 inoculum levels in soil build-up in-crop but decline during summer following rainfall under wheat, while under grass-free canola and legume crops inoculum levels decline in-crop and over summer.

Source: GRDC.

Crown root infection late into the crop season results in the build-up of inoculum in cereal crops. In the absence of host plants including weeds, summer rainfall events of more than 20 mm in a week can substantially reduce the level of inoculum. Dry spells, on the other hand, offer little opportunity for pathogen inoculum breakdown, with disease levels likely to remain stable if a host, or stubble, are present. Cropping systems with stubble retention, suppressive activity has been shown to increase over a five to eight-year period. GRDC funded CSIRO research showed suppressive soils generally contained higher populations of specific fungi and bacterial groups capable of antibiosis, mycoparasitism, plant growth promotion, nutrition and improved plant defenses.⁷³

9.9.1 Symptoms

The characteristic symptom of Rhizoctonia root rot is clearly defined bare patches in the crop. The reason these patches are clearly defined relates to the susceptibility of young seedlings, and the placement of the fungus within the soil profile. *Rhizoctonia solani* tends to reside in the upper layers of soil, but not in the surface, and only infects seedlings through the root tip soon after germination. Older plants have a more developed root epidermis that does not allow the penetration of fungal hyphae into the root. For this reason, once the crop is fully established, plants have either perished due to seedling infection or are reasonably healthy. Some yield loss may be associated with plants on the margins of the bare patch. Roots of a plant infected with *R. solani* AG8 will typically be shorter and have a brown 'spear tip' where they have rotted. Plants within a patch remain stunted with stiff, rolled leaves and can be darker green than those outside the patch.⁷⁴

⁷³ GRDC (2016) Tips and Tactics: Rhizoctonia Southern region. <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/rhizoctonia>

⁷⁴ Soilquality.org (2016) Rhizoctonia, NSW. Factsheet, Soilquality.org, <http://www.soilquality.org.au/factsheets/rhizoctonia-nsw>

What to look for in the paddock

- Severely stunted plants occur in patches with a distinct edge between diseased and healthy plants.
- Patches vary in size from less than half a metre to several metres in diameter.
- Patches of uneven growth occur from mid-winter when seminal roots have established (Photo 17).⁷⁵



Photo 17: Patches vary in size from less than a metre to several metres in diameter. Patches have a distinct edge.

Source: DAFWA

What to look for in the plant

- Affected plants are stunted with stiff, rolled leaves and are sometimes darker green than healthy plants (Photo 18).
- Roots of affected plants are short with characteristic pinched ends called 'spear tips' (Photo 19).

⁷⁵ DAFWA (2016) Diagnosing rhizoctonia root rot in cereals. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-rhizoctonia-root-rot-cereals>

SECTION 9 TRITICALE

TABLE OF CONTENTS

FEEDBACK

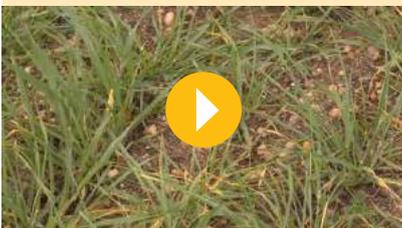


Photo 18: Affected plants are stunted with stiff, rolled leaves which are sometimes darker than those of healthy plants.

Source: DAFWA

VIDEOS

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Photo 19: Roots of affected plants are short with characteristic pinched ends or 'spear tips'.

Source: DAFWA

9.9.2 Conditions favouring development

Rhizoctonia solani survives best in organic matter just below the surface of undisturbed soil. The fungus benefits from summer rainfall by infecting and multiplying in weeds, and has a limited ability to survive on the residue of previous seasons crops. The break of season initiates the development of the fungus in soil, where it lies primed to infect germinating seeds. Infection by the pathogen is encouraged by factors that restrict root growth, such as low soil fertility and sulfonylurea herbicides (including residues). If there is a delay between the season break and seeding, it is imperative that weeds are controlled to minimise proliferation of the fungus. Good nitrogen nutrition helps to minimise the effects of the disease; bare patches are smaller and less severe.

In general, *Rhizoctonia* root rot is most likely to be a severe problem where the plant is under stress from factors other than the disease, for example, low rainfall or poor nutrition.

There are certain soil conditions that favour the development of the root rot during and after seeding.

Soil nutrition

The disease is most common in soils of poor fertility. Crops with access to sufficient nutrients for growth have a better ability to 'get ahead' of *Rhizoctonia solani* infections.

Soil disturbance

Rhizoctonia solani is sensitive to cultivation, with cultivation after rain and before sowing most effective at reducing infection. Disturbing the soil prevents the fungus from 'priming' itself for infection of the emerging crop.

Soil moisture

When it is moisture stressed the crop becomes more susceptible to *R. solani* infection and is less able to get ahead of the disease.

Weeds

Poor weed management following late summer and early autumn rain allows *R. solani* to infect grass weeds, thereby allowing the fungus to multiply in preparation for the crop.

Herbicides

Sulfonylurea herbicides can sometimes worsen *Rhizoctonia* root rot, and this is attributed to minor herbicidal effects on the crop.⁷⁶

9.9.3 Managing *Rhizoctonia* root rot

Key points:

- Management of *Rhizoctonia* requires an integrated approach to reduce inoculum and control infection and impact on yield (Table 8).
- *Rhizoctonia* inoculum levels will be greatest following cereals, particularly barley.
- Grass-free canola is the most effective in reducing inoculum levels.
- Legumes can also help reduce inoculum loading.
- Disturbance below the seed at sowing promotes rapid root growth away from the *Rhizoctonia* and disrupts hyphal networks. The ideal depth is 5–10 cm.
- Fungicides applied through in-furrow liquid banding can provide useful suppression of *Rhizoctonia* disease.
- Herbicides that slow root growth can increase the risk of *Rhizoctonia* root rot.⁷⁷

⁷⁶ Soilquality.org (2016) *Rhizoctonia*, NSW. Factsheet, Soilquality.org. <http://www.soilquality.org.au/factsheets/rhizoctonia-nsw>

⁷⁷ GRDC (2016) Tips and Tactics: *Rhizoctonia* Southern region. <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/rhizoctonia>

SECTION 9 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Table 8: Management strategies to reduce *Rhizoctonia* root rot.

Year 1 (Sept-Nov)	Summer (Dec-April)	Season break (April-May)	Year 2 crop (May-August)
Check for inoculum build-up	Facilitate inoculum decline	Select appropriate crop	Manage infection and disease impact through management practices
Paddocks can often be identified in the previous spring by estimating the area of bare patches and/or zones of uneven growth during spring—verify that poor plant growth is due to <i>Rhizoctonia</i> disease	In wet summers, early weed control will reduce inoculum. In dry summers, inoculum levels do not change Adopt practices that prolong soil moisture in the upper layers (e.g. stubble retention and no cultivation) which helps maintain higher microbial activity Consider soil testing for pathogen inoculum level (PreDicta B™ test in Feb/March), to identify high disease risk paddocks, if disease is not confirmed in the previous cereal crop, especially if planning to sow cereals back on cereals	Select a non-cereal crop (e.g. canola or pulses) if you want to reduce inoculum levels Remove autumn 'green bridge' before seeding with good weed control	Sow early; early-sown crops have a greater chance of escaping infection Use soil openers that disturb soil below the seed to facilitate root growth—knife points reduce disease risk compared to discs Avoid pre-sowing SU herbicides Supply adequate nutrition (N, P and trace elements) to encourage healthy seedling growth Avoid stubble incorporation at sowing to minimize N deficiency in seedlings Consider seed dressings and banding fungicides to reduce yield loss Remove grassy weeds early Apply nutrient/trace elements, foliar in crop, if required

Source: GRDC

Summer weed control

Summer weed control will reduce inoculum levels and the disease in the following winter by decreasing the living host plants for the disease. This complements the moisture and nitrogen conservation benefits of summer weed control.

Crop choice rotations

Cereals and grassy fallows promote the build-up of *Rhizoctonia* inoculum, with barley being the worst of these. Crop rotation with a grass-free non-cereal crop is one of the best available management strategies to reduce the impact of *Rhizoctonia* disease. Trials across the lower rainfall cropping region of southern Australia indicated that grass-free oilseeds, pulses, pasture legumes and fallow can result in significant reductions in *Rhizoctonia* inoculum in a cropping sequence. Non-cereal crops can be infected by *Rhizoctonia*, however, most do not allow the build-up of inoculum. Lupins

may be a less effective break crop and can suffer from yield damage in the presence of *Rhizoctonia*. The beneficial effect of rotation on reducing *Rhizoctonia* inoculum generally lasts for one cereal crop season.

Fungicide treatments

Fungicide treatments need to be used as part of an integrated management strategy. Yield responses can vary between seasons with the greatest responses occurring when spring rainfall is above average. In GRDC funded trials in southern Australia and Western Australia, on average seed treatments gave 5% (0 to 18%) yield responses in cereals. Several products have been registered for liquid banding. GRDC funded research has shown that: Product(s) registered for dual banding, in-furrow 3–4 cm below the seed and on the surface behind the press wheel, gave the most consistent yield and root health responses across seasons. Seed treatment combined with in-furrow application can provide intermediate benefit between seed treatment alone and a split application.

Nitrogen

Nitrogen-deficient crops are more susceptible to *Rhizoctonia*. Intensive cropping with cereals and stubble retention result in very low levels of mineral nitrogen over summer as soil microbes temporarily utilise all available nitrogen while breaking down the low nitrogen stubble residues. Application of adequate N fertiliser at sowing is necessary to ensure early seedling vigour so plants can push through the layer of inoculum concentrated in the top 10 cm. Ensure good nitrogen nutrition is present. Crops with adequate N will be less affected by the disease.

Disease suppression

Biological disease suppression can help control *Rhizoctonia* disease occurring in grower's crops. • Disease suppression is a function of activity and diversity of the microbial community. A management regime that increases Carbon inputs and turnover over a number of years (five to seven years) may improve suppressive activity. Management practices which encourage suppression include reduced tillage and stubble retention, controlling weed hosts, no grazing or stubble burning and avoiding bare fallows.⁷⁸

Cultivation practices

Where reduced tillage is practiced, *Rhizoctonia* root rot is best controlled by effectively managing weeds and maintaining adequate nutrition for the establishing crop. Spraying weeds with a fast-acting knockdown herbicide will minimise the development of the fungus in the ground prior to seeding, and good nutrition gives the crop a better chance of getting ahead of the disease.

Best-tillage practices involve deep cultivation and shallow sowing, with minimal time between the two. In no-till systems the use of modified sowing points that provide some soil disturbance 5–10 cm below the seed can be useful in controlling the disease.

In the past, tilling was the most effective method of reducing the impact of *Rhizoctonia solani*. The establishment of the fungus in the topsoil late in autumn was negated as cultivation broke the network of fungal hyphae, and it did not have time to recover before seedling establishment. In severely infected paddocks, cultivation may be an important management strategy.

Currently there are no resistant crop varieties, but there are products on the market for the control of *Rhizoctonia* root rot. Consult your local adviser for specific information.

In areas where the disease is known or suspected, the best practice is to clean knife points once the seeding is complete, to eliminate movement of the fungus from one paddock to the next. In general, maintaining adequate nutrition (especially

78 GRDC (2016) Tips and Tactics: *Rhizoctonia* Southern region. <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/rhizoctonia>

SECTION 9 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

MORE INFORMATION

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[Management to minimise Rhizoctonia disease in cereals](#)

nitrogen) during crop establishment is the best way to reduce the chance of *R. solani* infection.⁷⁹

9.10 Scald

Scald is caused by the fungus *Rhynchosporium commune* (formerly known as *R. secalis*) and is considered a minor disease of the traditional GRDC Northern region (north of Dubbo). However, in the southern part of the Northern region, and in seasons when environmental and epidemic conditions are particularly favourable the economic impact of this disease can be quite serious. Scald can cause yield loss in triticale (Photo 20).



Photo 20: Scald infection on a triticale plant.

Photo: H Wallwork.

Its severity varies between crops and seasons, being more prevalent in high rainfall areas and wet seasons. Scald is also favoured by an early break to the season. Grain yield losses due to scald are estimated to be between 10–30% in susceptible varieties, while individual losses as high as 45% have been recorded.

While scald can be common in cereals in the Southern cropping region (and also the southern part of the Northern cropping region), it has been over a decade since scald occurred at damaging levels in the Northern region, north of Dubbo.

Scald has been detected at levels that reduce yield as far north as Toowoomba but this is a rare occurrence. It was present at damaging levels in several crops in the Tamworth area in 2003 and at interest levels in 2005 and 2006. Though the 2016

79 Soilquality.org (2016) Rhizoctonia, NSW. Factsheet. Soilquality.org, <http://www.soilquality.org.au/factsheets/rhizoctonia-nsw>

experience is unlikely to be a frequent occurrence, it is a reminder that given the right conditions, minor diseases can rapidly increase and cause significant yield loss.

Most cereal varieties developed for the Northern region are susceptible (S) to very susceptible (VS) to scald, because resistance to the disease in this region is not seen as a breeding priority. This not only provides a susceptible host in areas where scald might over-season and infect any one variety; but it also provides large areas of other susceptible varieties, making an easy target for spores to be deposited and infect. Therefore, a high proportion of spores released by the pathogen will find a target host, infect and establish the disease in new areas.

Scald is a highly variable fungus and many pathotypes have been identified. It is claimed that numerous pathotypes can be isolated from just one square metre of infected crop. Consequently, virulent pathotypes are omnipresent.

The pathogen survives on barley stubble, on barley grass (*Hordeum leporinum*, *H. glaucum*) and can be seed-borne. Barley stubble is most likely the major source of inoculum in 2016. The disease has probably been present in crops at low levels in most seasons and has persisted over summers on crop residues. Winter environments in recent years have not suited the development and spread of scald in crop; so it has persisted at only low levels. It is unlikely that seed-borne infection played a major role in the recent epidemic.

Once infection occurs, scald can proliferate at an alarming rate. A single scald lesion can produce up to 1 million conidia.

The over-seasoning phases have implications for future disease management. Stubble from crops of barley, heavily infected in 2016, will be a major source of inoculum in 2017. Stubble could be removed but if this is not an option, do not sow barley back into those paddocks for at least two seasons. Stubble has been shown to support sporulation over a 10-month period.

Furthermore, if growers harvested seed from heavily infected crops in 2016 intending to save some for planting seed in 2017, it is recommended that they either buy in seed from non-infected crops or alternatively treat seed with a recommended fungicide. Transmission of scald from infected seed to seedlings can be as high as 86%.

The reappearance of scald in 2016 was a new experience for many Northern growers and agronomists. Consequently, it was easy to overlook the disease early in the season and later to underestimate the potential for epidemic increase. By the time scald was recognized as an issue, the optimal time for fungicide application had passed. No doubt the disease reduced yield in heavily infected crops.⁸⁰

9.10.1 Symptoms

Scald causes lesions of the leaf blades and sheaths. At first, scald appears as water-soaked, grey-green lesions, which change to a straw colour with a brown margin that are ovate to irregular in shape, (Photo 21). In severe infections, the disease may virtually cause defoliation by coalescing of the lesions.

⁸⁰ G Platz, L Snyman, R Fowler (2017) GRDC Update Papers: What we learnt in 2016 about scald and other wet season diseases. <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2017/02/What-we-learnt-in-2016-about-scald-and-other-wet-season-diseases>

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[GRDC Foliar Diseases—Ute Guide](#)



Photo 21: *Scald of barley. Early water-soaked, grey-green symptoms compared to later straw colour lesions with a distinctive brown margin.*

Source: CropPro.

Scald blotches may look similar to herbicide damage, however herbicide damage is often seen as more evenly-spread droplet-sized lesions.

9.10.2 Conditions favouring development

Scald requires free moisture for sporulation and infection and relies on rain splash to move spores up the plant and within the crop. Frequent rain periods therefore promote sporulation, disseminate conidia and favour infection. These conditions also promote crop growth; so that in dense crops leaf tissue can remain wet for 24 hours per day. Serious losses to scald occur in seasons with frequent rain.

The optimal temperature for spore production is 15–20°C which also favours infection. No doubt environmental conditions that promoted spore production, spore dissemination and infection occurred repeatedly in the problem areas in 2016 and played a major role in the development of epidemics.⁸¹

9.10.3 Management of Scald

Wet weather can be a trigger for disease control. If growers are in an area that has experienced diseases like scald before, be suspicious that these diseases may reappear. Monitor crops for the presence of the regular diseases but also with a purpose to detect other diseases that have appeared in previous wet seasons.

Usually minor diseases do not command routine procedures to control the disease. Although once detected in a favourable season, they demand close monitoring and timely fungicide intervention to minimize yield losses. Foliar fungicides are quite effective on scald and will give protection for 3–4 weeks depending on product and rate applied. In a season like 2016, application of fungicide at GS31-32 and again at GS39-41 may have been required to give an adequate level of control.⁸²

⁸¹ G Platz, L Snyman, R Fowler (2017) GRDC Update Papers: What we learnt in 2016 about scald and other wet season diseases. <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2017/02/What-we-learnt-in-2016-about-scald-and-other-wet-season-diseases>

⁸² G Platz, L Snyman, R Fowler (2017) GRDC Update Papers: What we learnt in 2016 about scald and other wet season diseases. <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2017/02/What-we-learnt-in-2016-about-scald-and-other-wet-season-diseases>

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[New fungicides and disease management strategies for wheat and barley](#)

Cultural Practices

Carry-over of scald inoculum can be reduced by grazing, burning or cultivation of stubble, volunteers and barley grass, however, these practices do not eliminate the disease altogether as scald will survive on small amounts of remaining residue. Rotations that avoid consecutive barley crops and ideally a two year or more break between susceptible crops is recommended to allow residue to sufficiently breakdown. Scald is also more severe in early sown crops, so avoiding early sowing of susceptible varieties, especially in high rainfall areas will reduce the loss caused by scald.

Resistant Varieties

Cultivation of resistant varieties gives the best control of scald, with the risk of grain yield and quality loss being greatly reduced by avoiding growing susceptible and very susceptible rated varieties. Unfortunately, *R. commune* is highly variable pathogenically and able to overcome resistances rapidly, meaning that variety ratings may also change frequently. It is important to check up to date cereal disease guides for the resistance status of varieties.

Fungicides

There are a range of fungicides available that will provide suppression of scald. Fertiliser and seed applied fungicides provide effective suppression during the seedling stages of crop development, while foliar fungicides are most effective when applied between the beginning of stem elongation (GS31) and flag leaf emergence (GS39). Two applications of fungicide are generally required to minimise grain yield and quality loss where disease pressure is sustained during the season. Application that coincide with the early stages of scald development are more effective than later applications as scald can rapidly cause damage when conditions are favourable. Crop monitoring is very important during seasons of risk of scald development.⁸³

9.11 Ergot

Triticale, like rye, is susceptible to ergot, a fungal disease, caused by *Claviceps purpurea*, that can ruin a year's crop. Careful crop rotation, the use of a clean seedbed, and diligent maintenance of field edges will minimise this chance, but triticale intended for human or animal consumption should be tested for toxins. Ergot can make grain less palatable to livestock, as well as causing serious health problems.⁸⁴

9.11.1 Damage caused by disease

Ergot bodies contain alkaloid chemicals that can cause lameness, gangrene of the extremities and nervous convulsions (staggers) that can lead to death in both humans and other animals. Symptoms begin to occur after long periods of low level ingestion as toxins accumulate in the body. Yields of crops affected by ergot are generally not much diminished yield losses, but economic losses can be quite severe, because grain tendered by growers is likely to be rejected at receipt.⁸⁵

Gangrenous ergotism of humans and cattle

In humans, gangrenous ergotism causes blockages of circulation to the extremities resulting first in tingling and then in gangrene in the fingers and toes, as well as vomiting, diarrhoea, and ulceration of the mouth. It is a dry form of gangrene, and limbs may fall off.

83 CropPro (2014) Scald of Barley. http://www.croppro.com.au/crop_disease_manual/ch02s17.php

84 UVM Extension Crops and Soils Team (2011) Triticale. University of Vermont, <http://northerngraingrowers.org/wp-content/uploads/TRITICALE.pdf>

85 AWB (n.d.) Ergot. Factsheet. AWB, https://www.awb.com.au/NR/rdonlyres/BFA96F0A-1967-4B8D-8B6C-631A00F15478/0/ERGOT_factsheet.pdf

In cattle there is lameness, especially in the hindquarters, gangrene of feet, ears and tail. Pregnant cows may abort. There is a characteristic band where the gangrenous tissue ends.

Convulsive ergotism

Symptoms are similar to those of gangrenous ergotism, and are followed by painful spasms of the limbs, epilepsy-like convulsions and delirium in humans. Cattle become excitable and run with a swaying, uncoordinated gait.⁸⁶

9.11.2 Symptoms

What to look for in the plant

Characteristically ergot pieces have a purple–black surface with a white to grey interior (Photo 22). They are usually horn-like in shape and replace one or more grains in the heads of cereals and grasses. These ergot bodies can be up to four times larger than normal grain.

- Hard, dry purple–black fungal bodies (ergots) that replace the grain in the seed head.
- Yellow droplets of sugary slime in infected heads during flowering.⁸⁷



Photo 22: Ergot bodies in cereal grain head.

Photo: C Wolinsky

What to look for in stock

Producers are encouraged to keep an eye on animals that may have eaten ergot-infected grain, especially in hot or sunny weather (Photo 23). Signs of ergot poisoning include animals seeking shade, being reluctant to move, and panting and distress following any exercise. Animals may also drool, have an increased respiratory rate, and reduced feed intake.⁸⁸

⁸⁶ HerbiGuide (n.d.) Rye. HerbiGuide, http://www.herbiguide.com.au/Descriptions/hq_Rye.htm

⁸⁷ DAFWA (2015) Diagnosing ergot. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-ergot>

⁸⁸ DAFWA (2015) Look out for ergots when selecting stock feed. DAFWA, <https://www.agric.wa.gov.au/news/media-releases/look-out-ergots-when-selecting-stock-feed>



Photo 23: Producers need to be aware that even a small amount of ergot in grain can cause serious illness to their stock.

Photo: Michael Raine

9.11.3 Conditions favouring development

Key points:

- Ergots survive in the soil for up to one year, producing spores that infect plants during flowering.
- Infection is more likely when there is cool, wet weather at flowering.
- It is spread by rain splash or by insects attracted to the sugary droplets.
- High levels of grass-weed contamination can increase ergot infection in cereals, or ergots produced in grasses can contaminate grain samples.⁸⁹

The development of ergot is promoted by moist soil surfaces during spring and early summer. In addition, wet conditions during the flowering of cereals and grasses increases the period of infection. The disease cycle of ergot consists of two stages. It begins in spring when the ergot bodies germinate in wet soils after winter and develop fruiting bodies that contain spores (ascospores). The spores can be spread to neighbouring, susceptible plants by wind and rain. To infect these plants, the spores must land on the florets. Within five days the second stage commences; this is referred to as the 'honeydew stage'. The infected florets exude a sugary slime that contains spores of a second type (conidia). These can infect other florets via insect vectors, rain splash and/or wind. This period of infection lasts for as long as the susceptible plants are in flower. The infected ovary in the floret then enlarges and is replaced by the purple–black ergot body, which can survive in soil for up to one year.

Crops are generally perceived to be at greatest risk when grass weed populations are high. Infected grasses usually produce slender ergots and in some cases can be fully responsible for the contamination of grain samples.⁹⁰

89 DAFWA (2015) Diagnosing ergot. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-ergot>

90 AWB (n.d.) Ergot. Factsheet. AWB, https://www.awb.com.au/NR/rdonlyres/BFA96F0A-1967-4B8D-8B6C-631A00F15478/0/ERGOT_factsheet.pdf

Ongoing periods of spring and summer rain can increase occurrence of ergots in ryegrass; therefore, ergots in crops are more likely to develop in years of above-average rain when ryegrass is flowering.⁹¹

9.11.4 Management of disease

Key points:

- Give contaminated paddocks a one-year break without cereals or grasses.
- Manage grass-weed contamination in crops.
- Clean seed.⁹²

For grain that is contaminated, grain-cleaning equipment can be used to remove the majority of ergot bodies (Photo 24). However, the grower will need to determine whether this is economically viable.



Photo 24: Ergot-contaminated seed.

Source: DAFWA

To avoid the development of ergot in subsequent cereal crops, effective farm-management practices are required. One option available to growers is the use of crop rotations away from cereals for at least one year to reduce the number of viable ergot pieces in the soil to negligible levels.

During planting, clean seed must be used, as there are currently no effective treatments against ergot. For growers using conventional tillage, ergot pieces need to be buried to a minimum depth of 4–5 cm. This prevents the fruiting bodies that are

91 DAFWA (2015) Look out for ergots when selecting stock feed. DAFWA, <https://www.agric.wa.gov.au/news/media-releases/look-out-ergots-when-selecting-stock-feed>

92 DAFWA (2015) Diagnosing ergot. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-ergot>

produced by the ergot from reaching the soil surface and releasing spores. This may have an effect on the usual sowing operations and guidance should be sought.

Finally, to eliminate the development of host reservoirs, growers may be able to mow or spray grass pastures to prevent flowering.⁹³

Control of grasses within cereal crops will help prevent cross-infection. This is best achieved by preventing seedset in the season before cropping, by clear fallowing, hard grazing or hay cutting, together with the use of selective herbicides.⁹⁴

The only practical control is to sow clean, year-old seed on land that hasn't grown cereal rye for at least a year. Mowing roadside and headland grass prior to seedset will reduce or eliminate this major source of ergot re-infestation.⁹⁵

Strategies to reduce the risk of ergot infection:

- Use ergot-free seed if possible.
- Rotate with crops resistant to ergot, such as canola and legumes.
- As the source of ergot infection is often the grass in headlands or ditches, mowing this grass before flowering or seedset will greatly reduce or eliminate the chances of ergot infection.
- Ergots germinate at or near the soil surface. To prevent them from germinating, work the paddock to a depth greater than 4–5 cm to bury the ergot bodies.
- Seed at a uniform depth as shallow as possible for adequate moisture to obtain a uniform early emergence.
- Separate the seed collected from the first few header rounds to prevent contamination of the entire lot, as most of the ergot infested grain will likely be concentrated in this region.⁹⁶

9.12 *Septoria tritici* blotch

Key points:

- Triticale has vastly superior tolerance over wheat to *Septoria tritici* blotch.⁹⁷
- The disease spends 14–21 days living inside leaves without causing visible symptoms. Then the pathogen transitions to causing visible disease symptoms including necrotic lesions in which the characteristic black fruiting structures are observed.
- An integrated approach that incorporates variety selection, cultural practices, crop rotation and fungicides is the most effective way to manage *Septoria tritici* blotch.
- The disease is starting to show resistance to some fungicide treatments used in Australia, so Integrated Disease Management strategies are increasingly important.

Septoria tritici blotch (STB) is an important stubble-borne foliar disease of cereals in southern parts of the Northern cropping region. This disease has increased in importance in the high-rainfall cropping regions recently, even though it has been well controlled in southern Australia for the last 30 years through the use of partially resistant varieties. The increase in STB in the high-rainfall zone has been favoured by stubble retention, intensive cereal production, susceptible cultivars and favourable disease conditions.

93 AWB (n.d.) Ergot. Wheat quality factsheet. AWB, https://www.awb.com.au/NR/rdonlyres/BFA96F0A-1967-4B8D-8B6C-631A00F15478/0/ERGOT_factsheet.pdf

94 R Clarke (1999) Ergot of pasture grasses. Note AG0721. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/ergot-of-pasture-grasses>

95 Alberta Agriculture and Forestry (2016) Fall rye production. Agdex 117/20–1. Revised. Alberta Government., [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/agdex1269/\\$file/117_20-1.pdf](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf)

96 Alberta Agriculture and Forestry (2016) Fall rye production. Agdex 117/20–1. Revised. Alberta Government., [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/agdex1269/\\$file/117_20-1.pdf](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf)

97 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI, <https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide>

When susceptible and very susceptible varieties are grown, *Septoria tritici* blotch is likely to cause annual average losses of up to 20%, with much higher losses possible in individual crops.

STB is prone to developing resistance to fungicides. Resistance to some triazole (**Group 3**) fungicides was detected in 2013/2014. To minimise the chance of further resistance developing it will be important pay careful attention to fungicide strategies and use an integrated approach to management.

9.12.1 Symptoms

The fungus causes pale grey to dark brown blotches on the leaves, and to a lesser extent stems and heads. The diagnostic feature of *Septoria tritici* blotch is the presence of black fruiting bodies (pycnidia) within the blotches (Photo 25).⁹⁸ These tiny black spots give the blotches a characteristic speckled appearance. When the disease is severe, entire leaves may be affected by disease lesions (Photo 26).

In the absence of the black fruiting bodies, which are visible to the naked eye, similar blotching symptoms may be caused by yellow leaf spot or nutritional disorders such as aluminium toxicity or zinc deficiency.

The only other disease that has black fruiting bodies within the blotches is *Septoria nodorum* blotch, but this disease is rare.



Photo 25: The presence of black fruiting bodies within the blotches is a diagnostic feature of *Septoria tritici* blotch.

Source: Agriculture Victoria



Photo 26: *Septoria tritici* blotch can cause complete death of leaves.

Source: Agriculture Victoria

⁹⁸ G Hollaway (2014) *Septoria tritici* blotch of wheat. Note AG1336. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/septoria-tritici-blotch-of-wheat>

9.12.2 Varietal resistance or tolerance

Table 9 lists the resistance of different varieties to *Septoria tritici* blotch.⁹⁹

Table 9: *Triticale variety resistance ratings to Septoria tritici blotch.*

Variety	<i>Septoria tritici</i>
Astute(D)	MR-MS
Berkshire(D)	R-MR
Bison(D)	MR
Canobolas(D)	R-MR
Chopper(D)	R-MR
Endeavour(D)	R
Fusion(D)	MR
Goanna	MR
KM10	MR
Rufus	R-MR
Tahara	R-MR
Tobruk(D)	R
Tuckerbox	R-MR
Yowie	R-MR

Maturity: E = early, M = mid-season, L = late, VL = very late Height: M = medium, T = tall Colour: W = white, Br = brown Disease resistance order from best to worst: R > R-MR > MR > MR-MS > MS > MS-S > S > S-VS > VS p = provisional ratings—treat with caution. R = resistant, M = moderately, S = susceptible, V = very. # Varieties marked may be more susceptible if alternative strains are present

Source: Agriculture Victoria

9.12.3 Conditions favouring development

Septoria tritici blotch, also called *Septoria* leaf spot or speckled leaf blotch is caused by the fungus *Mycosphaerella graminicola* (asexual stage *Zymoseptoria tritici*, synonym *Septoria tritici*).

The blotch survives from one season to the next on stubble. Following rain or heavy dew in late autumn and early winter, wind-borne spores (ascospores) are released from fruiting bodies (perithecia) embedded in the stubble of previously infected plants. The spores can be spread over large distances.

Early ascospore infections cause blotches on the leaves. Within these blotches a second type of fruiting body, pycnidia, are produced. Asexual spores ooze from pycnidia when the leaf surface is wet and spores are dispersed by rain splash to other leaves where they cause new infections. This phase of disease development depends on the rain splash of spores; therefore, *Septoria tritici* blotch will be most severe in seasons with above-average spring rainfall. A combination of wind and rain provides the most favourable conditions for spread of this disease within crops.

9.12.4 Management

An integrated approach that incorporates variety selection, cultural practices, crop rotation and fungicides is the most effective way to manage *Septoria tritici* blotch.

Variety selection

The majority of commercially grown varieties now have partial resistance (i.e. they are moderately susceptible) to *Septoria tritici* blotch. This resistance has to date been durable, and sufficient to effectively control this disease in Victoria.

⁹⁹ Agriculture Victoria (2016) Triticale [download]. In Victorian winter crop summary. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/victorian-winter-crop-summary>

SECTION 9 TRITICALE

TABLE OF CONTENTS

FEEDBACK

MORE INFORMATION

[Victorian Cereal Disease Guide](#)

It is important to avoid very susceptible varieties as they will build up inoculum levels. This will cause yield loss in that variety, and in adjacent moderately susceptible crops.

Cultural practices

Following an outbreak of *Septoria tritici* blotch do not sow cereal into infected stubble and avoid early sowing as a high number of ascospores are released early in the season. If this is not possible, destroying stubble by grazing or cultivation will reduce the number of spores available to infect the new season's crop. Such practices will have more effect if undertaken on a district basis. This practice is not, however, practicable in light soil areas where stubble must be kept to prevent erosion.

Crop rotations

Crop rotations are important to ensure triticale is not sown into paddocks with high levels of stubble-borne inoculum. A one-year rotation out of cereals is generally effective to provide disease break. However, the fungus may survive for over 18 months on stubble during very dry seasons.

Fungicides

Some seed-applied fungicides can suppress early infection and should be used in areas where *Septoria tritici* blotch is known to occur.

Effective foliar fungicide sprays are available if necessary. However, it is important to correctly identify *Septoria tritici* blotch before spraying with a fungicide as nutritional disorders such as aluminium toxicity or zinc deficiency can be confused with *Septoria tritici* blotch.

In high-risk areas, the timing of fungicides will be important to achieve adequate disease control. In early sown susceptible varieties, a fungicide application at growth stage 31–32 may be required to suppress the disease and protect emerging leaves. Once the flag leaf has fully emerged, at GS39, another fungicide application may be required to protect the upper canopy.

Since STB is prone to developing resistance to fungicides, and resistance has been detected in Australia, it is important that fungicide strategies to reduce the likelihood of resistance developing are adopted.

Fungicide resistance

Increasing resistance of *Zymoseptoria tritici* to some triazole ([Group 3](#)) fungicides was detected in Victoria in 2013/2014. Two mutations of *Septoria tritici* blotch giving resistance to triazole fungicides were identified. These mutations reduce the effectiveness of fungicides, rather than making them completely ineffective. However, continued use of triazole fungicides will put further selection pressure on the pathogen, and potentially new mutations will be selected.

Fungicides with reduced effectiveness against *Septoria tritici* blotch include triadimefon, triadimenol, tebuconazole, propiconazole and epoxiconazole. Epoxiconazole is not registered for control of *Septoria tritici* blotch in Australia.

Dr Milgate found that resistance may not be causing reduced spray efficacy at present, but a strategy to prolong fungicide effectiveness will prolong the life of this fungicide group.

Managing fungicide resistance

There are a few methods that are thought to reduce the selection rate for further mutations.

The first method is to alternate different triazoles, as not all triazole fungicides are affected equally by mutations of the *Septoria tritici* blotch fungus. This means not using the same triazole fungicide more than once in a crop, if multiple sprays are required during the season.

The second is to use fungicides that combine triazoles, such as Tilt Xtra® (propiconazole and cyproconazole) or Impact Topguard® (tebuconazole and flutriafol), which are registered for use on *Septoria tritici* blotch.

The third is to use fungicides with different modes of action. However, in Australia there is a limited choice in this regard. Products that combine a strobilurin (Group 11) fungicide with a triazole fungicide may reduce the risk of resistance development.

Strobilurins on their own are considered to be at high risk of developing resistance due to their single site mode of action. In the United Kingdom, resistance to strobilurins is so widespread in *Septoria tritici* blotch populations they are no longer effective, even in mixtures. Resistance of *Septoria tritici* blotch to strobilurins has been recently detected in New Zealand, too. While not yet registered in Australia, SDHI (Group 7) carboxamide fungicides mixed with triazole (Group 3) fungicides are being used in New Zealand and the United Kingdom to manage *Septoria tritici* blotch.

When using fungicides, it is important that growers always follow label guidelines and ensure maximum residue limits are adhered to.

Biosecurity

As resistant mutations of the *Septoria tritici* blotch fungus have been identified in other countries, including New Zealand, the United Kingdom and mainland Europe, it is important to take great care that these are not accidentally introduced into Australia after travelling overseas.

The risk of introducing exotic diseases or new mutations of a pathogen into Australia can be minimised by having a biosecurity hygiene plan, and implementing it following overseas travel. Basic biosecurity hygiene includes washing clothes and cleaning footwear before returning to Australia. If high-risk areas have been visited, consider leaving clothing and footwear behind. Remind family members, employees or others travelling to also take these precautions.¹⁰⁰

IN FOCUS

Septoria fungicide update—2017

Genetic mutations in the *Septoria tritici* blotch (STB) pathogen *Zymoseptoria tritici* can differentially influence the performance of triazole fungicides in the laboratory.

There should continue to be a focus on integrated disease management (IDM) to control STB, using rotation, cultivar resistance, later sowing, and other aspects of cultural control to complement fungicide control.

New research on foliar fungicides indicates that the principal fungicides still give good in-field control of STB up to 30 days after application when applied at full label rates.

There are significant differences in disease control amongst the different fungicide products and rates of application when monitored leaves are assessed more than 30 days after application.

In this study, single spray timings of foliar fungicide for control of STB made during the late tillering phase gave less effective disease control than applications made at first node (GS31). Spray application delayed until flag leaf gave the poorest control of STB but gave superior leaf rust control later in the season.

There was evidence of significantly better curative control of STB on the lowest leaf (flag -3) from Opus 125® (epoxiconazole) and Prosaro® 420 SC (tebuconazole and prothioconazole), though it should be emphasised that

¹⁰⁰ G Hollaway (2014) *Septoria tritici* blotch of wheat. Note AG1336. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/septoria-tritici-blotch-of-wheat>

 **MORE INFORMATION**

[Septoria fungicide update and latest developments in rust management](#)

though these products are approved for use in wheat, there is currently no label recommendation for STB control.

STB is a stubble borne disease with the majority of the spore release from the stubble taking place in the autumn and winter under wet humid conditions. This initial spore release from the stubble is airborne and gives rise to the characteristic STB symptoms on the lower leaves of the crop later in the winter/spring. Further infection from these blotch lesions takes place under wet conditions with secondary spores spread up the plant by rain splash or the rubbing of wet leaves in the wind. These secondary spores are unable to travel long distances which means that the infection base in spring is likely to be the source of further infection. This raises the question as to when foliar fungicides should be sprayed in the spring to secure the best disease control and greatest economic response. To help answer that question, single applications of fungicide were applied at late tillering GS25 (17th August), pseudo stem erect GS30 (1 Sept), first node GS31 (16 September) and flag leaf emergence GS39 (13 October). Spraying early should control the disease at an early stage of the epidemic, although the leaves protected will be less important to grain fill. Spraying later allows greater early infection on the lower leaves, but applies fungicide to the first of the physiologically more important leaves for grain fill (flag-2 and flag-1).

Results revealed that sprays applied at GS31 gave the optimum control of STB on the top four leaves when assessed at the ear emergence stage. This disease control was principally evident on flag-2 and flag-3. These two leaves emerged in the early September window.¹⁰¹

9.13 Cereal fungicides

All of the diseases addressed so far are caused by different fungi. Fungal disease is a major disease threat to all Australian crops, and keeping paddocks (and farms) healthy and disease loads low requires thoughtful management.

- Fungicides are only one component of a good management strategy.
- Correct identification of the cause of plant symptoms is essential, and an understanding of the growth and spread of any pathogen will assist in any decision making.
- Cultivar resistance is the best protection against fungal diseases. Ideally, when suitable varieties are available, opt for moderately resistant (MR) to resistant (R) varieties in disease-prone environments.
- Understand the role of the season and have a plan in place, and if growing susceptible varieties have the right chemicals on hand.
- For cereal rusts and mildew, remove the green bridge between crops to prevent rusts from over-seasoning.
- Monitor crops throughout the season.
- Spray if disease threatens key plant parts (flag to flag-2) of varieties that are moderately susceptible (MS) or susceptible (S).
- Fungicides do not increase yield; they protect yield potential and cannot retrieve lost yield if applied after infection is established.

¹⁰¹ N Poole, T Wylie (2017) GRDC Update Papers: Septoria fungicide update and latest developments in rust management. <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2017/02/Septoria-fungicide-update-and-latest-developments-in-rust-management>

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GRDC factsheet, [Cereal fungicides](#)

- Fungicide resistance is a major emerging issue. Do not use tebuconazole-based products on triticale if there is any chance of powdery mildew occurring, and select varieties that are resistant to powdery mildew.¹⁰²

9.13.1 Fungicide stewardship

There have been a number of pathogens, including *Septoria tritici* blotch, which have recently developed a level of fungicide insensitivity or resistance in Australia. The occurrence of these highlights the important role all growers play in fungicide resistance.

To help achieve fungicide-resistance management and disease management, there are three important steps growers need to implement.

1. Remove the source of infection:
 - For many pathogens, stubble is the source of the infection each year. By removing stubble before sowing, there is a substantial reduction of pathogen population size.
 - This reduces all forms of the pathogen irrespective of resistance, and reduces the initial establishment of disease.
 - To avoid rapid disease build up, do not sow cereal on cereal.
2. Choose more resistant varieties:
 - Under high disease pressure, a variety rated MR–MS can reduce the leaf area loss substantially. Where possible, choose a more resistant variety.
 - Host resistance reduces all forms of the pathogen irrespective of resistance, and reduces the need for multiple canopy fungicide applications.
 - But resistance ratings do change, so crops must still be monitored in season for higher than expected reactions and check each year for updates to disease ratings.
3. Follow best practice when choosing and using fungicides:
 - Do not use the same triazole active ingredient more than once in a season.
 - Aim for early control of necrotrophic diseases, such as Yellow Leaf Spot, in high-rainfall years. Reducing the disease in the lower canopy slows the upward movement of disease and ultimately the leaf area lost.
 - Follow label instructions at all times.

The timing of application in a disease epidemic is critical to getting the most out of fungicides.¹⁰³

9.14 Barley yellow dwarf virus

Key points:

- Barley yellow dwarf virus (BYDV) infects cereal crops such as triticale, wheat, barley, oats, rye and grasses.
- It is transmitted by aphids which can pass the disease onto plants within 15 minutes of feeding.
- The virus only survives in living tissues. It does not survive in stubbles or soils and is not airborne.
- It is most damaging in higher rainfall zones, including the northern Tablelands in NSW, where permanent grasses and pastures act as a reservoir for the virus and aphids over summer.
- The earlier the infection the more severe the damage. Leaves turn yellow from the tips and develop yellow stripes extending towards the base. Some reddening or purpling of the leaves may occur along the edges.

¹⁰² GRDC (2013) Managing cereal fungicide use, Northern Region. Factsheet. GRDC, <https://grdc.com.au/Resources/Factsheets/2013/05/Cereal-fungicides>

¹⁰³ A Milgate (2016) Cereal disease update and risks for southern NSW crops in 2016. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Cereal-disease-update-and-risks-for-southern-NSW-crops-in-2016>

- Growers should have a management plan which includes selecting resistant varieties, continual crop monitoring, managing the green bridge, presowing seed dressing and spraying foliar insecticides if required (noting correct label usage).

The yellow dwarf diseases of cereals have now been divided into two groups: Barley yellow dwarf virus (BYDV) and Cereal yellow dwarf virus (CYDV). They are the most important virus diseases of cereals worldwide. They have a wide host range which includes triticale, wheat, barley, oats and over 150 non-commercial grass species.

The virus is usually spread by aphids from infected grasses to crops. Wet summers and autumns promote growth of host grasses and build up of aphid vectors, resulting in early crop infection, severe symptoms and yield losses. Yellow dwarf viruses (YDVs) tend to be more serious in the high-rainfall cropping regions in southern Australia, but can occur in all cropping regions.

All early BYDV infections of cereal plants will mean they have less above-ground biomass and a less extensive root system. Grain size can be smaller or it can become shriveled, which causes lower yields, higher screenings and reduced marketing options. Victorian Department of Primary Industries Field Crops Pathology Group (Horsham, 1984) research found yield losses of between 9% and 79% occurred when plants were infected early in the growing season (before the end of tillering) and losses of 69% may occur when plants are infected after tillering.

Growers in high rainfall zones should be proactive and develop a Barley Yellow Dwarf Virus (BYDV) management plan which includes crop monitoring, green bridge management, foliar pesticide sprays and pre-sowing seed treatment. These actions will control aphid populations which spread BYDV. The virus is best controlled by monitoring and spraying for aphids early in the season.¹⁰⁴

9.14.1 Symptoms

After infection, symptoms take at least three weeks to appear. They usually appear as patches of yellow or red stunted plants. The symptoms first appear where aphids have landed. Flying aphids may infect individuals or groups of plants dotted throughout the crop. If the aphids colonise the crop, rings or patches develop which increase in size with time (Photo 27).¹⁰⁵ If crawling aphids move into the crop from adjoining pastures or crops then symptoms will appear along the fence line first.

104 GRDC (2013) Barley yellow dwarf virus factsheet. <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2013/09/barley-yellow-dwarf-virus>

105 DAFWA (2015) Managing barley yellow dwarf virus and cereal yellow dwarf virus in cereals. DAFWA, https://www.agric.wa.gov.au/barley/managing-barley-yellow-dwarf-virus-and-cereal-yellow-dwarf-virus-cereals?page=0_1

SECTION 9 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 27: Patches where aphids have landed and transmitted the virus.

Source: DAFWA

The symptoms of the yellow dwarf virus (YDV) can be variable and can differ with host species, cultivar and time of infection. Sometimes, infection of cereals may occur without visible symptoms. Distinct symptoms usually occur on cereals although many infected grasses are symptomless.¹⁰⁶

Infected triticale plants develop a slight to severe yellowing or pale striping between veins (interveinal chlorosis) in young leaves (Photo 28). Leaf tips can also die (necrosis). Reddening of the leaf tips (particularly of the flag leaf) can often be seen and is the most characteristic symptom of virus infection in triticale. If a sensitive variety is infected before tillering, the plant is usually stunted, has fewer tillers and more sterile ones. Grain matures early, yield is greatly reduced and grain is shrivelled. Effects are milder with a late infection.¹⁰⁷



Photo 28: Barley yellow dwarf virus infection of a cereal plant.

Source: DAFWA

i MORE INFORMATION

[GRDC Foliar Diseases—Ute Guide](#)

¹⁰⁶ Agriculture Victoria (2011) Barley yellow dwarf virus. Note AG1113. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/barley-yellow-dwarf-virus>

¹⁰⁷ DAFWA (2015) Managing barley yellow dwarf virus and cereal yellow dwarf virus in cereals. DAFWA, <https://www.agric.wa.gov.au/barley/managing-barley-yellow-dwarf-virus-and-cereal-yellow-dwarf-virus-cereals>

9.14.2 Conditions favouring development

The prevalence of BYDV depends on environmental conditions, host-pathogen dynamics and aphid populations. The virus is generally worse in seasons with a wet summer (which allows for significant volunteer or green bridge growth) followed by a mild autumn and winter. However, the aphids are able to survive in hot summers in perennial grasses—such as perennial ryegrass, kikuyu, paspalum, couch and African love grass—in permanent or irrigated pasture areas and along waterways. Winged aphids are able to migrate around the southern grain growing region regardless of summer conditions. Growers should not be complacent in dry summers. BYDV can be caused by relatively few infected aphids if they arrive early in the growing season and are very mobile through the crop.¹⁰⁸

There are five species of aphids that transfer different types of BYDV, including oat aphid (*Rhopalosiphum padi*), the corn aphid (*R. maidis*), the English grain aphid (*Sitobian miscanthi*) and the rose-grain aphid (*Metopolophium dirhodum*). The viruses are not transmitted by any other insects and are not transmittable through seed, soil or sap. The aphids need to feed on an infected plant for at least 15 minutes, which is followed by a latent period of 12 hours, before the virus will transmit to a healthy plant. Aphids remain infected for the rest of their life.

See [Section 7: Insect control](#) for more information on aphids.

Outbreaks of YDV are likely to be worse in years when wet, cool summers allow larger than normal numbers of aphids and alternate hosts to survive summer, followed by a mild winter which favours the build-up of aphid numbers. Early sown crops or long season crops sown in high rainfall areas are particularly vulnerable to this disease.¹⁰⁹

9.14.3 Management

Key points:

- Control summer weeds (the green bridge) as weeds, volunteer cereals and annual grasses can act as hosts for aphids. Growers in irrigated areas and with forage crops should be aware that these can harbour aphids over the summer.
- Choose varieties which have appropriate ratings. Refer to your local cereal variety disease guide for information on variety ratings.
- Investigate sowing time. Crops sown later in low rainfall regions may avoid being colonised by the major autumn aphid flight. However, this needs to be carefully considered against the risk of frost. The crop may still be infected by aphids from another source.
- Trials results have led to the recommendation that sprays should be applied three and seven weeks after crop emergence. These applications will enable aphid populations to be managed before the problem has spread.
- Communicate with your neighbour if BYDV is found. This will enable a faster response to management and help to decrease aphid outbreaks.
- Record all spray applications, use appropriate safety equipment and follow label rates and directions at all times.¹¹⁰

Resistant varieties, when available, are the preferred option for management. Where it is not possible to grow resistant varieties, BYDV can be reduced by controlling aphid activity in crops, especially early in the season to prevent the spread of the disease, and or delayed sowing to avoid the main aphid flights in the autumn. Later sowing will reduce the incidence of BYDV, but this needs to be weighed up against possible yield reduction from delayed sowing.

108 GRDC (2013) Barley yellow dwarf virus factsheet. <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2013/09/barley-yellow-dwarf-virus>

109 Agriculture Victoria (2011) Barley yellow dwarf virus. Note AG1113. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/barley-yellow-dwarf-virus>

110 GRDC (2013) Barley yellow dwarf virus factsheet. <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2013/09/barley-yellow-dwarf-virus>

It is vital to prevent spread of the virus by aphids during the first 8–10 weeks after crop emergence by using insecticides. In situations where aphids are likely to be a problem in the first few weeks after sowing, a seed treatment containing imidacloprid could be used for protection.¹¹¹

For grain growers who decide to manage aphids, it is critical to plan the control strategy and have it in place before sowing starts. Do not wait until aphids are found because infection or damage will have already occurred. Growers in high risk areas should treat each year as a 'BYDV year' unless there has been low rainfall over summer and autumn. Waiting until aphids or BYDV symptoms are found is too late.

Seed dressings

Seed dressings with imidacloprid have been shown to reduce aphids in cereal crops at the early stage of growth when cereals are most susceptible to BYDV. Do not graze treated cereal crops within nine weeks of sowing. In high risk areas, a top-up spray (see insecticides section) is recommended at six to eight weeks after sowing.

Insecticides

Growers must work to prevent the spread of BYDV early after crop emergence because this is when plants are most vulnerable. In high risk areas, such as the long season areas which have received high summer rainfall, growers can apply insecticides before aphids and/or BYDV symptoms are evident. This is considered a risk-based application. The insecticides will help kill and repel the aphids, leading to increased yields, particularly when plants are young and small. Growers can utilise a range of approved insecticides to manage the aphids. As well as pyrethroids, there are spray options which can have less impact on non-target insects. These may suit farmers trying to incorporate integrated pest management into their system. Advice prior to spraying is essential.

Trial results have led to the recommendation that sprays are applied three and seven weeks after crop emergence. This is because BYDV symptoms are usually not obvious until three weeks after the aphids have fed on plants. These applications will enable aphid populations to be managed before the problem has been noticed and the aphids have spread even further. Considerable BYDV spread can occur even when aphid numbers are low. Symptoms can be hard to see in winter. Consultation with an agronomist or crop pathologist is recommended. In years conducive to aphid build-up, a follow-up insecticide application in spring, with both the early foliar or seed treatment strategies, may be required to limit feeding damage. The effect of late BYDV infection by itself is generally not sufficient to warrant spraying in spring so the decision should be purely based on aphid pressure.¹¹²

Foliar sprays can be used soon after crop emergence if aphids are easily found. There are a number of products registered for control of aphids in cereals. The active ingredient pirimicarb only effects aphids, and will have less effect on any beneficial insects present at the time of spraying. Synthetic pyrethroids are also registered for use on aphids in cereals, but will have a detrimental effect on many beneficial insects. Consult a local agronomist to determine the most suitable treatment.¹¹³

Delayed sowing

Delayed sowing avoids the main autumn peak of aphid flights and can reduce the incidence of BYDV. However, other yield penalties associated with late sowing make this option generally considered a poor choice over using insecticides. Growers in the late sown high rainfall areas should note that late sowing may coincide with peak spring flights of aphids resulting in more severe damage.

111 DAFWA (2015) Managing Barley yellow dwarf virus and cereal yellow dwarf virus in cereals. DAFWA, <https://www.agric.wa.gov.au/barley/managing-barley-yellow-dwarf-virus-and-cereal-yellow-dwarf-virus-cereals>

112 GRDC (2013) Barley yellow dwarf virus factsheet. <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2013/09/barley-yellow-dwarf-virus>

113 Agriculture Victoria (2011) Barley yellow dwarf virus. Note AG1113. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/barley-yellow-dwarf-virus>

SECTION 9 TRITICALE

TABLE OF CONTENTS

FEEDBACK

 **MORE INFORMATION**[Barley yellow dwarf virus Fact Sheet](#)[Crop diseases after drought](#)

Control during the green bridge

Management of the green bridge (volunteer cereals and grass weeds) through appropriate herbicides is important for managing BYDV, not to mention the associated benefits of moisture/nutrient conservation. On top of summer weed control, spraying out perennial grasses near and around cereal paddocks at least three weeks before sowing may reduce aphid numbers.¹¹⁴

9.15 Disease following extreme weather

9.15.1 Cereal disease after drought

Drought reduces the breakdown of plant residues. This means that inoculum of some diseases does not decrease as quickly as expected, and will carry over for more than one growing season, such as with crown rot. The expected benefits of crop rotation may not occur or may be limited. Inversely, bacterial numbers decline in dry soil. Some bacteria are important antagonists of soil-borne fungal diseases such as common root rot. These diseases can be more severe after drought.

During a drought year, inoculum of some diseases favoured by a wet season may not increase as expected.

Large amounts of seed produced in abandoned crops, or seed pinched as a result of drought stress, will fall to the ground. If there are summer rains, large numbers of volunteers will provide a summer green bridge and autumn green ramp. Low stock numbers make it difficult to control volunteers, which provide a green bridge for rusts, viruses and virus vectors, and many other pathogens.

Weeds that harbour diseases are harder to kill.

Soil water and nitrogen may be unbalanced and these are likely to impact on diseases.¹¹⁵

9.15.2 Cereal disease after flood

For disease to occur, the pathogen must have virulence to the particular variety, inoculum must be available and easily transported, and there must be favourable conditions for infection and disease development.

The legacy of the floods and above average rain include the transport of inoculum (e.g. of crown rot, nematodes, leaf spots through movement of infected stubble and soil) (Photo 29), development of sexual stages (e.g. in leaf spots, head blights), survival of volunteers (unharvested material and self-sown plants in double-crop situations), and weather-damaged seed.¹¹⁶

114 GRDC (2013) Barley yellow dwarf virus factsheet. <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2013/09/barley-yellow-dwarf-virus>

115 G Murray, T Hind-Lanoiselet, K Moore, S Simpfendorfer, J Edwards (2006) Crop diseases after drought. Primefacts. No. 408. NSW DPI,

116 DAF Qld (2013) Winter cereals pathology. DAF Queensland,

SECTION 9 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 29: *Yellow leaf spot-infected stubble following flood.*

Photo: Rachel Bowman, Seedbed Media

Plant growth regulators and canopy management

Key messages

- In Australian cereal production, plant growth regulators (PGRs) are mostly used with the intention of producing a smaller plant that is resistant to lodging, or with the intention of reducing excessive growth in irrigated broadacre crops. They are not registered for use in triticale.
- Canopy management includes a range of tools to help manage crop growth and development with the aim of maintaining canopy size and duration to optimise photosynthetic capacity and grain production.
- Canopy management starts at seeding: sowing date, variety, plant population and row spacing are fundamental. There is more to it than delaying the application of nitrogen (N).
- So far, the best results for canopy management have been seen in early sown, long-season varieties with high yield potential and that are very responsive to N with high N-fertiliser inputs.

MORE INFORMATION

[Plant growth regulators](#)

[Plant growth regulators in broadacre crops](#)

[PGRs and their agronomic and economic benefits to high yield potential cereal, pulse and oilseed crops](#)

10.1 Plant Growth Regulators

A plant growth regulator (PGR) is an organic compound, either natural or synthetic, that modifies or controls one or more physiological processes within a plant. They include many agricultural and horticultural chemicals that influence plant growth and development. PGRs are intended to accelerate or retard the rate of growth or maturation, or otherwise alter the behaviour of plants or their produce.¹ This influence can be positive, e.g. larger fruit or more pasture growth, or negative, e.g. shorter stems or smaller plant canopies.

There are no Plant Growth Regulators registered for use on triticale in Australia.

In Australia, there have been mixed results in the ability of PGRs to promote increased yield and profits.

10.2 Canopy management

Key points:

- Correct identification of the key growth stages for input is essential, particularly during early stem elongation when the most important leaves of the crop canopy emerge.
- Knowledge of the status of soil moisture and soil nitrogen reserves and supply need to be taken into account in order to match canopy size to the environment.
- Crop models can help integrate crop development, environmental conditions and nutrient status in order to make better canopy-management decisions.²

10.2.1 What is canopy management?

The concept of canopy management was developed primarily in Europe and New Zealand, where production environments are different, but not dissimilar to the higher rainfall areas of southern NSW, Victoria and Tasmania.

Canopy management involves the use of several tools to manage crop growth and development, with the aim of maintaining canopy size and duration so as to optimise

¹ P Lemaux (1999) Plant growth regulators and biotechnology. Presentation. Western Plant Growth Regulator Society, <http://ucbiotech.org/resources/biotech/talks/misc/regulat.html>

² GRDC (2009) Canopy management. Factsheet. GRDC, https://grdc.com.au/_data/assets/pdf_file/0014/202523/canopy-management.pdf

SECTION 10 TRITICALE

TABLE OF CONTENTS

FEEDBACK

photosynthesis that translates into greater grain production (Photo 1).³ One of the main tools is the rate and timing of the application of fertiliser N. The main difference between canopy management and previous N topdressing research is that, in canopy management, all or part of the N inputs are tactically delayed until later in the growing season. This tends to reduce early canopy size, but the canopy is maintained for longer, as measured by green leaf retention, during grainfilling.⁴



Photo 1: An example of the benefits of controlling canopy cover. The crop with the thinner crop canopy (left) yielded 6.18 t/ha and 12% protein, and crop with the thicker canopy (right) yielded 6.20 t/ha and 10.6% protein. Experiment conducted with Kellalac wheat sown 11 June, Gnarwarre in Victoria's high-rainfall zone. The crops received the same amount of nitrogen, but the timing of application differed.

Source: GRDC

Adopting canopy management principles to avoid excessively vegetative crops may enable growers to ensure a better match of canopy size and yield potential, as defined by the water available.

Canopy management is not only about a delayed N strategy, but starts at seeding by determining the correct plant establishment for the chosen seeding date and row spacing. This must also take into account available soil moisture and nutrients (Figure 1).⁵

Other than sowing date, plant population is the first point at which the grower can influence the size and duration of the crop canopy. One of the main tools for growers to use is the rate and timing of application of fertiliser N.

If the canopy becomes too big, it competes with the growing heads for resources, especially during the critical 30-day period before flowering. This is when the main yield component (grain number per unit area) is set. Increased competition from the canopy with the head may reduce yield by reducing the number of grains that survive for grainfill.

After flowering, temperature and evaporative demand increase rapidly. If there is not enough soil moisture, the canopy dies faster than the grain develops, and results in small grain. Excessive N application and high seeding rates are the main causes of excessive vegetative production. Unfortunately, optimum N and seeding rates are season-dependent. In droughts, N application and seeding rates that would be regarded as inadequate in normal conditions may maximise yield, whereas higher input rates may result in progressively lower yields. In years of above-average rainfall, yield may be compromised by using normal input rates. At the extreme, excessive early growth results in haying-off. In this situation, a large amount of

3 N Poole (2005) Cereal growth stages. GRDC, <https://www.researchgate.net/file/PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798>

4 G McMullen (2009) Canopy management in the northern grains region: the research view. NSW DPI, <http://www.nqa.org.au/results-and-publications/download/31/australian-grain-articles/general-1/canopy-management-tactical-nitrogen-in-winter-cereals-july-2009-pdf>

5 GRDC (2009) Canopy management. Factsheet. GRDC, https://grdc.com.au/_data/assets/pdf_file/0014/202523/canopy-management.pdf

SECTION 10 TRITICALE

TABLE OF CONTENTS

FEEDBACK

biomass is produced using a lot of water and many other resources, and later in the season there is insufficient moisture to keep the canopy photosynthesising and not enough stored water-soluble carbohydrates to fill the grain. Therefore, grain size and yield decrease.

To attain maximum yield, it is important to achieve a balance between biomass and available resources. The main factors that growers can manage are:

- plant population
- row spacing
- inputs of N
- sowing date
- weed, pest and disease control
- plant growth regulation with grazing

Of these, the most important to canopy management are N, row spacing and plant population.⁶

Applying N or fungicide at stem elongation increases the opportunity to match input costs to the potential yield for that season. While seeding applications may still be required for healthy establishment, crop models help support decisions on application timing. Models such as APSIM and Yield Prophet® simulate growth stage and season.

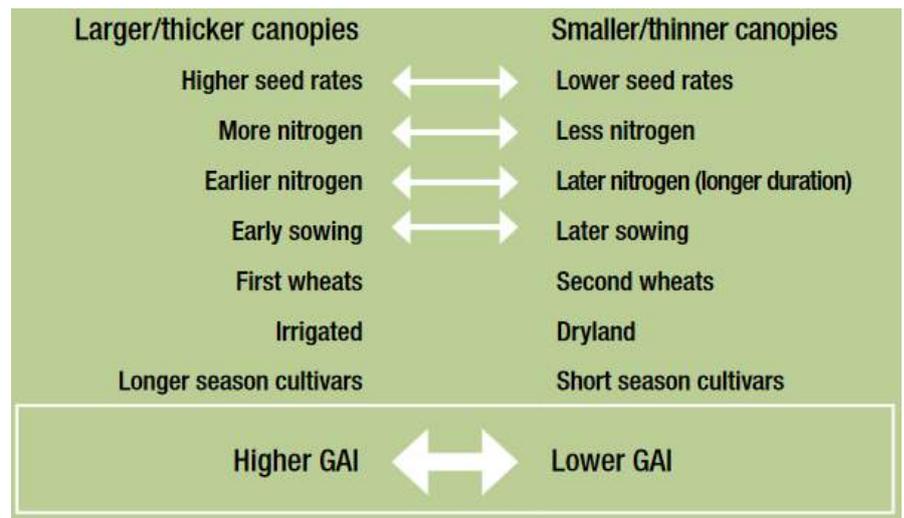


Figure 1: Factors under the grower's control that influence canopy density, size and duration. GAI = green area index (amount of green surface area).

Source: GRDC

The timing and rate of N application should also be considered in conjunction with the inter-related factors of:

- soil moisture
- soil nitrogen reserves
- seeding date
- seed rate and variety

To practice canopy management, it is important to understand the principal interactions between the growth stages of plants, available water and nutrients, and disease pressure. They are complex, but tools from simple visual indicators through to crop models can assist.

i MORE INFORMATION

[Zadoks growth scale](#)

⁶ N Fettell, P Bowden, T McNee, N Border (2010) Barley growth and development. NSW Department of Industry and Investment, http://www.dpi.nsw.gov.au/data/assets/pdf_file/0003/516180/Proccrop-barley-growth-and-development.pdf

SECTION 10 TRITICALE

TABLE OF CONTENTS

FEEDBACK

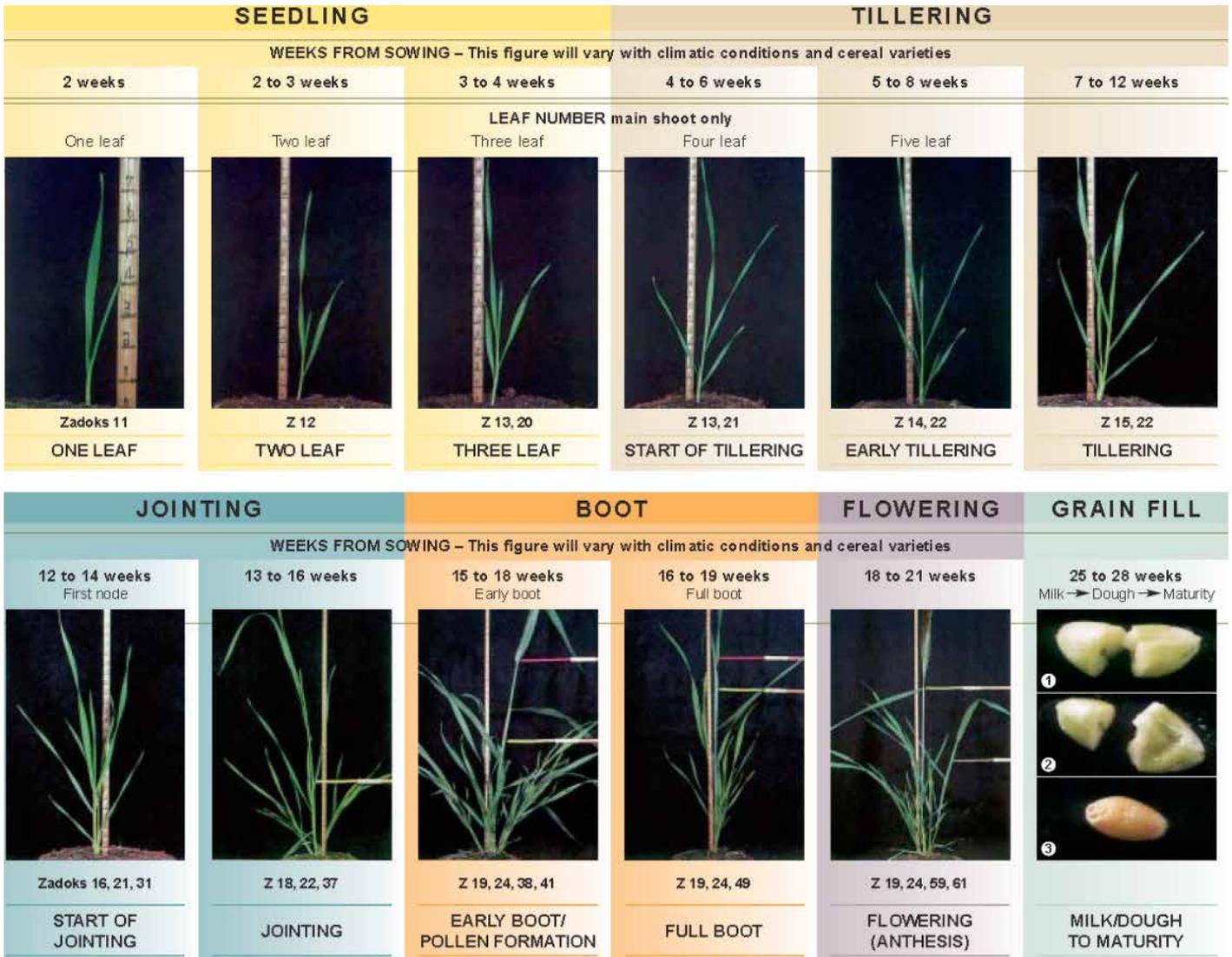


Figure 2: Zadoks growth scale for cereal growth stages.

Source: NVTOnline.

IN FOCUS

Canopy management in the Liverpool Plains

From 2006 to 2009 trials were conducted by a collaborative group of NSW DPI, Northern Grower Alliance, AgVance Farming, and Nick Poole from the Foundation for Arable Research in New Zealand. Their work was funded by GRDC. They focused on the interaction on delayed N applications in high-yielding wheat crops on the Liverpool Plains, (note that results for wheat may be similar to those expected in triticale).

To test if canopy management principles did improve crop performance in Northern Region cereal crops, the researchers established trials using overhead irrigation systems to supplement the water supply at the critical growth stages when urea was applied to the soil surface. N was applied in different combinations at three growth stages during each season: to the seedbed (SB), during early stem elongation (GS 31), or after flag-leaf

SECTION 10 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

emergence (GS 39). Details of the research sites and treatments are in Tables 1 and 2.

Table 1: Nitrogen timings.

Treatment	At sowing (SB)	Stem elongation (GS 31)	Flag-leaf emergence (GS 39)
No N	–	–	–
Single application	100% N	– 100% N	– 100% N
Split applications	50% N–50% N	50% N 50% N	– 50% N 50% N

Source: McMullen 2009

Table 2: Overview of canopy management trials.

Year	2006	2007	2008
Location	Caroona	Caroona	Spring Ridge
Sowing date	27 June	14 of July	29 May, 3 July
Variety	Ventura	Ventura	EGA Gregory and Ventura
Starting Nitrate-N (0–90 cm)	25 kg N/ha	74 kg N/ha	78 kg N/ha
Previous crop	2005, sorghum	2006, sorghum	2007, sorghum
Total N applied	110 kg N/ha	140 kg N/ha	160 kg N/ha
In-crop rainfall	234 mm (123 mm irrigation)	285 mm (150 mm irrigation)	450 mm (including irrigation)

Source: McMullen 2009

Results

In 2006 and 2007, the response to tactically delaying N until later in the growing season was relatively consistent for main to late-sown, short-season crops (cv. Ventura). In both years, delaying or splitting fertiliser N did not result in significant increases in grain yields compared to applying N to the seedbed. Grain yield was maintained when N was split between SB and GS 31. Delaying all N until after GS 31, or splitting application between GS 31 and GS 39 resulted in lower grain yields but higher grain proteins.

In 2008, the responses when all N was delayed were much the same as in 2006 and 2007, with no advantage in delaying N. However, there was a 12% increase in grain yield when the application of N was split between SB and GS 31. Over the three years, with late June or July sowings there was an average 0.3 t/ha benefit to splitting N between SB and GS 31 over the standard SB treatment (yield neutral in 2006, plus 0.2 t/ha in 2007 and plus 0.7 t/ha in 2008).

The results from the main sowing time in 2008 were encouraging, but one of the key questions after 2006 and 2007 was what the response in early sown, long-season crops would be. In 2008, EGA Gregory was sown on the 29 May to assess these responses. The researchers were surprised by the magnitude of the response. As in previous years, the site was strongly responsive to N; in fact, canopy size as measured by crop dry matter showed a threefold reduction by delaying N until GS 31 (Figure 3). When treatments were delayed to flag-leaf emergence and flowering, the canopies were still significantly smaller than when N was applied to the seedbed. However, by crop maturity all delayed N treatments, except when

SECTION 10 TRITICALE

TABLE OF CONTENTS

FEEDBACK

all N was applied after GS 39, had reached higher peak dry-matter levels compared to the SB-applied N treatment.

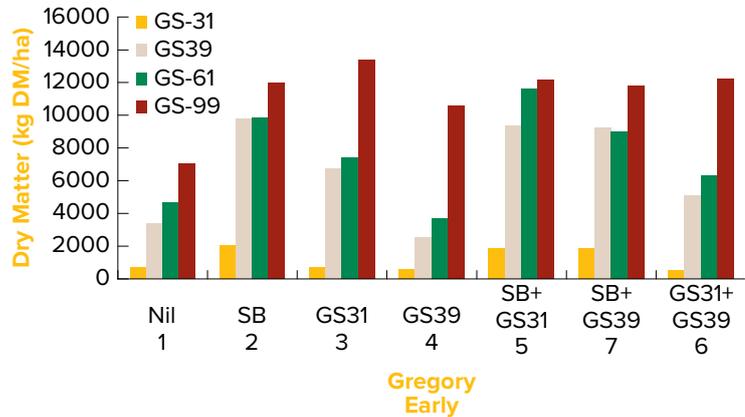


Figure 3: Effect of delayed N on crop dry matter (kg dry matter/ha) of early sown wheat, cv. EGA Gregory, in 2008.

Source: McMullen 2009

The large differences in canopy size translated into very strong grain yield and protein responses (Figure 4). For the longer-season EGA Gregory, all delayed N treatments resulted in significantly higher grain yields compared to the SB- applied N.

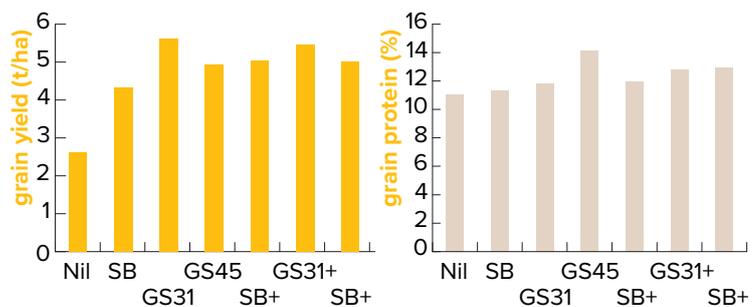


Figure 4: Effect of delayed N on grain yield and protein of early sown wheat, cv. EGA Gregory, in a trial in 2008.

Source: McMullen 2009

The highest yield was attained when all N was delayed until GS 31, which gave more than 1 t/ha extra yield, a result that appeared to be linked to the crop canopy staying greener for longer during grainfill. This increase in yield was accompanied by increased grain proteins for all delayed treatments, the greatest of which was when all N was applied after flag-leaf emergence at booting (GS 45).⁷

⁷ G McMullen (2009) Canopy management in the Northern grains region: the research view. NSW DPI, <http://www.nqa.org.au/results-and-publications/download/31/australian-grain-articles/general-1/canopy-management-tactical-nitrogen-in-winter-cereals-july-2009-.pdf>

10.2.2 Canopy management in a nutshell

1. Adjust canopy management based on paddock nutrition, history, and seeding time to achieve target head density.
2. Lower end of range (80–100 plants/m²)—suitable for earlier sowings or high fertility and/or low yield potential, low-rainfall environments.
3. Higher end of the range (150–200 plants/m²)—suitable for later sowings, lower fertility and/or higher-rainfall regions.
4. During stem elongation (GS 30–39), provide the crop with necessary nutrition (particularly N at GS 30–33, pseudo-stem erect—third node), matched to water supply and fungicides to:
 5. maximise potential grain size and grain number per head;
 6. maximise transpiration efficiency;
 7. ensure complete radiation interception from when the flag leaf has emerged (GS 39); and
 8. keep the canopy green for as long as possible following anthesis.

The timing of the applied N during the GS 30–33 window can be adjusted to take account of the target head number; earlier applications in the window (GS 30) and can be employed where tiller numbers and soil nitrogen seem deficient for the desired head number. Where tiller numbers are high and crops are still regarded as too thick, N can be delayed further, until the second or third node (GS 32–33), which will result in fewer tillers surviving to produce a head.⁸

10.2.3 Setting up the canopy

Research has shown that extra tillers produced by more plants per unit area are more strongly correlated to yield than are extra shoots stimulated by increased nitrogen at seeding.

Boosting tiller numbers with seeding N results in greater tiller loss between stem elongation and grain fill. This occurs specifically in two situations: in low-rainfall, short-season environments; and when soil moisture is limited. In these situations moisture and nutrient resources are used before the stems lengthen to produce biomass that fails to contribute to grain yield. Indeed, diverting these resources to unsuccessful tillers limits the potential of surviving tillers.

Therefore, identifying the correct population for a particular sowing date, soil-nitrogen reserve and region is the basis for setting up the crop canopy.

10.2.4 Status of soil moisture

Under Australian conditions, soil moisture is the biggest driver of the size and duration of the crop canopy of cereals. Therefore, an understanding of how much water a soil can hold, and how much water a soil is holding at seeding and stem elongation, are central to canopy management. Knowing the soil Plant Available Water Capacity (PAWC) is also important.

The start of stem elongation (GS 30) is the pivotal point for deciding on inputs, as from this point canopy expansion is rapid, and nitrogen and water reserves in the soil can be quickly used up.

If soil moisture is limited at the start of stem elongation, the ability to manipulate the crop canopy with nitrogen is limited. In many cases the best canopy management is not to apply inputs such as nitrogen and fungicides.

Modelling demonstrates that by setting up a smaller crop canopy, growers can reserve limited supplies of moisture stored in the for use at grainfill, rather than have it depleted by excessive early growth. However, in higher-rainfall regions and in a good season, setting up a small canopy may result in yield falling below potential.

⁸ N Poole, J Hunt (2014) Advancing the management of crop canopies. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/publications/2014/01/qc105-canopymanagement>

Calculating potential yield and then plotting actual rainfall against decile readings for the region is a way of getting a broad picture of whether there will be sufficient soil moisture to consider additional nitrogen at stem elongation.

The decision-support tool *Yield Prophet*[®] (developed in Australia) and the Sirius Wheat Calculator (developed in New Zealand) offer simple tools to record and assess multiple options that cover the relationship between growing plants and the environment, including available water and nutrients.

10.2.5 Soil nitrogen

It is important to have an understanding of soil-N reserves to the depth of the root-zone. Higher soil-nitrogen reserves provide much more flexibility in managing the canopy with nitrogen applied tactically during stem elongation.

It is difficult to use visual appearance unless you have a benchmark; this has led to the concept of the N-rich strip (Photo 2).⁹ A useful guide that requires no sophisticated equipment is to apply an excess of nitrogen at sowing, for example 50–100 kg N/ha, to 2 m × 10 m area of the paddock, and use that as a benchmark.¹⁰



Photo 2: An N-rich strip gives a large difference in visual appearance that can help the grower set a benchmark for N use: the enriched strip was given 110 kg N/ha at seeding. Here it is viewed at GS 31, when only low soil reserves of N (25 kg N/ha, 0–90 cm) remain. Left: 443 tillers/m² in N-rich soil. Right: 266 tillers/m².

Source: GRDC

During winter and spring, by comparing crop vigour (tiller number) and greenness in these small N-rich areas with the rest of the crop, an indication of N supply can be obtained. The advantage of using the plant rather than depending totally on a soil test is that the plant directly registers soil-N supply, whereas the soil test measures the soil-nitrogen reserve, which crop roots may not always be able to access.

This visual difference can be quantified by using crop sensors that measure the light reflectance from the crop canopy. By measuring reflectance at the red and near-infrared wavelengths, it is possible to quantify canopy greenness using a number of vegetative indices, the most common of which is termed the Normalised Difference Vegetative Index (NDVI). This index gives an indication of both biomass present and the greenness of that biomass. Canopy sensing can be done remotely from aircraft or satellites, or with a hand-held or vehicle-mounted sensor.

⁹ GRDC (2009) Canopy management. Factsheet. GRDC, https://grdc.com.au/_data/assets/pdf_file/0014/202523/canopy-management.pdf.pdf

¹⁰ GRDC (2009) Canopy management. Factsheet. GRDC, https://grdc.com.au/_data/assets/pdf_file/0014/202523/canopy-management.pdf.pdf

10.2.6 Seeding rate and date

Achieving the correct plant population is fundamental if sufficient tillers are to be set. Seeding rates need to be adjusted for seed size and planting date; if this does not occur the first step in controlling the canopy is lost. How many plants are targeted depends on:

- region—as a general guide, drier regions sustain lower plant populations than wetter environments; and
- sowing date—earlier sowings require lower plant populations compared to later sowings, as the tillering window is longer and more tillers are produced per plant.

Overall, earlier planting provides greater opportunities to manipulate the crop canopy during the stem elongation period: the plant’s development periods are extended along with the earlier tillering period.

10.2.7 Row spacing

Key points:

- Increased interest in no-till farming has created a trend for wider spacing of crop rows (Figure 5).¹¹
- In general, increasing row spacing up to 50 cm has minimal effect on cereal yield when yield potential is less than 2 t/ha.
- In higher-rainfall areas, where cereal crops have higher potential yields, significant yield decreases have been recorded with row spacing greater than 25 cm.
- The yields of broadleaf crops vary in their response to wider row spacing.
- Precision agriculture allows for easier inter-row sowing and fertiliser applications at wider row spacing.¹²

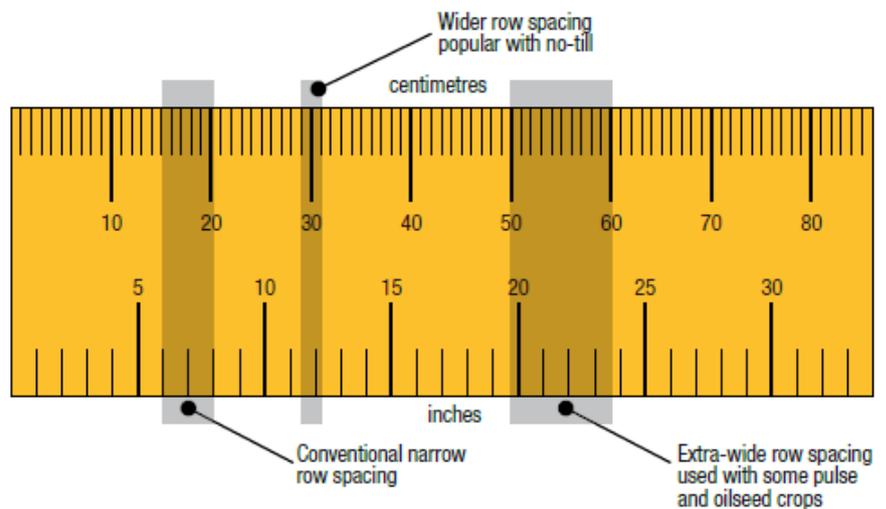


Figure 5: Common row spaces in metric and imperial measurements.

Source: GRDC

¹¹ GRDC (2011) Crop placement and row spacing, Southern. Factsheet. GRDC, <https://grdc.com.au/Resources/Factsheets/2011/02/Crop-Placement-and-Row-Spacing-Southern-Fact-Sheet>

¹² GRDC (2011) Crop placement and row spacing, Southern. Factsheet. GRDC, https://grdc.com.au/_data/assets/pdf_file/0015/210264/crop-placement-and-row-spacing-southern-fact-sheet.pdf.pdf

Yield

There are a number of reasons why growers might wish to pursue wider row spacing in cereals, e.g. residue flow, and disease control. However, in canopy-management trials conducted from 2007–2010 on wheat grown in a wide range of rainfall scenarios, increasing row width reduced yield.

- The yield reduction in wheat was particularly significant when rows were wider than 30 cm.
- Crop row spacing is an important factor for weed competition (Photo 3).¹³
- At row widths of 30 cm, the reduction in wheat yield compared to narrower 20–22.5 cm row spacing depended on overall yield potential:
- At yields of 2–3 t/ha yield reduction was negligible.
- At yields of 5 t/ha yield reduction was 5–7%, and averaged about 6%.
- Data from a single site suggested that wheat's position in the rotation may influence its yield response in wider row spacing. In wheat-on-wheat plantings, there was less yield reduction with wider rows than in an equivalent trial at the same site which was in wheat after canola.¹⁴



Photo 3: Narrow row spacing (left) and wide row spacing (right). The higher the yield potential, the greater the negative impact of wider rows on crop yields.

Source: WeedSmart

Plant spacing

- Increasing row width decreases the plant-to-plant spacing within the row, leading to more competition within the row and lower seedling establishment (for reasons that are not clearly understood).
- Increasing plant populations when using wider rows can be counterproductive with regard to yield, particularly where plant populations exceed 100 plants per square metre.
- Limited data indicates that increasing seeding rates so that the average plant-to-plant spacing in the row drops below 2.5 cm are either negative or neutral in terms of grain yield.
- Planting seed in a band (as opposed to a row) will increase plant-to-plant spacing, but may also increase weed germination and moisture loss because there is greater soil disturbance.¹⁵

Dry matter

- Rows of 30 cm and more reduced harvest dry matter relative to rows of 22.5 cm and under, with differences growing steadily (in kilograms per hectare) from crop emergence to harvest, by which time differences were in the order of 1–3 t/ha depending on row width and growing-season rainfall.

¹³ WeedSmart (2015) Narrow row spacing: is it worth going back? WeedSmart, <http://weedsmart.org.au/narrow-row-spacing/>

¹⁴ N Poole, J Hunt (2014) Advancing the management of crop canopies. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/publications/2014/01/qc105-canopymanagement>

¹⁵ N Poole, J Hunt (2014) Advancing the management of crop canopies. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/publications/2014/01/qc105-canopymanagement>

- The reduction in dry matter in wide rows was also significant at flowering (GS 60–69), frequently 1 t/ha reduction when row spacing increased 10 cm or more over a 20 cm base. This could be important when considering harvesting for hay rather than grain.¹⁶

Grain quality

- The most noticeable effect of row width on grain quality was on protein: wider rows reduced yield and increased grain protein, but the net nitrogen taken off the paddock is about the same.
- Differences in grain quality were typically small in terms of test weights and screenings, with very small benefits to wider rows over narrow rows on some occasions.¹⁷

Nitrogen management

The way nitrogen is managed has not been found to interact with row spacing, so optimum N regimes for narrow rows (22.5 cm or less) can be the same as for wider rows (30 cm or more). The greater nitrogen efficiency observed with N applied at stem elongation was more important with narrow row spacing, since higher yields lead to a tendency for lower protein.¹⁸

10.2.8 In-crop nitrogen

Delaying N inputs from seeding until stem elongation (GS 30–31) means they can be better matched to the season. So, in a dry spring, no application may be warranted. In spring, with adequate rainfall to justify N application, project trials have shown stem-elongation N to give yields equal to or better than wheat crops grown with seeding N, providing there is some level of N in the soil at sowing. However, applying N in advance of a rain front to ensure good incorporation has been found to be more important than applying it at an exact growth stage. While GS 31 should be the target growth stage for in-crop N application, the window can be expanded from GS 25 to GS 31 in order to take advantage of rainfall. Even applications delayed until flag leaf can be successful where starting soil nitrogen is not too low (Figure 6).¹⁹

Figure 6 presents the results from winter wheat-cropping trials across Australia on trials on the use of in-crop solid nitrogen at stem elongation. The trials showed that, where soil-nitrogen reserves are low, N applied at stem elongation is not always the most appropriate strategy if yield is to be optimised. Stem-elongation N applications were found to be less appropriate with shorter-season varieties and late-sown crops. Drought conditions during the trial period (2006 to 2008) limited the results from these trials. They assessed N use at stem elongation in cereals grown on wider row spacings (30–35 cm, compared to 17.5–20 cm. However, at the same seeding rate, moving to wider rows was found to reduce the number of tillers per unit area and final ear population and yield, the latter by approximately 6% in the high-rainfall zone (HRZ).²⁰

¹⁶ N Poole, J Hunt (2014) Advancing the management of crop canopies. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/publications/2014/01/qc105-canopymanagement>

¹⁷ N Poole, J Hunt (2014) Advancing the management of crop canopies. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/publications/2014/01/qc105-canopymanagement>

¹⁸ N Poole, J Hunt (2014) Advancing the management of crop canopies. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/publications/2014/01/qc105-canopymanagement>

¹⁹ GRDC (2009) Canopy management. Factsheet. GRDC, https://grdc.com.au/_data/assets/pdf_file/0014/202523/canopy-management.pdf.pdf

²⁰ GRDC (2009) Canopy management. Factsheet. GRDC, https://grdc.com.au/_data/assets/pdf_file/0014/202523/canopy-management.pdf.pdf

SECTION 10 TRITICALE

TABLE OF CONTENTS

FEEDBACK

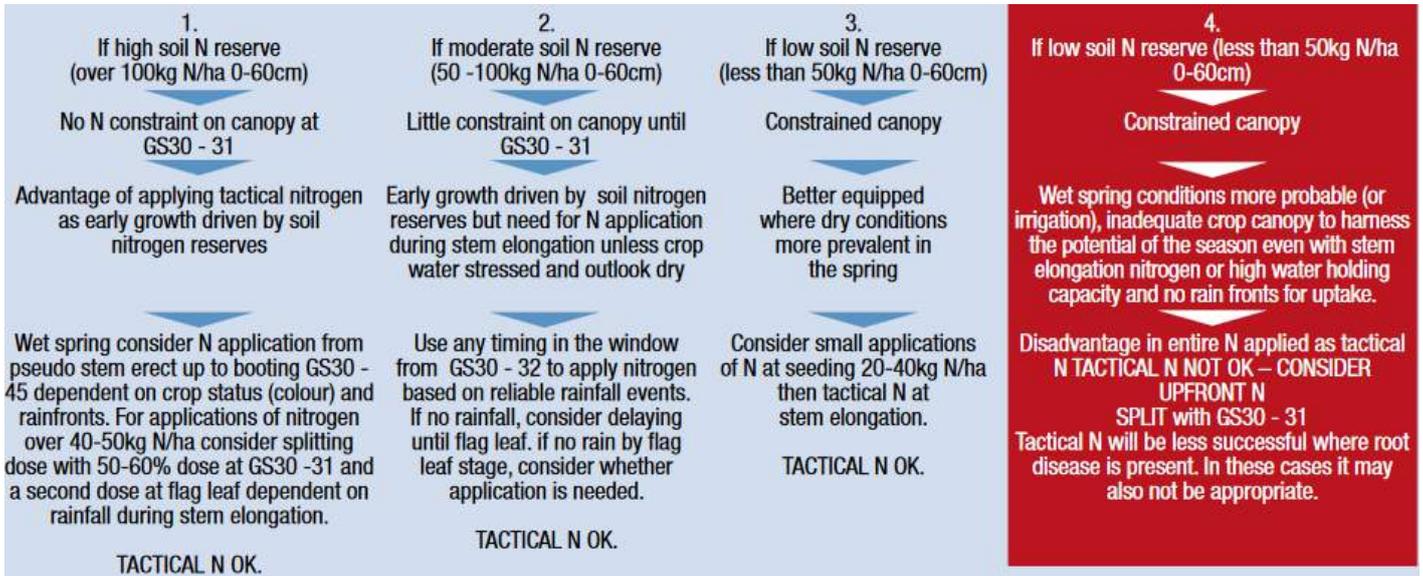


Figure 6: Broad scenarios for N application, based on soil-nitrogen levels.

Source: GRDC

i MORE INFORMATION

[Canopy management factsheet](#)

[Cereal growth stages](#)

[Advancing the management of crop canopies](#)

[Canopy management in the northern grains region: the research view](#)

Limitations of tactical nitrogen application

The main limitation to tactical N application is the ability to reliably apply N before a rain event, when it would be applied to enable roots to access soluble N in the root-zone. Predicted rain fronts may pass without yielding anything; therefore, dependably applying N throughout the season is risky.

Foliar N application is gaining popularity; however, this is only suitable for relatively low rates of N addition. Where higher N input is required, an efficient system to apply N into the wet soil profile; i.e. after rain, needs to be devised.

As technologies such as NDVI imaging and paddock management in zones become prevalent, the addition of N later in the crop cycle will also become more prevalent and will force the development of equipment to make the system work.

By combining knowledge gained from trials and from paddock experience, the aim of improving the economic outcome of the season by manipulating the most costly input is taking shape. Adoption of these techniques would be further aided by the development of efficient, in-soil N-application equipment.

Crop desiccation/spray out

Not applicable for this crop.

Harvest

Key messages

- Harvesting and storage management for triticale is generally similar to that for wheat. However, spring triticale for grain matures later than wheat, and is also more susceptible to sprouting at harvest than wheat.
- Preferred harvest moisture content to protect against damage due to heating caused by mould is 12.5%.
- For best returns, aim to harvest crops at 12% moisture or less, produce grain with a minimum test weight of 65 kg/hL and minimise other cereal grain contaminants.
- A drawback of triticale grown for grain is that it is prone to shattering.
- Harvester settings should be set similar to those for wheat, with care taken to slow the cylinder speed to minimise grain cracking and splitting.
- Some varieties are difficult to thresh cleanly, and may end up with intact head sections in the grain sample, or with cracked grain because of tight concave settings. Some varieties are prone to shedding in windy conditions.

12.1 Harvesting issues

Triticale grown for grain can be prone to shattering (Photo 1). There is a spot about a quarter to a third of the way down from the tip on the rachis (stem) that is very weak.¹



Photo 1: *Shattered cereal grain.*

Source: USDA Agricultural Research Service

¹ PNW-Ag (n.d.) Alternative crops: triticale in the US. Washington State University.

Triticale varieties vary strongly in how cleanly they can be threshed. Some varieties are difficult in this regard, and leave intact head sections in the harvested grain, or the grain cracks because of tight concave settings. Some varieties are prone to shedding in windy conditions.

The level of carried over (hard seed) self-sown plants that occurs after a triticale crop appears to be higher than with other winter cereals. No data exists on varietal differences in hard-seed levels, but especially where some seed shedding has occurred carryover will need careful management.²

12.1.1 Windrowing

Windrowing, or swathing, involves cutting the crop and placing it in rows held together by interlaced straws, and supported above the ground by the remaining stubble. Triticale is not often windrowed. The practice can be considered as an option where:

- The crop is uneven in maturity, or the climate does not allow for rapid drying of the grain naturally.
- There is a risk of crop losses from shedding and lodging.
- Windrowing is not a common practice in Australia.

If the crop is too thin or the stubble too short to support the windrow above the ground, it should not be windrowed. Heads on the ground may sprout, and attempts to pick up heads that are lying close to the soil surface will result in picking up soil and contaminating the grain.

Timing

If growers to choose to windrow triticale, windrowing can begin when grain moisture content (MC) is below 35% (this being the very upper level); i.e. when the grain is at the medium dough stage (hard, but can still be dented with the thumbnail).

I usually use the thumbnail denting and add 3- 5 days on the youngest tiller. My older tillers would be closer to hard dough stage, so 35% grain moisture is on the high end of the scale when deciding windrow timing.

Agronomist's view

Harvest settings should be set similar to those for wheat, with care taken to slow the cylinder speed to minimise grain cracking and splitting.³

When considering windrowing triticale, note that:

- It is better to windrow early to prevent losses from shedding and lodging, but not when the ground is wet after rain.
- Avoid windrowing too early as the grain is not fully developed and will result in small pinched grain.
- Although it may be easier to windrow later, the windrows of a ripe crop may not interlock well enough to withstand disturbance by strong winds.

Cutting

- Cut across the sowing direction or at 45° for crops planted on wider rows, so the windrow sits up on the stubble. Windrowing is not recommended for paddocks where the crop row spacing is wider than 25 cm.
- Avoid placing windrows in the same location each year, so nutrients do not become concentrated in one place.

² RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report.pdf

³ Alberta Agriculture and Forestry (2016) Triticale crop production. Alberta Agriculture and Forestry, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/fcd10571](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571)

- Windrow size or width of cut should match header capacity. A double-up attachment to the windrower, or placing two windrows side by side, requires a larger-capacity header and concentrates the residue in a narrow band in the paddock.
- Cutting height should be adjusted to keep sufficient straw on the head to hold the windrow together (minimum 30 cm) and sufficient stubble height to support the windrow.
- Start the windrow height at 10–20 cm above the ground (i.e. one-third crop height) and adjust to produce an even windrow with well-interlaced straws that sit above the ground, to allow good air circulation and rapid drying should rain occur.

Harvesting the windrow

Complete harvesting of the windrowed crop as soon as possible, ideally within 10 days of windrowing.

- If left too long and subjected to long periods of wetting (more than 25 mm of rain over four to eight days), grain may sprout and become stained.
- When the windrow is picked up, the reel should be rotating slightly faster than ground speed, but not fast enough to knock the heads off the stems.
- The conveyor canvas should be revolving at sufficient speed to prevent the crop material banking up.
- Rows pick up best when the header follows the direction of the windrow (i.e. heads first).

12.2 Harvest timing

Harvesting for triticale is generally similar to that for wheat (Photo 2). However, triticale for grain is late-maturing, and is also more susceptible to sprouting conditions at harvest than wheat.



Photo 2: *When conditions allow, direct heading of triticale is best.*

Source: Capital Press

Growers with access to grain dryers and aerated silos can harvest triticale at a higher MC (e.g. 13–14%) however, majority of growers in the Northern region often wait until triticale grain reaches 12.5% MC before harvesting. Moisture content lower than 12.5% is very desirable, as most moulds and insects tend to be inactive below this

moisture level. Deliveries to bulk handlers can be at 12.5%. Triticale is prone to weevil infestation during storage so ensure that these moisture content values are met.

For more information on storing triticale, see Section 13: Storage.

For the best returns, aim to harvest crops at 12% MC or less, produce grain with a minimum test weight of 65 kg/hL and minimise other cereal grain contaminants.

12.2.1 Lodging

Triticale is taller than wheat and has larger ears, both of which contribute to a higher risk of its lodging.⁴

Lodging is when the crop falls over. A normal, standing crop is finely balanced, so anything that upsets the balance can cause it to lodge: strong winds, heavy rain, a very wet soil during late grainfilling, tall thin stems that bend easily, root or stem rots that weaken the plant base. The worst combination is winds associated with excess water. Lodging can also occur in very fertile soils, in which case it is best to plan to harvest early.⁵

Lodging can destroy canopy structure. Solar radiation is no longer intercepted efficiently as it is in a standing crop, where greater amounts of light falling on the young, upper leaves and lesser amounts on the old leaves. Heads get covered in the tangle, and the collapsed crop becomes more susceptible to pests and diseases.

Lodging during early stem elongation has a relatively small effect on yield, as the crop is able to right itself and reform the canopy. The stem nodes alter their angle of extension, and make new growth vertical. However, from anthesis onwards the effects of lodging are large. For every day that the crop is lodged, yield declines by more than 1%. So in crops that lodged badly shortly after anthesis and remain fallen, the final yield will be less than half that of the upright part of the crop.

Any lodging also makes harvesting more difficult and increases the likelihood of losing grain during harvesting⁶ (Photo 3).⁷



Photo 3: Lodged cereal crop.

Source: Farming UK

4 D Kindred (n.d.) The triticale challenge. ADAS, http://www.elsoms.com/assets/downloads/ADAS_The_triticale_challenge.pdf

5 Albert Lea Seed (n.d.) Triticale. Albert Lea Seed, <http://www.alseed.com/UserFiles/Documents/Product%20Info%20Sheets-PDF/Basics%20Triticale-2010.pdf>

6 CIMMYT (n.d.) Wheat Doctor: Lodging. International Maize and Wheat Improvement Center, <http://wheatdoctor.org/lodging>

7 Farming UK (2015) Scene is set for cereal lodging risks. 12 February 2015. Farming UK, https://www.farminguk.com/News/Scene-is-set-for-cereal-lodging-risks_32861.html

Salvaging lodged crops generally requires a combination of equipment, as is or modified, and technique. Crop lifters, which can be attached to the sickle bar of most headers. Check with your machinery dealer to make sure any attachments will fit on your model of header. Innovative farmers have also developed their own modifications, with varied success; care must be taken not to damage the rest of the machine.

Lifting the lodged crop is preferable to having the header on the deck. Not only will you run less plant material through the combine, you are likely to leave more residues attached by the roots. Running less plant material through the combine can save fuel and wear on the header, allow faster harvesting,

Equipment choice and modifications alone will not maximise the harvest efficiency of lodged crops. Recommendations are to travel slowly, and to choose the optimum direction of travel. If wind was a significant factor in the lodging of crops, most of the plants are likely to be lying in one direction. This situation generally allows harvesting to occur in the two directions that are perpendicular to the direction in which the plants are leaning or lying. The best results may be obtained by harvesting in one direction, likely at an angle against the direction the plants are lying, and 'deadheading' back for the next pass. If the lodging is more random, as might occur with severe stalk weakness, the direction of travel may not matter. Once as much of the crop as possible has been harvested mechanically, producers may also consider grazing. Livestock may require supplementation to meet their nutrient requirements. It is recommended to remove livestock before excessive residue is removed and the land is at risk of wind or water erosion.⁸

The keys for preventing lodging are:

- Irrigation timing—do not irrigate when you expect wind. Avoid irrigating if high winds are forecast. The yield loss associated with extensive lodging is greater than for a day of water stress.
- Late irrigation—avoid over-wetting the soil late in grainfilling.
- Variety—change to a shorter variety if your area is prone to high winds or rainstorms during the later stages of growth.
- Nitrogen—reduce nitrogen applications, particularly very late applications, to unimproved, tall varieties. Split nitrogen applications between planting and first node.
- Plant density—reduce seeding density and/or planting depth to encourage early tillering and crown-root production. This can give plants a stronger base.
- Diseases—control crown and root diseases by appropriate agronomy and/or seed dressings.
- Potassium—use a potassium fertiliser.
- Raised beds—adopt the raised bed planting system. Irrigation in this system does not wet the soil around the base of the plant to the same extent as flat plantings.⁹

12.3 Harvesting triticale for silage

The cutting and storage of triticale forage for silage is similar to that of any small-cereal forage crop. The harvest date of triticale for silage is very important. As plants develop beyond the boot stage and into early grainfill, the protein and energy levels drop, while the fibre level increases rapidly. Although there is a general increase in dry-matter yield as the crop matures, the increased yield is more often offset by the reduction in forage quality. Consequently, the best time to cut triticale for silage is in the boot stage to early-heading stage.¹⁰

When timing the harvest, consider the following:

⁸ B Fanning (2013) Harvesting lodged crops. South Dakota State University, <https://igrow.org/agronomy/corn/harvesting-lodged-crops/>
⁹ CIMMYT (n.d.) Wheat Doctor: Lodging. International Maize and Wheat Improvement Center, <http://wheatdoctor.org/lodging>
¹⁰ M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

SECTION 12 TRITICALE

[TABLE OF CONTENTS](#)[FEEDBACK](#)

MORE INFORMATION

[When to cut forage cereals](#)

[Triticale for silage](#)

- End use of the silage, i.e. for animal production v. maintenance rations.
- Weather conditions at harvest.
- Soil type and soil moisture conditions at harvest.
- If spring sowing, when the follow-up pasture is to be sown.
- If double-cropping, when the follow-up crop needs to be sown.
- Availability of suitable harvesting machinery.
- Effect on dry-matter yield.

Cereals can be harvested at two stages:

- Flag leaf/boot—early ear emergence stages; and
- Soft-dough stage.

When using triticale for silage, the optimum time for harvest is recommended as being at the soft-dough stage, in order to get the best balance between quality and yield.¹¹

Triticale is particularly well-adapted for producing a high forage yield on highly fertile paddocks. Harvesting protocols and timing must be adjusted to accommodate the differences between triticale and barley in these situations. In high-productivity systems where lodging is a problem, triticale should be compared to semi-dwarf barley, which is also specially adapted to high-fertility conditions.

12.4 Considerations for harvest equipment

Harvester settings should be set similar to those for wheat, with care taken to slow the cylinder speed to minimize grain cracking and splitting (Photo 4).¹²

Seed size can be of concern when harvesting triticale. Compared to bread wheat, triticale varieties generally have a large seed and a large embryo with an elongated beak. Caution must be taken to ensure that any mechanical harvesters are appropriately set so that there is no damage to the embryo. Embryo damage and seed cracking can have a significant impact on seed viability during storage. This can be a problem since many triticale varieties are hard to thresh compared to wheat and rye.

In triticale varieties without the wheat rachis, threshing frequently results in incomplete seed and chaff removal from the spike, and breakage may occur at the rachis nodes. In the wheat-rachis types, breakage does not occur.¹³

Harvest triticale as you would wheat, although adjust harvester speed to slightly slower than for harvesting wheat.¹⁴

¹¹ Alberta Agriculture and Forestry (2016) Triticale for silage. Alberta Agriculture and Forestry, [www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/fcd10569](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10569)

¹² Alberta Agriculture and Forestry (2016) Triticale crop production. Alberta Agriculture and Forestry, [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/fcd10571](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571)

¹³ M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

¹⁴ UVM Extension Crops and Soils Team (2011) Triticale. University of Vermont, <http://northerngraingrowers.org/wp-content/uploads/TRITICALE.pdf>



Photo 4: *Triticale being harvested using a combine harvester.*

Source: Midwest Cover Crops Council

12.4.1 Setting header height

In 2014 trials in Victoria’s high-rainfall zone (HRZ) it was found that there is a 10% gain in header efficiency for every 10-cm increase in harvest height. The trials compared three harvest heights—15 cm, 30 cm and 50 cm—in wheat and barley. The trials showed that harvesting at a height of 15 cm makes harvesting much slower, and also incurs additional fuel consumption. At the other end of the scale, at a height 50 cm, harvesting was around 25% faster than 30 cm. A rule of thumb is a 10% efficiency gain for every 10 cm increase in harvest height. If a 100-ha crop is harvested at 15 cm it will take about 20% more time to harvest than a crop cut at 30 cm, or 38% more time than if it had been harvested at 50 cm.¹⁵

On the taller triticale varieties, harvest height will be lower than most wheat, as triticale is more uneven in tiller height than wheat. You generally have to take 10–20% more stubble than wheat when harvesting triticale.

Agronomist’s view

Harvesting low is done to reduce stubble loads, and is achieved by baling or burning the windrows, or spreading the trash and straw as evenly as possible across the header windrow. Harvesting low and treating weed seeds can also help to reduce the weed seedbank over time, and that, in turn, can assist with managing weeds and herbicide resistance.

Whatever height the header is set to, it is important to ensure that all equipment is clean and free of anything that might contaminate the harvested grain (Photo 5).

¹⁵ A Lawson (2015) Header efficiency increases with harvest height. Ground Cover, Issue 118, September–October 2015. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-118-Sep-Oct-2015/Header-efficiency-increases-with-harvest-height>



Photo 5: Cereal harvest underway. It is important to clean all equipment prior to and after harvesting.

Source: Agência Brasil

12.4.2 Forage harvesters

Ideally, whole-crop cereals should be harvested using a precision-chopping forage harvester to ensure a short chop length of 20–50 mm. This ensures the material can be well compacted in the stack or pit, so minimising the amount of air trapped and reducing losses of nutritive value and dry matter (DM). Losses are due to continued plant and microbial respiration during the early phases of fermentation. Increased density also reduces the rate of aerobic spoilage when the stack is opened; this is a common though not an insurmountable problem with cereal silages.

Most other forage-harvesting machines, such as self-loading wagons, cut the material to varying lengths, often over 200 mm, making adequate compaction very difficult.

The drier the DM content of the crop at harvest, the shorter the chop length required. Chopping the material short also ensures a thorough mixing of the highly nutritious heads with the much less nutritious stems and leaves. When all parts of the forage are well mixed, less wastage also as animals cannot easily select the heads and leave the stem material.

Farmers direct-harvesting forage cereals at the later growth stage are increasingly using forage harvesters that have a cutter bar instead of the typical rotary disc mowers, as this reduces grain loss. When using disc mowers, grain loss from the gaps in the housing of the chopping and feeding mechanisms can be minimised by fitting blanking plates.

Grain loss may be slightly higher in pre-mown crops due to the rotary disc action of the mower and, particularly if raked before harvesting, DM yield and nutritional value will also be slightly lower.

If the crop is harvested after the soft-dough stage, the grain will be hardening as it matures. In this case, forage harvesters, which are fitted with specific rollers for cracking grain, often referred to as ‘primary processing’, will be essential.¹⁶

¹⁶ F Mikan (2008) Harvesting forage cereals. Note AG1244. Revised. Agriculture Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/harvesting-forage-cereals>

12.5 Fire prevention

With so much flammable grain dust and chaff generated by harvesters during summer harvests, fire is a big risk, so grain growers must take precautions to minimise the likelihood of fires. Fires are a regular occurrence during harvest in stubble as well as standing crops. The main cause is hot machinery harvesting with combustible material. This is exacerbated on hot, dry, windy days. Seasonal conditions can also contribute to lower moisture content in grain, and this, too, increases the risk of fires.

12.5.1 Harvester fire-reduction checklist

1. Recognise the big four factors that contribute to fires: relative humidity, ambient temperature, wind, and crop type and conditions. Stop harvesting when the danger is extreme.
2. On the more hazardous days, focus on service, maintenance and machine hygiene. Follow systematic preparation and prevention procedures.
3. Use every means possible to avoid the accumulation of flammable material on the manifold, turbocharger and the exhaust system. Be aware of cross-winds and tailwinds that can disrupt the radiator fan air blast that normally keeps the exhaust area clean.
4. Be on the lookout for places where chaffing can occur, e.g. fuel lines, battery cables, wiring looms, tyres and drive belts.
5. Avoid overloading electrical circuits. Do not replace a blown fuse with a higher-ampere fuse. It is your only protection against wiring damage from shorts and overloading.
6. Periodically check bearings around the harvester front and the machine. Use a hand-held digital heat-measuring gun for temperature diagnostics on bearings and brakes.
7. Maintain fire extinguishers on the harvester and consider adding a water-type extinguisher for residue fires. Keep a well-maintained fire fighting unit close by and ready to respond.
8. Static electricity will not start a fire, but may help dust accumulate. Drag chains or cables may help dissipate electrical charges but are not universally successful in all conditions. As an alternative, there are some machine-mounted fire-suppression options on the market.
9. If fitted, use the battery isolation switch when the harvester is parked. Use vermin deterrents in the cab and elsewhere, as vermin chew some types of electrical insulation.
10. Observe the Grassland Fire Danger Index (GFDI) protocol on days of high fire risk.
11. Maintain two-way or mobile phone contact with a base and others, and establish a plan with the harvest team so that everyone can respond to a fire if it occurs.¹⁷

To preventing machinery fires, it is imperative that all headers, chaser bins, tractors and augers be regularly cleaned and maintained. All machinery and vehicles must have an effective spark arrester fitted to the exhaust system. To prevent overheating, tractors, motorcycles, off-road vehicles and mechanical equipment also need to be properly serviced and maintained. Fire-fighting equipment must be available and maintained—this is not just common sense, it is a legal requirement.

Take great care when using this equipment outdoors:

- Most harvester fires start in the engine or engine bay.
- Other fires are caused by failed bearings, brakes and electricals, and rock strikes.¹⁸

¹⁷ R Barr (2015) Plant of attack needed for harvester fires. GRDC, <https://grdc.com.au/Media-Centre/Media-News/South/2015/10/Plan-of-attack-needed-for-harvester-fires>

¹⁸ N Baxter (2012) A few steps to preventing header fires. Ground Cover. Issue 101, November–December 2012. GRDC, <http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-101/A-few-steps-to-preventing-header-fires>

- Be extremely careful when using cutting equipment, angle grinds and welders to repair plant equipment.
- Ensure that machinery components, including brakes and bearings, do not overheat, as they can drop hot metal onto the ground and start a fire.
- Use machinery correctly, as incorrect usage can cause it to overheat and ignite.
- Be aware that when the blades of slashers, mowers and similar equipment hit rocks or metal, they can create sparks and ignite dry grass.
- Avoid using machinery during when temperatures are high, humidity is low and winds are strong.
- Do repairs and maintenance in a hazard-free, clean working area such as on bare ground, on concrete or in a workshop, rather than in the paddock.
- Keep machinery clean and as free of fine debris as possible, to reduce the likelihood of onboard ignitions.¹⁹

With research showing an average of 1,000 combine harvester fires and 12 harvesters burnt to the ground every year in Australia (Photo 6)²⁰, agricultural engineers encourage care in keeping headers clean to reduce the potential for crop and machinery losses.



Photo 6: GRDC figures show that there are 1,000 combine harvester fires in Australia each year.

Source: Weekly Times

12.5.2 Harvesting in low-risk conditions

Growers can use the GFDI 35 guide to assess the wind speed at which harvest should cease. The Country Fire Service of South Australia publishes this ready-reckoner, which combines wind speed, relative humidity and temperature to arrive at conditions at which harvesting should be halted (Figure 1).²¹ To use the table:

1. Find the current temperature on the left-hand side in the red section.
2. Find the current relative humidity, rounded down, in the blue section. Find the intersection between these two values.
3. Read the wind speed at the intersection point, in the yellow section. If your current wind speed is the same or higher, you should stop harvesting until conditions take you under the threshold. In the worked example, the temperature

¹⁹ NSW Rural Fire Service (n.d.) Farm fire safety. NSW Rural Fire Service, http://www.rfs.nsw.gov.au/dsp_content.cfm?cat_id=1161

²⁰ J Law (2016) Use commonsense to prevent combine harvester fire during harvest. 2 September 2016. Weekly Times, <http://www.weeklytimesnow.com.au/machine/use-commonsense-to-prevent-combine-harvester-fire-during-harvest/news-story/f033c730547be732cedd997f4f6dbca7>

²¹ CFSSA (2014) Grain harvesting operation weather restrictions [download]. In CFS Code of Practice: Grain Harvesting. Country Fire Service South Australia, https://www.cfs.sa.gov.au/utills/html_view.jsp?id=56784

SECTION 12 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

PODCAST

GRDC podcast: [Harvester fires](#)

MORE INFORMATION

[GRDC Reducing Harvester Fire Risk: The Back Pocket Guide](#)

[An investigation into combine harvester fires](#)

[Plan of attack needed for harvester fires](#)

[Grain Trade Australia, Cereal rye and triticale trading standards 2016–2017 season](#)

is 35°C and the relative humidity is 10%, so the wind speed at which harvesting stops is 26 km/h.

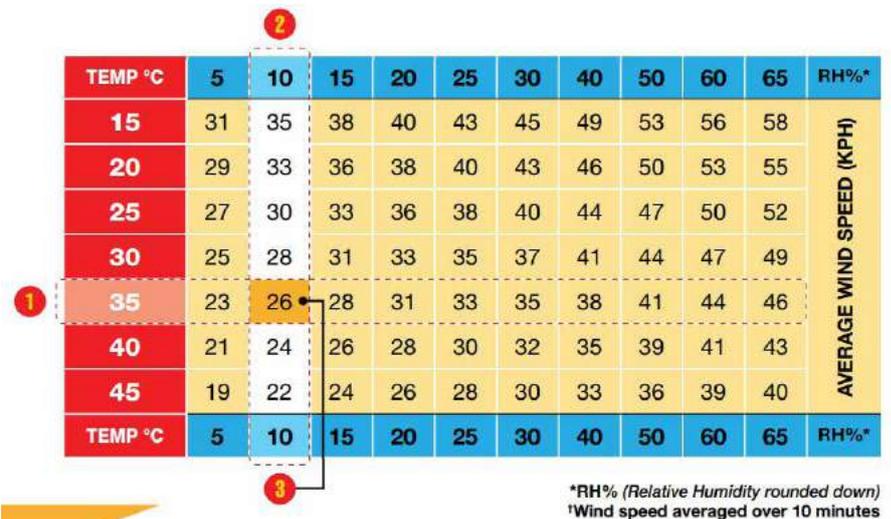


Figure 1: GFDI 35 calculator for determining when harvesting may ignite grassland fires. In this example, if the temperature is 35°C and the relative humidity is 10%, harvesting should be halted when the wind speed reaches 26 km/h.

Source: Country Fire Service South Australia

12.6 Receival standards

It is important to stay up to date with the Grain Trade Australia (GTA) national grain receival standards, as they change from time to time. The GTA Trading Standards are a critical tool for anyone purchasing, selling, trading, broking or otherwise operating in the commercial grain industry. They cover all grains, oilseeds and pulses, and related commodities.

For triticale, there is no minimum variety specification, and a load may be delivered with a varietal mix at any level. Any variety is eligible for delivery into the triticale grade (Table 1).²²

Table 1: Triticale receival standards current at 1 August 2016 for the Northern region.

Parameter	Specification	Comment / variation
Description	n/a	Approved varieties only
Moisture Max (%)	12.5	
Test Weight Min (kg/hl)	65.0	
Unmillable Material below the screen Max (% by weight)	10.0	All matter passing through a 2.0 mm slotted screen – 40 shakes in the direction of the slots
Unmillable Material above the screen Max (% by weight)	5.0	Includes whiteheads, chaff, backbone, Wild Radish pods, Milk Thistle pods or other seedpods not otherwise listed. Excludes contaminants where tolerances already exist
Defective grain max (% by count, 300 grain sample, unless otherwise stated)		
Sprouted	2.0	Split germ or visible signs of rootlet growth

²² CBH (2016) 2016–17 CBH public receival standards WA as at 1st October 2016 [download]. In Grain standards in Western Australia, <http://www.giwa.org.au/standards>

SECTION 12 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Parameter	Specification	Comment / variation
Insect Damaged	2.0	
Stained, of which:	15.0	Includes Weather Stained, Field Fungi
Pink Stained	5.0	Various fungal species that cause pink staining
Bin Burnt, Heat Damaged or Storage Mould (count per half litre)	1	
Dry Green or Sappy	2.0	
Frost Damaged	2.0	
Foreign seed contaminants max (count of seeds in total per half litre unless otherwise stated)		
Type 1 (Individual seed basis)	8	Colocynth, Double Gee/Spiny Emex/ Three Cornered Jack, Jute, Long Headed Poppy, Mexican Poppy, Field Poppy, Horned Poppy, Wild Poppy, New Zealand Spinach, Parthenium Weed (Qld only)
Type 2 (entire load)	Nil	Castor Oil Plant, Coriander, Crow Garlic/ Wild Garlic, Darling Pea, Opium Poppy, Peanut seeds and pods, Ragweed, Rattlepods, Starburr, St. John's Wort
Type 3 (a)	2	Bathurst Burr, Bellvine, Branched Broomrape, Bulls Head/Caltrop/Cats Head, Cape Tulip, Cottonseed, Dodder, Noogoora Burr, Thornapple/False Castor Oil
Type 3 (b)	4	Vetch (Blue/Tare), Vetch (Commercial)
Type 3 (c)	8	Heliotrope (Blue), Heliotrope (Common)
Type 4	20	Bindweed (Field), Cutleaf Mignonette seeds or pods, Damel, Hexham Scent (Hexham Scent is only acceptable if no tainting odour is present) or King Island Melilot, Hoary Cress, Mintweed, Nightshades, Paddy Melon, Skeleton Weed, Variegated Thistle
Type 5	40	Knapweed (Creeping/Russian), Patterson's Curse/Salvation Jane, Sesbania pea
Type 6	50	Saffron Thistle, Johnson Grass, Columbus Grass
Type 7 (a)	10	Broad Beans, Chickpeas, Corn (Maize), Cowpea, Faba Beans, Lentils, Lupin, Peas (Field), Safflower, Soybean, Sunflower and any other seeds or pods greater than 5 mm in diameter
Type 7 (b)	150	Barley, Bindweed (Australian), Bindweed (Black), Wheat, Durum, Oats (Black), Oats (Sand), Oats (Wild), Oats (Common), Rice, Rye (Cereal), Sorghum (Forage), Sorghum (Grain), Turnip Weed and any other weed seeds not specified in Types 1–7(a) or SFS
Small Foreign Seeds (% by weight)	1.2	All foreign seeds not specified in Types 1–7(b) that fall below the 2.0 mm screen during the Screenings process

Source: [Grain Trade Australia](#)

12.7 Harvest weed-seed management

Many northern grain growers have been sceptical about introducing harvest weed-seed control (HWSC) as another tool for combating herbicide resistance. The Queensland Department of Agriculture and Fisheries (DAF) principal weed science researcher Dr Michael Widderick says few growers in Queensland or New South Wales incorporate HWSC into their management practices, but, like other leading researchers, he believes this will change. Nationally, HWSC has been proven to reduce the weed seedbank, and if it could be made to work well in the Northern Region it would be a major positive for weed control in what is an increasingly herbicide-resistant environment.

There are several commercially available HWSC methods that effectively target the weed-seed-bearing chaff fraction during harvest. The main ones are narrow windrow burning, chaff carts, bale-direct stubble (BDS), and the integrated Harrington Seed Destructor (iHSD). Studies of these practices have clearly demonstrated their efficacy in preventing inputs of viable seed into the seedbank. Each is suited to a different set of problems and conditions, so two or more may need to be combined. With the ongoing development and refinement of HWSC options, two relatively new systems, chaff tramlining and the iHSD, have been introduced. Expectations are that their adoption will be high in the Northern Region.

Chaff tramlining is a simple, effective approach that removes the need for residue burning for HWSC. It is particularly suited to high-residue situations with dedicated tramlines. The newly commercialised iHSD, an update on the HSD, is a more sophisticated approach to HWSC where two hydraulically driven chaff-processing mills are neatly fitted to the rear of the harvester. This very effective system also reduces the need for residue burning, and has the added advantage of redistributing all residues back across the paddock.²³

12.7.1 Which northern weeds suit HWSC?

HWSC works for many northern weeds:

- Definitely in—turnip weed and African turnip weed are potentially very good candidates for HWSC, although they are not yet resistant to herbicides (note that these have only been tested in winter weeds—not tested in summer crops yet).
- Definitely in (winter crops)—annual ryegrass and wild oats at the start of harvest, even though wild oats sheds seed at about 2% a day and ryegrass at 1% a day.
- Possibly in (winter crops)—barnyard grass and feathertop Rhodes grass are known to shed their seed in summer crops, but where they germinate in spring in winter crops they may be suitable for HWSC.
- Possibly in (summer crops)—feathertop Rhodes grass provides an opportunity for HWSC in summer crops where there is a high percentage of seed retention at the start of harvest.²⁴

12.7.2 Harvest weed-seed controls

Weed-seed capture and control at harvest can be a valuable addition to the suite of tactics employed to put the weed seedbank into decline. For example, up to 95% of annual ryegrass seeds that enter the harvester exit in the chaff fraction. If the chaff can be captured, the seeds can be destroyed or removed.

Western Australian farmers and researchers have developed several systems to effectively reduce the return of annual ryegrass and wild radish seed into the seedbank, and help put weed populations into decline. Such practices have potential in the Northern region.

23 M Walsh (2016) Harvest weed seed control systems for the northern region. GRDC Update Paper. GRDC. <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Harvest-weed-seed-control-systems-for-the-northern-region>

24 T Somes (2016) Can harvest weed-seed control work for the north? Ground Cover. Issue 124, September–October 2016. GRDC. <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-124-September-October-2016/Can-harvest-weed-seed-control-work-in-the-north>

i MORE INFORMATION

[IWM manual section on harvest-weed management](#)

[Harvest weed seed control systems for the northern region](#)

[IWM manual section on narrow windrow burning](#)

[Windrow burning for weed control: WA fad or a viable option for the east?](#)

▶ VIDEOS

WATCH: Grain Orana Alliance - [Windrow burning for weed control in central western NSW](#)



WATCH: Grain Orana Alliance—[Burning the barriers to windrow burning in NSW](#)



Early harvest

A key strategy for all operations to control harvest weed seeds is to maximise the percentage of weed seeds that enter the header. This means harvesting early, before weed seed is shed, and harvesting as low as is practical, e.g. ‘beer-can height’.

Narrow windrow burning

During traditional whole-paddock stubble burning, high temperatures are not able to be sustained for long enough to kill most weed seeds. By concentrating harvest residues and weed seed into a narrow windrow, the fuel load is increased and the period of high temperatures extends to several minutes, improving the kill of weed seeds.

But is burning narrow windrows to control weeds a WA fad or a viable option for the east? There are several reasons Northern Region growers might consider it:

- Continued reliance on herbicides alone is not enough in continuous-cropping systems. Rotating herbicides alone will not prevent the development of resistance.
- Early implementation of windrow burning will prolong the usefulness of herbicides, not replace them.
- Windrow burning is the cheapest non-chemical technique for managing weed seeds present at harvest.
- Even with higher summer rainfall, windrow burning is a viable option for Northern cropping systems.
- Windrow burning is effective, even in the absence of resistance.
- Growers need to begin experimenting now on small areas to gain the experience needed to successfully implement the strategy farm-wide.²⁵

Narrow windrow burning is extremely effective—it destroys up to 99% of annual ryegrass and wild radish seeds—but it must be done properly. For ryegrass, a temperature of 400°C for at least 10 second is needed to destroy the viability of seeds. For wild radish, the temperature needs to be 500°C for at least 10 seconds.²⁶

Chaff carts

Chaff carts are towed behind headers during harvest to collect the chaff fraction (Photo 7). The chaff can then be handled easily.

Chaff carts will collect and remove up to 85% of annual ryegrass and wild radish seeds that pass through a header. The chaff collected this way must be managed to ensure the seeds are removed permanently from the cropping system. This can be done by burning in the following autumn or by removing the chaff from the paddock and using it as a livestock feed.²⁷

25 M Street, G Shepherd (2013) Windrow burning for weed control: WA fad or a viable option for the east? GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Windrow-burning-for-weed-control-WA-fad-or-viable-option-for-the-east>

26 S Clarry (2015) Trials measure harvest weed-seed control. Ground Cover. Issue 115, March–April 2015. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-115-MarApr-2015/Trials-measure-harvest-weed-seed-control>

27 Clarry S. (2015). Trials measure harvest weed-seed control. <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-115-MarApr-2015/Trials-measure-harvest-weed-seed-control>

i MORE INFORMATION

[IWM manual section on chaff carts](#)

[IWM manual section on bale-direct systems](#)

[The 'Glenvar' bale-direct story](#)



Photo 7: Chaff cart in action.

Photo: A. Storrie

Bale-direct systems

With the bale-direct system, a large baler is attached to the back of the harvester to collect all chaff and straw. As well as removing weed seeds, the baled material has an economic value as a livestock feed source.

Harrington Seed Destructor

The integrated HSD is the invention of Ray Harrington, a progressive farmer from Darkan, WA (Photo 8).²⁸ Developed as a unit that trails behind the harvester, the iHSD comprises a chaff-processing cage mill, and chaff and straw delivery systems. The HSD, which renders seeds non-viable by collecting and impacting the chaff as it exits the harvester, can be 92–99% effective, depending on seed species.²⁹

All harvest residues are retained. Therefore, compared with windrow burning, chaff carts and baling, the farmer using the iHSD reduces the loss or banding of nutrients, maintains all organic matter to protect the soil from wind and water erosion, and reduces evaporation.³⁰

28 A Roginski (2012) Seed destructor shows its national potential. Ground Cover. Issue 100, September–October 2012. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-issue-100/Seed-destructor-shows-its-national-potential>

29 Clarry S. (2015). Trials measure harvest weed-seed control. <https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-115-MarApr-2015/Trials-measure-harvest-weed-seed-control>

30 GRDC (n.d.) Section 6. Managing weeds at harvest. Integrated Weed Management Hub. GRDC, <https://grdc.com.au/resources-and-publications/iwmhub/section-7-managing-weeds-at-harvest>

SECTION 12 TRITICALE

[TABLE OF CONTENTS](#)

[FEEDBACK](#)

VIDEOS

WATCH: [Harvest weed seed control for the high rainfall zone](#)



WATCH: [Harvest the time to get on top of resistant weeds](#)

University of Adelaide weed management expert Dr Chris Prentice calls on growers to explore more about pre-emergent, harvest-time control options, to cope with growing herbicide resistance issues.

WATCH: [A beginner's guide to harvest weed seed control](#)



MORE INFORMATION

[IWM manual section on Harrington Seed Destructor](#)

Section on the Harrington Seed Destructor in GRDC's [Tactics for managing weed populations](#)

[Chaff deck concentrates weeds in controlled traffic](#)



Photo 8: *Harrington Seed Destructor at work.*

Source: GRDC

The chaff deck places the chaff exiting the sieves of the harvester on to permanent wheel tracks. Growers using chaff decks have observed that few weeds germinate from the chaff fraction and believe that many weed seeds rot in it. A permanent tramline farming system is necessary to be able to implement the chaff deck system.³¹

³¹ Roberts P. (2014). New systems broaden harvest weed control options. GRDC. <https://grdc.com.au/Media-Centre/Media-News/West/2014/11/New-systems-broaden-harvest-weed-control-options>

Storage

Key messages

- Long-term on-farm storage of triticale will be a problem unless the storage facility is sealed silos.
- Triticale grain is softer than wheat and barley grain. Soft grain is more prone to attack from weevils and other grain storage insects.
- Maintain grain at under 10% moisture content to minimise insect infestation.
- Fumigation during storage in sealed silos effectively reduces the risk of insect damage when storing triticale.
- Storing grain at levels less than 12% moisture content does not eliminate the need for treating it with insecticide, although it does avoid spoilage from mould and fungus growth.
- It is recommended to use a protectant when storing triticale after harvest. Aeration is also recommended.
- The moisture content and the temperature of the grain at harvest determine the safe storage period. Drying and cooling of freshly harvested, moist, warm grain is an important operation before it goes for processing or storage.

Drying and storing triticale is similar to the process for wheat or rye. However, more care must be taken, especially for long-term storage, since triticale has a softer kernel and is extremely sensitive to grain-insect infestations, far more so than wheat, and more so than barley (Photo 1).¹



Photo 1: Warehouse beetle found in stored cereal grain.

Source: DAFWA

Triticale should be stored in a dry, well-ventilated area to reduce the likelihood of damage from moisture. The preferred harvest moisture content (MC) to reduce damage due to heating caused by moulding is 12% or less.² However, the lower the MC the better. Storing grain at less than 12% does not eliminate the need for treating it with insecticide; however, it does avoid spoilage from mould and fungus growth.³

¹ DAFWA (2016) Insect pests of stored grain. DAFWA, <https://www.agric.wa.gov.au/pest-insects/insect-pests-stored-grain>

² M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

³ Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkrcr.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

It is recommended to use a protectant and aeration when storing triticale after harvest.⁴ When storing, it is critical to pay attention to:

- truck, auger, silo or storage bin hygiene
- grain temperature
- grain moisture content
- grain insecticide treatment
- regular monitoring

Seek professional advice about storing triticale to reduce the risk of insect infestation and, subsequently, significant grain losses.

Triticale may also support fungal development. Some triticales show high levels of enzymatic activity, even in the absence of visual sprouting or spike wetting. In sprouted grain, this may promote fungal development during storage, or may have deleterious effects on the food-processing characteristics of grain.⁵

13.1 GRDC's Stored Grain Information Hub

Following the work already done through the Grain Storage Extension Project, the GRDC funded another three years of work, allowing grain storage extension support to continue to 2018.

The project provides an online facility, the Stored Grain Information Hub, to equip growers with the skills and knowledge to carry out the best management of on-farm grain storage. Apart from the resources on the dedicated website, more information on the grain storage extension project and to arrange for a workshop in your area, you can contact a member of the team:

- National hotline, 1800 933 845 (1800 weevil)
- Queensland and northern NSW, Philip Burrill, philip.burrill@daff.qld.gov.au
- Southern NSW, Victoria, SA and Tasmania, Peter Botta, pbotta@bigpond.com
- WA, Ben White, ben@storedgrain.com.au
- Project coordinator, Chris Warrick, info@storedgrain.com.au

13.2 How to store grain on-farm

On-farm grain storage is a significant investment. Many farms have older storage facilities that cannot be sealed for grain fumigation purposes, but replacing them with sealable silos may not be economically viable.

Growers might only plan to store grain on the farm for a short time, but markets can change, requiring grain to be stored for longer than anticipated, so investing in gas-tight sealable structures means you can treat pests reliably and safely, and remain open to a range of markets.

Growers should approach storage as they would purchasing machinery. They spend a lot of time researching a header purchase to make sure it is fit for their purpose; in the same way, because grain storage can also be a significant investment, and even a permanent one, it pays to do thorough research and develop a storage plan that adds value to your enterprise into the future.

Agronomist's tip: Decide what you want to achieve with storage, critique existing infrastructure and be prepared for future changes. A good storage plan can remove a lot of stress at harvest: growers need a system that works so they capture a better return in their system.⁶

4 Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkrcr.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

5 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

6 GRDC (2015) Extension tailored for regional challenges. Ground Cover. Issue 119. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-119--Grain-storage/Extension-tailored-for-regional-challenges>

SECTION 13 TRITICALE

TABLE OF CONTENTS

FEEDBACK

A mixed-storage strategy could be the solution. The strategy is to purchase a small number of sealable silos and to use them to batch-fumigate grain prior to sale. This works because grain silos in the Northern Region are aeration cooled for most of the time, and only sealed for the purpose of fumigation.

There are several reasons why growers might consider storing grain on the farm including:

- improving harvest logistics
- taking advantage of higher grain prices some time after harvest
- supplying a local market (e.g. feedlot, dairy)
- avoiding high freight costs at peak time
- adding value by cleaning, drying or blending grain
- retaining planting seed

In most cases, for on-farm storage to be economical it needs to deliver on more than one of these benefits. There are advantages and disadvantages with each of the four main storage systems: sealed silos, unsealed silos, storage bags, and storage sheds (Table 1). Under very favourable circumstances, grain-storage facilities can pay for themselves within a few years, but it is also possible for an investment in on-farm storage to remain unprofitable. A grain storage cost–benefit [analysis template](#) is very useful tool in the decision-making process to test the viability of grain storage on your farm.⁷

Table 1: Advantages and disadvantages of grain storage options.

Storage type	Advantages	Disadvantages
Gas-tight, sealable silo	<ul style="list-style-type: none"> Gas-tight, sealable status allows phosphine and controlled atmospheres to control insects Easily aerated with fans Fabricated on-site, or off-site and transported Capacity from 15 t to 3,000 t 25 years or more of service life Simple in-loading and out-loading Easily administered hygiene (cone-based silos particularly) Can be used multiple times in a season 	<ul style="list-style-type: none"> Requires foundation to be constructed Relatively high initial investment required Seals must be maintained regularly Access requires safety equipment and infrastructure Requires annual test to check gas-tight sealing
Unsealed silo	<ul style="list-style-type: none"> Easily aerated with fans 7–10% cheaper than sealed silos Capacity from 15 t to 3,000 t Up to 25 year service life Can be used multiple times in a season 	<ul style="list-style-type: none"> Requires foundation to be constructed Silo cannot be used for fumigation Insect control limited to protectants in eastern states and Dryacide® in WA Access requires safety equipment and infrastructure

⁷ GRDC (2015) Grain storage strategies in the northern region. GRDC, <https://grdc.com.au/Media-Centre/Hot-Topics/Grain-storage-strategies-in-the-northern-region>

SECTION 13 TRITICALE

TABLE OF CONTENTS

FEEDBACK

MORE INFORMATION

[Benefits flow from on-farm storage](#)

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[Grain storage: invest today for the system of tomorrow](#)

Storage type	Advantages	Disadvantages
Grain-storage bags	<ul style="list-style-type: none"> Low initial cost Can be laid on a prepared pad in the paddock Provide harvest logistics support Can provide segregation options Are ground operated 	<ul style="list-style-type: none"> Requires purchase or lease of loader and unloader Increased risk of damage to grain beyond short-term storage (typically three months) Limited insect control options, with fumigation possible only under specific protocols Requires regular inspection and maintenance, which need to be budgeted for Aeration of grain bags currently limited to research trials only Must be fenced off Prone to attack by mice, birds, foxes, etc. Limited wet-weather access if stored in paddock Need to dispose of bag after use Single-use only
Grain-storage sheds	<ul style="list-style-type: none"> Can be used for dual purposes 30 years or more of service life Low cost per stored tonne 	<ul style="list-style-type: none"> Aeration systems require specific design Risk of contamination from dual purpose use Difficult to seal for fumigation Vermin control is difficult Limited insect control options without sealing Difficult to unload

Source: Kondinin Group

13.2.1 Silos

As triticale is very prone to damage from insects during storage due to its soft kernel, the grain should be stored at less than 10% MC, preferably in sealed silos (Photo 2).⁸ Treat the grain as it enters the silo and then check regularly (every 2–3 months) for reinfestation.

8 Stored Grain Information Hub (2014) Pressure testing sealable silos. GRDC, <http://storedgrain.com.au/pressure-testing/>



PHOTOS: CHRIS WARRICK, KONDINN GROUP

Photo 2: Sealable silos help growers protect triticale from insect attack, but for silos to remain effective, they must be maintained and regularly pressure-tested.

Source: GRDC

Sealed silos offer a more permanent grain storage option than grain storage bags. Depending on the amount of storage required, they will have a higher initial capital cost than bags, and can be depreciated over a longer time frame than the machinery required for the grain bags. With a silo system, as stored tonnage increases, the capital cost of storage increases.

The advantages of using sealed grain silos as a method for grain storage include improved harvest management, reduced harvest stress, reduced harvest-freight requirements, minimal insecticide exposure for the grower and farm workers, and the opportunity to segregate and blend grain.

The disadvantages include the initial capital outlay, the outlay required to meet occupational health and safety (OH&S) requirements, the additional handling required on the farm, and the additional site-maintenance requirements.⁹

Pressure testing

- A silo sold as a sealable unit needs to be pressure tested to be sure it's gas-tight.
- It is strongly recommended that growers ask the manufacturer or reseller to quote the Standards Australia number AS2628 on the invoice as a means of legal reference to the quality of the silo being paid for.
- Pressure-test sealable silos upon erection, annually, and before fumigating, by conducting a five-minute half-life pressure test.
- Maintenance is the key to ensuring a silo purchased as sealable can be sealed and gas-tight.

A silo is only truly sealable if it passes a five-minute half-life pressure test according to the Australian Standard AS2628. Often silos are sold as sealed but are not gas-tight—rendering them unsuitable for fumigation.

There is no compulsory manufacturing standard for sealed silos in Australia. Although a voluntary industry standard was adopted in 2010, it remains in the buyer's own interests to test silos before purchase.

Even if a silo is sold as sealable it is not until it is proven to be gas-tight using a pressure test. The term 'sealed' has been used loosely in the past, and some silos

⁹ J Francis (2006) An analysis of grain storage bags, sealed grain silos and warehousing for storing grain. Holmes Sackett and Associates, <https://grdc.com.au/uploads/documents/Final%20report%20Grain%20Storage%20Bags%2021%20Jul%20061.pdf>

SECTION 13 TRITICALE

TABLE OF CONTENTS

FEEDBACK

MORE INFORMATION

Stored Grain Information Hub, [Pressure testing sealable silos](#)

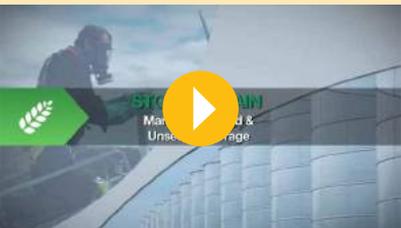
GRDC, [Silo buyer's guide](#)

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WATCH: [Stored grain: Managing sealed and unsealed storage](#)



WATCH: [GCTV2: National standards for sealed silos](#)



may not have been gas-tight from the day they were constructed. However, even a silo that was gas-tight to the standard on construction will deteriorate over time, so it needs annual maintenance to remain gas-tight.

Why test the pressure?

In order to kill grain pests at all stages of their life cycle (egg, larvae, pupae, adult), phosphine gas concentrations need to reach and remain at 300 parts per million (ppm) for seven days, or 200 ppm for 10 days.

The importance of a gas-tight silo

National agricultural surveys have revealed that around 85% of growers have used phosphine at least once during the previous five years, and that ~37% of growers use phosphine every year. A Grains Research and Development Corporation survey during 2010 revealed that only 36% of growers using phosphine applied it correctly, i.e. in a gas-tight, sealed silo (Figure 1).

Research shows that fumigating in a storage that does not meet the industry standard does not achieve a high enough concentration of fumigant for a long enough period to kill pests at all life-cycle stages (Figure 2). For effective phosphine fumigation, a minimum gas concentration of 300 ppm for seven days, or 200 ppm for 10 days, is required. Fumigation trials in silos with small leaks demonstrated that phosphine levels are as low as 3 ppm close to the leaks. In the rest of the silo gas levels are also too low.¹⁰

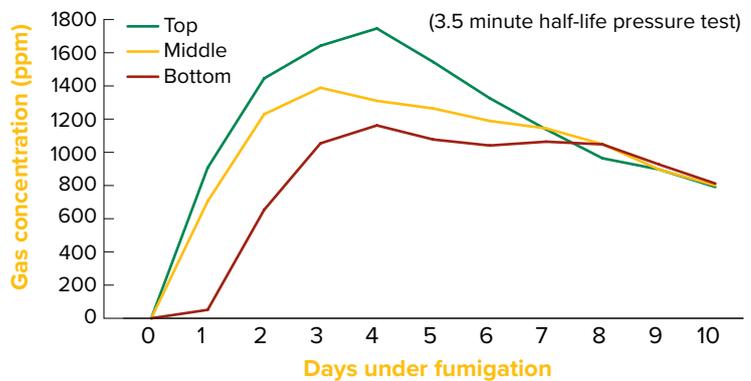


Figure 1: Gas concentration in gas-tight silo.

Source: GRDC

¹⁰ P Botta, P Burrill, C Newman (2010) Pressure testing sealable silos. Factsheet. GRDC, <http://storedgrain.com.au/pressure-testing/>

SECTION 13 TRITICALE

TABLE OF CONTENTS

FEEDBACK

i MORE INFORMATION

Fumigating with phosphine, other fumigants and controlled atmospheres

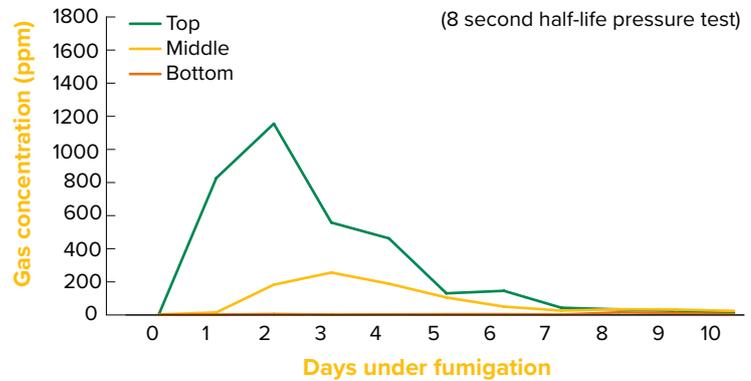


Figure 2: Gas concentration in non-gas-tight silo.

Source: GRDC

It is recommended to pressure-test silos that are sealable once a year to check for damaged seals on openings.

13.2.2 Grain bags

Grain-storage bags are a relatively new technology, and offer a low-cost alternative to silos for the temporary storage of grain on the farm. They are made of a multilayer polyethylene material similar to that used for silage fodder. Bags typically store 200–220 t of cereal grain, and are filled and emptied using specialised machinery (Photo 3).¹¹ The bags are sealed after filling, producing a relatively airtight environment which, under favourable storage conditions, protects grain from insect damage without the use of insecticides.

The potential advantages of using grain-storage bags include the low capital set-up costs, improved harvest management, less harvest stress, reduced harvest-freight requirements, minimal cost for OH&S requirements, reduced grain-insecticide requirements, and the opportunity to segregate and blend grain.

The potential disadvantages include the need to dispose of used bags, and the relatively short period of storage (~6–8 months) before bags begin to deteriorate and management becomes necessary to ensure bag integrity. Grain bags can also be prone to animal attacks from birds, foxes and pigs. Another potential disadvantage of this system, when compared to permanent structures, is that once the storage period is complete there is no asset value in the storage system other than the bagging machinery.¹²

¹¹ T Meersman (2014) More farmers seeking storage are turning to grain bags. 4 October. Star Tribune, <http://www.startribune.com/more-farmers-seeking-storage-are-turning-to-grain-bags/278072461/>

¹² J Francis (2006) An analysis of grain storage bags, sealed grain silos and warehousing for storing grain. Holmes Sackett and Associates, <https://grdc.com.au/uploads/documents/Final%20report%20Grain%20Storage%20Bags%2021%20Jul%20061.pdf>

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WATCH: [GCTV extension files: Grain bags—a grower's perspective](#)



WATCH: [GCTV2: Grain silo hygiene](#)



Photo 3: A 100 m bag can be filled in 30 minutes when there is a constant supply of grain.

Source: Star Tribune

13.2.3 Hygiene

The first grain harvested is often the grain at the greatest risk of early insect infestation, due to contamination by pests that have been inadvertently harboured in machinery and equipment since the previous harvest. One on-farm test found more than 1,000 lesser grain borers in the first 40 L of wheat that passed through the harvester.

This shows how important it is to remove grain residues from empty storages and grain-handling equipment, including harvesters, field bins, augers and silos to ensure an uncontaminated start for new-season grain.

Clean equipment by blowing or hosing out residues and dust, and then consider a structural treatment. Bury, use or burn any grain left in hoppers and bags from the grain-storage site so it doesn't provide a habitat for pests during the off-season. Always thoroughly clean trucks, augers and storages prior to storing triticale. Dust and grain from previous years' grain should all be completely removed to avoid rapid infestation with stored-grain insects.¹³

13.2.4 Monitoring stored grain

Check the grain regularly during storage for signs of insect activity, and be prepared to deal with an infestation if it occurs.¹⁴ When monitoring grain temperature and moisture content, take note of the following:

- Pests and grain moulds thrive in warm, moist conditions. Monitor grain moisture content and temperature to prevent storage problems.
- Use a grain-temperature probe to check storage conditions and aeration performance (Photo 4).
- When checking grain, smell the air at the top of storages for signs of high grain moisture or mould problems.
- Check germination and vigour of planting seed in storage.
- Aeration fans can be used to cool and dry grain to reduce problems of the storage environment.

¹³ Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcra.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

¹⁴ Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcra.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

It is vital to monitor grain moisture content to prevent pests and grain moulds from thriving.¹⁵



Photo 4: Use a digital probe to monitor moisture and temperature from both the top and the bottom of silos, if safe to do so.

Source: Plant Health Australia

13.2.5 Grain storage: get the economics right

As growers continue to expand their on-farm grain storage, the question of economic viability gains in significance. There are many examples of growers investing in on-farm grain storage and paying for it in one or two years because they struck the market at the right time, but are these examples enough to justify greater expansion of on-farm grain storage for most farmers?

The grain-storage extension team conducts approximately 100 grower workshops every year Australia wide, and it's evident from these that no two growers use on-farm storage in the exact same way: like many other economic comparisons in farming, the viability of grain storage is different for each grower. Depending on the business's operating style, the location, the resources, and the most limiting factor to increase profit, grain storage may—or may not—be the next best investment. For this reason, everyone needs to do a simple cost–benefit analysis of their own operation.

Comparing on-farm storages

To make a sound financial decision, growers need to make two comparisons. The first is to compare the expected returns from using storage with expected returns from other farm-business investments and decisions, such as more land, a chaser bin, a wider boomspray, a second truck, or paying off debt. The other comparison is to determine if they can store grain on the farm cheaper than paying a bulk handler to store it.

Calculating the costs and benefits of on-farm storage will give the grower a return on investment (ROI) figure, which can be compared with other investment choices and the total cost of storage with bulk handlers.

¹⁵ Plant Health Australia (2015) Monitoring stored grain on farm. Plant Health Australia, <http://www.planthealthaustralia.com.au/wp-content/uploads/2018/03/Monitoring-stored-grain-on-farm-2018.pdf>

Cheapest form of storage

The key to a useful cost–benefit analysis is identifying which financial benefits to plan for, and costing an appropriate storage to suit that plan. People often ask, ‘What’s the cheapest form of storage?’ The answer is the storage that suits the planned benefits. Short-term storage for harvest logistics or freight advantages can be suited to grain bags or bunkers. If flexibility is required for longer-term storage, gas-tight, sealable silos with aeration cooling allow quality control and insect control.

Benefits

To compare the benefits and costs in the same form, work everything out on the basis of dollars per tonne. On the benefit side, the majority of growers will require multiple financial gains for storing grain to make money out of it. These might include harvest logistics or timeliness, market premiums, freight savings or cleaning, blending, or drying grain to add value.

Costs

The costs of grain storage can be broken down into fixed and variable. The fixed costs are those that don’t change from year to year and have to be covered over the life of the storage. Examples are depreciation and the opportunity or interest cost on the capital. The variable costs are all those that vary with the amount of grain stored and the length of time it’s stored for. Interestingly, the costs of good hygiene, aeration cooling and monitoring are relatively low compared to the potential impact they can have on maintaining grain at a high quality. One of the most significant variable costs, and one that is often overlooked, is the opportunity cost of the stored grain; i.e. the cost of having grain in storage rather than having the money in the bank paying off an overdraft or a term loan.

The result

While it’s difficult to put a precise dollar value on each of the potential benefits and costs, a calculated estimate will determine if it’s worth a more thorough investigation. If a grower compares the investment of on-farm grain storage to other investments and the result is similar, then they can revisit the numbers and work on increasing their accuracy. If the return is not even in the ball park, the grower has potentially avoided a costly mistake. On the contrary, if after checking the numbers the return is favourable, they can proceed with the investment confidently.

Summary

Unlike a machinery purchase, grain storage is a long-term investment that cannot be easily changed or sold. Based on what the grain-storage extension team is seeing around Australia, those growers who take a planned approach to on-farm grain storage and do it well are being rewarded for it. Grain buyers are seeking out growers who have a well-designed storage system that can deliver insect-free, quality grain without delay.

Table 2 can be used to figure out the likely economic result of on-farm grain storage for an individual business. Each column can be used to compare storage options, including type of storage, length of time held or paying a bulk handler.¹⁶

¹⁶ C Warrick (2016) Grain storage: get the economics right. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/09/Grain-storage-get-the-economics-right>

SECTION 13 TRITICALE

TABLE OF CONTENTS

FEEDBACK

MORE INFORMATION

Stored Grain Information Hub, [Economics of on-farm grain storage, cost benefit analysis](#)

[Economics of on-farm grain storage: a grains industry guide](#)

VIDEOS

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WATCH: [GCTV: Stay safe around grain storage](#)



Table 2: Cost–benefit template for grain storage.

Financial gains from storage		Example \$/t	Your \$/t
Harvest logistics, timeliness	Grain price x reduction in value after damage % x probability of damage %	\$16.00	
Marketing	Post-harvest grain price–harvest grain price		
Freight	Peak rate \$/t–post harvest rate \$/t	\$20.00	
Cleaning to improve grade	Clean grain price–original grain price–cleaning costs–shrinkage		
Blending to lift average grade	Blended price–((low grade price x %mix) + (high grade price x %mix))		
Total benefits	Sum of benefits	\$36.20	
Capital cost	Infrastructure cost/storage capacity	\$155.00	
Fixed costs			
Annualised depreciation cost	Capital cost \$/t ÷ expected life storage (e.g. 25, for 25 years)	\$6.20	
Opportunity cost on capital	Capital cost \$/t x opportunity or interest rate e.g. 8% / 2	\$6.20	
Total fixed costs	Sum of fixed costs	\$12.40	
Variable costs			
Storage hygiene	(Labour rate \$/h x time to clean hours ÷ storage capacity) + structural treatment	\$0.23	
Aeration cooling	Indicatively \$0.23 for the first 8 days, then \$0.18 per month/t	\$0.91	
Repairs and maintenance	Estimate e.g. capital cost \$/t x 1%	\$1.51	
Inload/outload time and fuel	Labour rate \$/h/60 minutes ÷ auger rate t/m x 3	\$0.88	
Time to monitor and manage	Labour rate \$/h x total time to manage hours ÷ storage capacity	\$0.24	
Opportunity cost of stored grain	Grain price x opportunity interest rate e.g. 8% / 12 x number of months stored	\$7.20	
Insect treatment cost	Treatment cost \$/t x number of treatments	\$0.35	
Cost of bags or bunker trap	Price of bag ÷ bag capacity tonne		
Total variable costs	Sum of variable costs	\$11.32	
Total cost of storage	Total fixed costs + total variable costs	\$23.72	
Profit/Loss on storage	Total benefits–total costs of storage	\$12.48	
Return on investment	Profit or loss/capital cost x 100	8.1%	

Source: GRDC

13.3 Stored grain pests

Key points:

- Effective grain hygiene and aeration cooling can overcome 85% of pest problems.
- When fumigation is needed it must be carried out in pressure-tested, sealed silos.
- Monitor stored grain monthly for moisture, temperature and pests.

13.3.1 Insecticide treatment

There are three options for insecticide treatment:

- Chemical protectant—applied directly to the grain, it is used to treat uninfested grain, and protects grain for three to nine months, depending on the product.
- Fumigation—only done in a sealed silo; the fumigant is put in a tray or sachet, and put in the head-space of silo so as to prevent physical contact with the grain; it is residue-free; and it minimises insect resistance to chemicals.
- Aeration cooling—is a residue-free means of lowering the temperature of grain to reduce possible insect infestation.

Prevention is better than cure

The combination of meticulous grain hygiene and well-managed aeration cooling generally overcomes 85% of storage pest problems. For grain storage, three key factors provide significant gains for both grain storage pest control and grain quality: hygiene, aeration cooling, and correct fumigation.¹⁷

13.3.2 Common species

The most common insect pests of stored cereal grains in Australia are

- weevils (*Sitophilus spp.*)—rice weevil is the most common weevil in cereals in Australia
- lesser grain borer (*Rhizopertha dominica*)
- rust-red flour beetle (*Tribolium spp.*)
- saw-toothed grain beetle (*Oryzaephilus spp.*)
- flat grain beetle (*Cryptolestes spp.*)
- Indian meal moth (*Plodia interpunctella*)
- angoumois grain moth (*Sitotroga cerealella*)

The most common ones are quite distinct from each other, and should be fairly readily identifiable (Figure 3).¹⁸ Another dozen or so beetles, psocids (booklice) and mites are sometimes present as pests in stored cereal grain as well.

¹⁷ Stored Grain Information Hub (2016) Northern and Southern Regions grain storage pest control guide. GRDC, <http://storedgrain.com.au/pest-control-guide-ns/>

¹⁸ Stored Grain Information Hub (2013) Northern and southern regions stored grain pests: identification. GRDC, <http://storedgrain.com.au/stored-grain-pests-id-ns/>

FIGURE 1 IDENTIFICATION OF COMMON PESTS OF STORED GRAIN

The following flow chart provides a useful guide for grain pest identification.

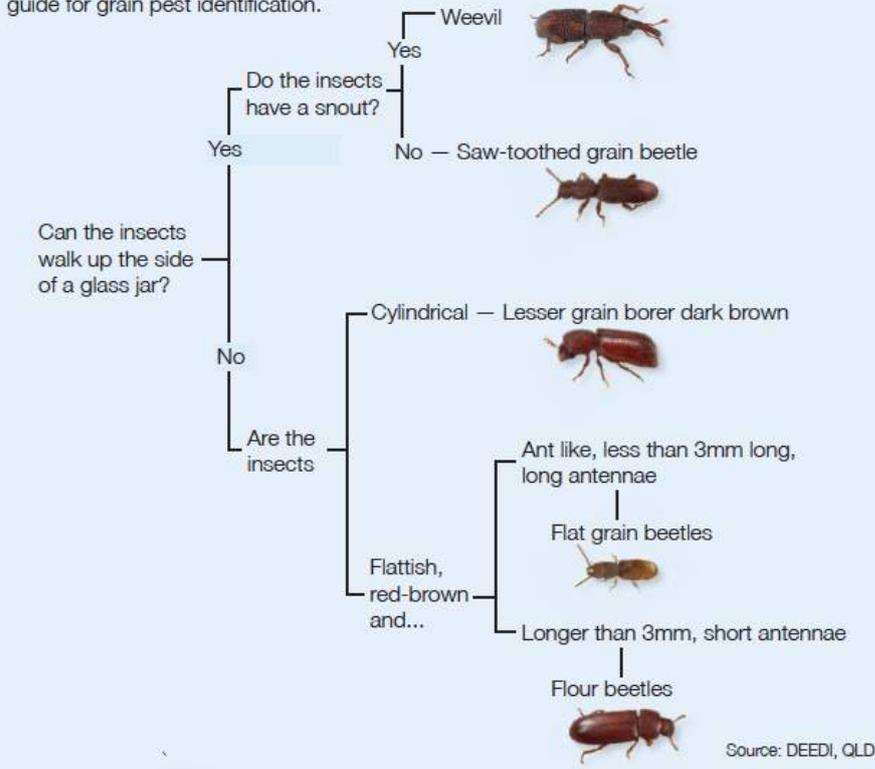


Figure 3: Identification of common pests of stored grain.

Source: Stored Grain Information Hub

Why identify insect pests of stored grain pests?

Most insect-control methods for stored grain work against all species, so it is not necessary to identify the storage pests to make decisions about most control methods. But if you intend to spray grain with insecticides you may need to know which species are present if:

- A previous application has failed and you want to know whether resistance was the reason—if more than one species survived, resistance is unlikely to be the cause.
- You intend using a residual protectant to treat infested grain—pyrimiphos-methyl, fenitrothion and chlorpyrifos-methyl are ineffective against the lesser grain borer, and pyrimiphos-methyl and fenitrothion are generally ineffective against the saw-toothed grain beetle.
- You intend to use dichlorvos to treat infested grain—if the lesser grain borer is present you need to apply the higher dose rate, which increases the withholding period (WHP) before grain can be marketed from 7 days to 28 days.

13.3.3 Monitoring grain for pests

Damage by grain pests often goes unnoticed until the grain is removed from the storage. Regular monitoring will help to ensure that grain quality is maintained.

- Sample each grain storage at least monthly. During warmer periods of the year fortnightly sampling is recommended.

i MORE INFORMATION

[Stored grain pests: identification](#)

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[Stored grain pests: the back pocket guide](#)

[Monitoring stored grain on farm](#)

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- Take samples from the top and bottom of grain stores and sieve using 2 mm mesh onto a white tray to separate any insects (Photo 5).¹⁹
- Hold the tray in the sunlight for 10–20 seconds to trigger movement in any insects, making them easier to see. Use a magnifying glass to identify pests.
- Also use grain probes or pitfall traps to check for insects. Traps are kept in the grain while it is being stored and are often able to detect the start of an infestation.
- Push the probe or trap into the grain surface and pull up for inspection fortnightly or monthly. Place 1–2 traps in the top of a silo or several traps in a grain shed.
- Be sure to check grain three weeks before sale to allow time for treatment if required.²⁰



Photo 5: A 2 mm mesh sieve will separate insects from grain.

Source: Plant Health Australia

13.3.4 Hygiene

Key points:

- Effective grain hygiene requires the complete removal of all waste grain from storages and equipment.
- Be meticulous with grain hygiene: pests only need a small amount of grain for survival.

A bag of infested grain can produce more than one million insects in a year—and these million can walk and fly to other grain storages where they will start new infestations. Therefore, meticulous grain hygiene is important. It involves removing any grain that can harbour pests and allow them to breed. It also includes regular inspection of seed and stockfeed grain so any pest infestations can be controlled before pests spread.

Where to clean

Removing an environment for pests to live and breed in is the basis of grain hygiene, and encompasses all grain-handling equipment and storages. Grain pests live in dark, sheltered areas and breed best in warm conditions. Common places to find them are:

¹⁹ Plant Health Australia (2015) Monitoring stored grain on farm. Plant Health Australia, <http://www.planthealthaustralia.com.au/wp-content/uploads/2018/03/Monitoring-stored-grain-on-farm-2018.pdf>

²⁰ Plant Health Australia (2015) Monitoring stored grain on farm. Plant Health Australia, <http://www.planthealthaustralia.com.au/wp-content/uploads/2018/03/Monitoring-stored-grain-on-farm-2018.pdf>

- empty silos and grain storages
- aeration ducts, augers and conveyers
- harvesters, field bins and chaser bins
- leftover bags or loose grain in grain trucks
- spilt grain around grain storages
- equipment and rubbish around storages
- seed grain
- stockfeed grain

Successful grain hygiene involves cleaning all areas where grain gets trapped in storages and equipment (Photo 6).²¹ Grain pests can survive in a tiny amount of grain, so any parcel of fresh grain in a machine or storage can become infested.



Photo 6: Grain left in trucks is an ideal place for grain pests to breed. Keep trucks, field bins and chaser bins clean.

Source: Stored Grain Information Hub

When to clean

Straight after harvest is the best time to clean grain-handling equipment and storages, before they become infested with pests. One trial revealed more than 1,000 lesser grain borers in the first 40 L of grain through a harvester at the start of harvest; the harvester had been considered to be reasonably clean at the end of the previous season. Discarding the first few bags of grain at the start of the next harvest is a good idea to help keep grain pest-free. Other studies have showed that insects are least mobile during the colder months of the year, so cleaning around silos in July–August can reduce insect numbers before they become mobile.

How to clean

The better the cleaning job, the less the chance of pests being harboured. The best tools to get rid of all grain residues are a combination of:

- brooms
- vacuum cleaners
- compressed air
- blow–vacuum guns
- pressure washers
- fire-fighting hoses

²¹ Stored Grain Information Hub (2013) Hygiene and structural treatments for grain storage. Factsheet. GRDC, <http://storedgrain.com.au/hygiene-structural-treatments/>

SECTION 13 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Using a broom or compressed air gets rid of most grain residues (Photo 7)²², and a follow-up wash-down removes grain and dust left in crevices and hard-to-reach spots. Choose a warm, dry day to wash storages and equipment so it dries out quickly and doesn't rust. When inspecting empty storages, look for ways to make the structures easier to keep clean. Seal or fill any cracks and crevices to prevent grain lodging and insects harbouring. Bags of leftover grain lying around storages and in sheds create a perfect harbour and breeding ground for storage pests. After collecting spilt grain and residues, dispose of them well away from any grain storage areas.



Photo 7: Clean silos, including the silo wall, with air or water to provide a residue-free surface to apply structural treatments.

Source: Stored Grain Information Hub

The process of cleaning on-farm storages and handling equipment should start with the physical removal, blowing and/or hosing out of all residues. Once the structure is clean and dry, consider the application of diatomaceous earth (DE) as a structural treatment. See Section 1.2.4 Structural treatments for more information.

A concrete slab underneath silos makes cleaning much easier (Photo 8).



Photo 8: A concrete slab under silo makes cleaning up spilled grain much easier.

Source: Stored Grain Information Hub

VIDEOS

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²² Stored Grain Information Hub (2013) Hygiene and structural treatments for grain storage. Factsheet. GRDC, <http://storedgrain.com.au/hygiene-structural-treatments/>

i MORE INFORMATION

[Aeration cooling for pest control](#)

[Hygiene and structural treatments for grain storages](#)

13.3.5 Aeration cooling for pest control

While adult insects can still survive at low temperatures, most juveniles stop developing at temperatures below 18–20°C (see Table 3).²³ At temperatures below 15°C the common rice weevil stops developing.

At low temperatures insect pest life cycles (egg, larvae, pupae and adult) are lengthened from the typical four weeks at warm temperatures (30–35°C) to 12–17 weeks at cooler temperatures (20–23°C).

Table 3: The effect of grain temperature on the development of insects and mould.

Grain temp (°C)	Insect and mould development	Grain moisture content (%)
40–55	Seed damage occurs, reducing viability	–
30–40	Mould and insects are prolific	>18
25–30	Mould and insects are active	13–18
20–25	Mould development is limited	10–13
18–20	Young insects stop developing	9
<15	Most insects stop reproducing, mould stops developing	<8

Source: Kondinin Group

For more information, see Section [13.4.2 Aeration cooling](#) below

13.3.6 Structural treatments

Key points:

- Structural treatments such as diatomaceous earth (DE) can be used on storages and equipment to protect against grain pests.
- Check delivery requirements before using chemical treatments.

Growers who use chemicals as structural treatments run the risk of exceeding the maximum residue limit (MRL) and so this is not recommended. These chemicals do not list storage as a registered use on their labels or their MRLs. If you are storing pulses, or intend to in the future, be aware that MRLs are either extremely low or nil.

A better product to use is diatomaceous earth (DE), sometimes called inert dust. It is an amorphous silica commercially known as Dryacide® and acts by absorbing the insect's cuticle (protective waxy exterior), causing death by desiccation. Using DE as a structural treatment is possible, but the storage and equipment must be washed and dried before using for pulses. This will ensure the DE doesn't discolour the grain surface. If applied correctly, i.e. with complete coverage in a dry environment, DE can provide up to 12 months of protection for storages and equipment.

If unsure, check with the grain buyer before using any product that will come in contact with the stored grain.²⁴

13.3.7 Application

Inert dust requires a moving airstream to direct it onto the surface being treated; alternatively, it can be mixed into a slurry with water and sprayed onto surface. Read and follow label directions. Throwing dust into silos by hand will not achieve an even coverage, and so will not be effective. For very small grain silos and bins, a hand-operated duster, such as a bellows duster, is suitable. Larger silos and storages require a powered duster, e.g. a Venturi duster such as the Blovac BV-22 gun (Photo 9), operated by compressed air or a fan. If compressed air is available, it is the most economical and suitable option for use on the farm.

²³ Stored Grain Information Hub (2014) Aeration cooling for pest control. Revised. GRDC, <http://storedgrain.com.au/aeration-cooling/>

²⁴ Stored Grain Information Hub (2014) Storing pulses. Factsheet. Revised. GRDC, <http://storedgrain.com.au/storing-pulses/>

SECTION 13 TRITICALE

TABLE OF CONTENTS

FEEDBACK



Photo 9: A blower–vacuum gun such as the Venturi gun is the best applicator for inert dusts. Aim for an event coat of diatomaceous earth across the roof, walls and base.

Photo: C. Warrick, Proadvice

The application rate is calculated at 2 g/m² of surface area treated. Although DE is inert, breathing in excessive amounts of it is not ideal, so use a disposable dust mask and goggles during application. Apply DE at the recommended rates (Table 4).

Silo application

Apply inert dust in silos, starting at the top (if safe), by coating the inside of the roof then working your way down the silo walls, finishing by pointing the stream at the bottom of the silo. If silos are fitted with aeration systems, distribute the inert dust into the ducting, taking care not to get it into the motor, where it could cause damage.²⁵

Table 4: DE application guide.

Storage capacity (t)	Dust quantity (kg)
20	0.12
56	0.25
112	0.42
224	0.60
450	1.00
900	1.70
1800	2.60

13.3.8 Fumigation

There are a number of chemical options for the control of grain pests in stored cereals (Table 5).²⁶

VIDEOS

WATCH: [GCTV7: Applying diatomaceous earth demonstration](#)



MORE INFORMATION

[Hygiene and structural treatment for grain storages](#)

²⁵ Pulse Australia (2013) Northern Chickpea—Best Management Practices Training Course Manual 2013. Pulse Australia.

²⁶ Stored Grain Information Hub (2016) Northern and southern regions grain storage pest control guide. Factsheet. Revised. GRDC, <http://storedgrain.com.au/pest-control-guide-ns/>

SECTION 13 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Table 5: Resistance and efficacy guide for stored grain insects.

Treatment and example product	WHP	Lesser grain borer	Rust-red flour beetle	Rice weevil	Saw-toothed grain beetle	Flat grain beetle	Psocids (booklice)	Structural treatments
Grain disinfectants—used on infested grain to control full life cycle (adults, eggs, larvae, pupae)								
Phosphine (Fumitoxin [®]) ^{1,3} when used in gas-tight, sealable stores	2	Effective control	Effective control	Effective control	Effective control	High-level resistance in flat grain beetle has been identified, send insects for testing if fumigation failures occur	Effective control	
Sulfuryl fluoride (ProFume [®]) ¹⁰	1	Effective control	Effective control	Effective control	Effective control	Effective control	Effective control	
Grain protectants—applied postharvest. Poor adult control if applied to infested grain								
Pirimiphos-methyl (Actellic 900 [®])	nil ²		Effective control	Effective control	Resistant species likely to survive this structural treatment for storage and equipment	Effective control		Resistant species likely to survive this structural treatment for storage and equipment
Fenitrothion (Fenitrothion 1000 [®]) ^{4,7}	1–90		Effective control	Effective control	Resistant species likely to survive this structural treatment for storage and equipment	Effective control		Resistant species likely to survive this structural treatment for storage and equipment
Chlorpyrifos-methyl (Reldan Grain Protector [®]) ⁵	Nil ²	Resistance widespread (unlikely to be effective)	Effective control	Effective control	Resistant species likely to survive this structural treatment for storage and equipment	Effective control		Resistant species likely to survive this structural treatment for storage and equipment
‘Combined products’ (Reldan Plus IGR Grain Protector)	Nil ²	Resistance widespread (unlikely to be effective)	Effective control	Effective control	Resistant species likely to survive this structural treatment for storage and equipment	Effective control		Resistant species likely to survive this structural treatment for storage and equipment
Deltamethrin (K-Obiol [®]) ¹⁰	Nil ²	Effective control	Effective control	Resistance widespread (unlikely to be effective)	Effective control	Effective control		Resistant species likely to survive this structural treatment for storage and equipment
Spinosad and Chlorpyrifos-methyl (eg Conserve On-Form [™]) ⁹		Effective control	Effective control	Effective control	Effective control	Effective control		Resistant species likely to survive this structural treatment for storage and equipment
Diatomaceous earth, amorphous silica—effective internal structural treatment for storages and equipment. Specific-use grain treatments								
Diatomaceous earth, amorphous silica (Dryacide [®]) ⁸	Nil ²	Effective control	Effective control	Effective control	Effective control	Effective control		Effective control

- Not registered for this pest
- High-level resistance in flat grain beetle has been identified, send insects for testing if fumigation failures occur
- Resistant species likely to survive this structural treatment for storage and equipment
- Resistance widespread (unlikely to be effective)
- Effective control

1 Unlikely to be effective in unsealed sites, causing resistance, see label for definitions
 2 When used as directed on label
 3 Total of (exposure + ventilation + withholding) = 10 to 27 days
 4 Nufarm label only
 5 Stored grains except malting barley and rice/ stored lupins registration for Victoria only/ not on stored maize destined for export
 6 When applied as directed, do not move treated grain for 24 hours
 7 Periods of 6–9 months storage including mixture in adulticide (e.g. Fenitrothion at label rate)
 8 Do not use on stored maize destined for export, or on grain delivered to bulk-handling authorities
 9 Dichlorvos 500 g/L registration only
 10 Restricted to licensed fumigators or approved users
 11 Restricted to use under permit 14075 only. Unlikely to be practical for use on farm

Source: Registration information courtesy of Pestgenie, APVMA and InfoPest (DEED) websites
 Before applying, check with your grain buyers and bulk handlers and read labels carefully.
 Source: GRDC

Fumigation with phosphine is a common component of many integrated pest-control strategies (Photo 10).

Taking fumigation shortcuts may kill enough adult insects in grain so it passes delivery standards, but the repercussions of such practices are detrimental to the grains industry: poor fumigation techniques fail to kill pests at all stages of the life cycle, so while some adults may die, grain will soon be reinfested again as soon as larvae and eggs develop. What’s worse, every time fumigation is carried out poorly, insects with some resistance survive, making the chemical less effective in the future.

VIDEOS

WATCH: [GCTV Stored grain: Fumigation recirculation](#)



WATCH: [GCTV Stored grain: Phosphine dose rates](#)

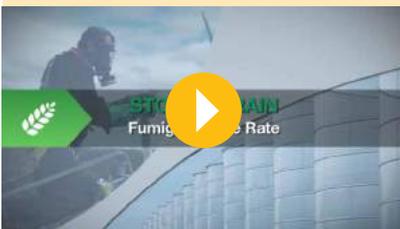


Photo 10: Phosphine is widely accepted as having no residue concerns.

Photo: DAF Qld

It is important to use phosphine as directed. While there is some resistance to phosphine, it is widely accepted as having no residue concerns for use in grains or pulses. The grain industry has adopted a voluntary strategy to manage the build-up of phosphine resistance in pests: its core recommendations are to limit the number of conventional phosphine fumigations on undisturbed grain to three per year, and to employ a break strategy.²⁷

Phosphine application

For effective phosphine fumigation, a minimum of 300 ppm gas concentration for seven days or 200 ppm for 10 days is required.

Achieve effective fumigation by placing phosphine at the correct rates (as directed on the label) onto a tray and hanging it in the top of a pressure-tested, sealed silo, or into a ground-level application system if the silo is fitted with recirculation.

After fumigation, ventilate grain for a minimum of one day with aeration fans running, or for five days if no fans are fitted.

After ventilation, a minimum withholding (WHP) period of two days is required before grain can be used for human consumption or stockfeed.

The total time needed for fumigating is 10–17 days.

As a general rule, only keep a silo sealed while carrying out the fumigation (e.g. one to two weeks). After fumigation has been completed, return to aeration cooling to hold the stored grain at a suitable temperature level.

Handle with care

Phosphine is a highly toxic gas with potentially fatal consequences if handled incorrectly. As a minimum requirement, the label directs users to wear cotton overalls buttoned at the neck and wrist, eye protection, elbow-length PVC gloves, and a breathing respirator with a combined dust and gas cartridge.

²⁷ P Collins (2009) Strategy to manage resistance to phosphine in the Australian grain industry, Cooperative Research Centre for National Plant Biosecurity, <http://www.graintrade.org.au/sites/default/files/file/NWPGP/Phosphine%20Resistance%20Strategy.pdf>

 **MORE INFORMATION**

GRDC, [Grain fumigation guide](#)

[Fumigating with phosphine, other fumigants and controlled atmospheres](#)

DAF Queensland, [Fumigation to control insects in stored grain](#)

Where to apply

Arrange the tablets where as much surface area as possible is exposed to air, so the gas can disperse freely throughout the grain stack. Spread phosphine tablets evenly across trays before hanging them in the head space or placing them level on the grain surface inside a gas-tight, sealed silo. Hang bag chains in the head space or roll out flat on the top of the grain so air can freely pass around them as the gas dissipates. Bottom-application facilities must have a passive or active air circulation system to carry the phosphine gas out of the confined space as it evolves. Without air movement, if left in a confined space, phosphine can reach explosive levels.

Non-chemical treatment options

Two non-chemical treatment options are:

- Carbon dioxide—treatment involves displacing the oxygen inside a gas-tight silo with CO₂, which creates an atmosphere toxic to grain pests. To achieve a complete kill of all the main grain pests at all life stages, CO₂ must be retained at a minimum concentration of 35% for 15 days.
- Nitrogen—grain stored under N₂ provides insect control and quality preservation with the advantages of also being safe to use and environmentally acceptable. The main operating cost is the capital cost of equipment and electricity. N₂ also produces no residues, so grains can be traded at any time (compared with chemical fumigants, which have withholding periods). Insect control with N₂ entails using pressure-swinging adsorption (PSA) technology to modify the atmosphere inside the grain storage to remove everything except N₂, thereby starving pests of oxygen.²⁸

13.3.9 Maximum residue limits (MRLs)

Key points:

- Grain samples are tested for pesticide residues in Australia and when export shipments leave the port to ensure they are within maximum residue limits (MRLs).
- A single violation of an importing country's MRL can lead to punitive measures on all Australian grain exported to that country and undermine Australian grains' reputation internationally.
- Consequences may include costs awarded against the exporter and/or grower. If repeated violations are detected with the same chemical, that chemical may be banned.
- It is essential that growers ensure both pre-harvest and post-harvest chemical applications adhere to the Australian Grain Industry Code of Practice.
- Use only registered products and observe all label recommendations including label rates and withholding periods.
- Trucks or augers that have been used to transport treated seed or fertiliser can be a source of contamination. Pay particular attention to storage and transport hygiene.
- Silos that have held treated fertiliser or pickled grain will have dust remnants that require particular attention. These silos either need to be cleaned or designated as non-food-grade storage.
- Compliance with Australian MRLs does not guarantee the grain will meet an importing country's MRL (which may be nil).
- Know the destination of your grain. When signing contracts, check the importing countries' MRLs to determine what pesticides are permitted on that crop.

By observing several precautions, growers can ensure that grain coming off their farm is compliant with the maximum pesticide residue limits that apply to Australian exports. Violations of maximum residue limits (MRLs) affect the marketability of

28 C Warrick (2012) Fumigating with phosphine, other fumigants and controlled atmospheres. GRDC, <http://storedgrain.com.au/fumigating-with-phosphine-and-ca/>

i MORE INFORMATION

[Managing MRLs factsheet](#)

Australian grain exports, and consequences may include costs being imposed on exporters and/or growers.

It is essential that both pre-harvest and post-harvest chemical applications adhere to the Australian Grain Industry Code of Practice, only registered products are used and all label recommendations, including rates and withholding periods, must be observed. Other key points include:

- Trucks or augers that have been used to transport treated seed or fertiliser can be a source of contamination—pay particular attention to storage and transport hygiene;
- Silos that have held treated fertiliser or pickled grain will have dust remnants—these silos either need to be cleaned or designated as non-food grade storage;
- Know the destination of your grain. When signing contracts, check the importing countries' MRLs to determine what pesticides are permitted on a particular crop.²⁹

13.4 Aeration during storage

13.4.1 Dealing with moist grain

Key points:

- Deal with high-moisture grain promptly.
- Monitoring grain moisture and temperature daily will enable early detection of mould and insects.
- Aeration drying requires airflow rates in excess of 15 litres per second per tonne (L/s/t).
- Dedicated-batch or continuous-flow dryers are a more reliable way to dry grain than aeration drying in less-than-ideal ambient conditions.

Aeration is recommended when storing triticale. In a Queensland trial, wheat at 16.5% MC and a temperature of 28°C was put into a silo with no aeration. Within hours, the grain temperature reached 39°C, and within two days reached 46°C, providing ideal conditions for mould growth and grain damage (Figure 4).³⁰ Grain that is over the standard safe storage moisture content of 12.5% can be dealt with by:

- Blending—mixing high-moisture grain with low-moisture grain, then aerating.
- Aeration cooling—for a short time holding grain of moderate moisture, up to 15% MC, under aeration cooling until drying equipment is available.
- Aeration drying—forcing large volumes of air to push a drying front through the grain in storage to slowly remove moisture. Supplementary heating can be added.
- Continuous-flow drying—transferring grain through a dryer, which uses a high volume of heated air to pass through the continual flow of grain.
- Batch drying—using a transportable trailer to dry 10–20 tonnes of grain at a time with a high volume of heated air, which passes through the grain and out perforated walls.

²⁹ GRDC. (2014). Managing maximum residue limits in export grain - Factsheet. <https://grdc.com.au/GRDC-FS-ManagingMRLs>

³⁰ Stored Grain Information Hub (2013) Dealing with high-moisture grain. Factsheet. GRDC, <http://storedgrain.com.au/dealing-with-high-moisture-grain/>

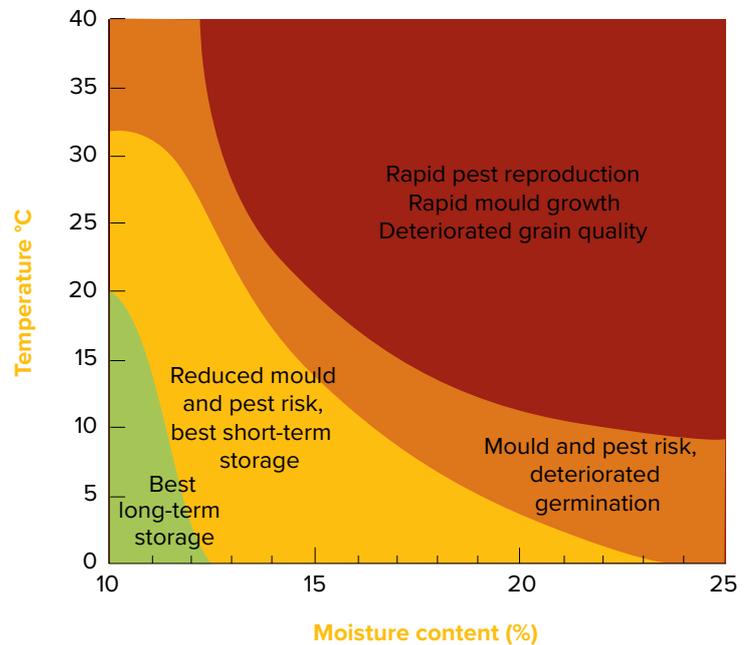


Figure 4: Effects of temperature and moisture on stored grain.

Source: GRDC

13.4.2 Aeration cooling

Key points:

- Grain temperatures below 20°C significantly reduce mould and insect development.
- Reducing grain temperature with aeration cooling protects seed viability.
- Controlling aeration cooling is a three-stage process: continual, rapid, and maintenance.
- Stop aeration if ambient, relative humidity exceeds 85%.
- Automatic grain aeration controllers that select optimum fan running times give the most reliable results.

Aeration cooling can be used to reduce the risk of mould and insect development for a month or two until drying equipment is available to dry grain down to a safe level for long-term storage or delivery. In most circumstances, grain can be stored at up to 14–15% MC safely with aeration cooling fans running continuously and delivering at least 2–3 L/s/t. It is important to keep fans running for the entire period, stopping them only if the ambient relative humidity is above 85% for more than about 12 hours, to avoid wetting the grain further.³¹

Blending

Blending is the practice of mixing slightly over-moist grain with lower-moisture grain to achieve an average moisture content below the ideal 12.5% MC. It is successful with grain with MC up to 13.5%, and can be an inexpensive way of dealing with wet grain, providing the infrastructure is available. Aeration cooling does allow blending in layers but if aeration cooling is not available, blending must be evenly distributed (Figure 5).³²

³¹ Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcra.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

³² Stored Grain Information Hub (2013) Dealing with high moisture grain. Factsheet. GRDC, <http://storedgrain.com.au/dealing-with-high-moisture-grain/>

VIDEOS

WATCH: [GCTV2: Grain storage cooling aeration](#)



MORE INFORMATION

GRDC, [Aerating stored grain](#)

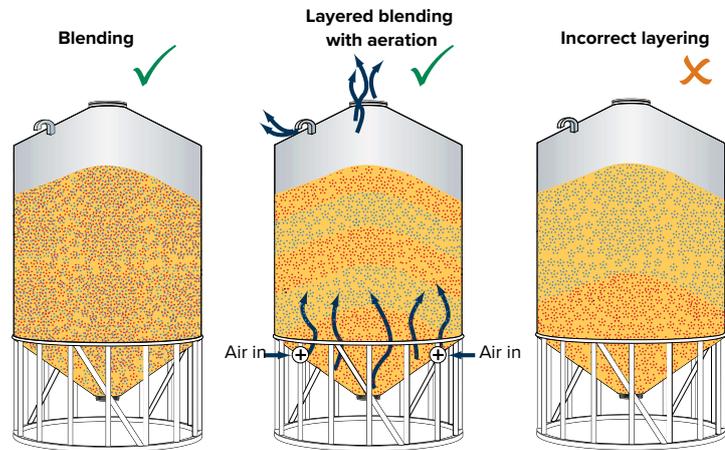


Figure 5: Diagram demonstrating the correct practices for blending.

Source: GRDC

Seed viability

Research trials have revealed that cereal grain stored at 12% MC for six months at 30–35°C (unaerated grain temperature) will have reduced seedling vigour and a lower rate of germination.

13.4.3 Aeration drying

Aeration drying relies on a high air volume and is usually done in a purpose-built drying silo or a partly filled silo with high-capacity aeration fans. Aeration drying is a slow process and relies on four factors:

- High airflow rates.
- Well-designed ducting for even airflow through the grain.
- Exhaust vents in the silo roof.
- Warm, dry weather.

It is important to seek reliable advice on equipment requirements and correct management of fan running times, otherwise there is a high risk of damaging the grain and reducing its quality.

High airflow for drying

Unlike aeration cooling, aeration drying requires high airflow, in excess of 15 L/s/t, to move drying fronts quickly through the whole grain profile and depth, and carry moisture out of the grain bulk. As air passes through the grain, it collects moisture from the grain, and forms a drying front. If airflow is too low, the drying front will take too long to reach the top of the grain stack, an occurrence that is often referred to as a ‘stalled drying front’. Providing the storage has sufficient aeration ducting, a drying front can pass through a shallow stack of grain much faster than a deep stack of grain. As air will take the path of least resistance, make sure the grain is spread to an even depth to ensure even and adequate drying.

Ducting for drying

The way to avoid hot spots is with adequate ducting to deliver an evenly distributed flow of air through the entire grain stack (as can be seen on the silo sides in Photo 11).

³³ A flat-bottomed silo with a full floor aeration plenum is ideal providing it can deliver

³³ Stored Grain Information Hub (2013) Dealing with high moisture grain. Factsheet. GRDC, <http://storedgrain.com.au/dealing-with-high-moisture-grain/>

air at at least 15 L/s/t. The silo may only be able to be part filled, which in many cases is better than trying to dry grain in a cone-bottomed silo with insufficient ducting.



Photo 11: Aeration drying requires careful management, high airflow rates, well designed ducting, exhaust vents and warm, dry weather.

Source: GRDC

Venting for drying

Adequate ventilation maximises airflow and allows moisture to escape rather than forming condensation on the underside of the roof and wetting the grain at the top of the stack. The amount of moisture that has to escape with the exhaust air is 10 L for every 1% MC removed per tonne of grain.

Weather conditions for drying

For moisture transfer to occur and drying to succeed, the external air, which is harnessed for pushing through the grain, must have a lower relative humidity than the grain's equilibrium moisture content. For example, grain at 25°C and 14% MC has an equilibrium point of the air around it at 70% relative humidity: in order to make this grain drier, the aeration drying fans would need to be turned on when the ambient air was below 70% relative humidity (Table 6).³⁴

Phase one of drying

Aeration drying fans can be turned on as soon as the aeration ducting is covered with grain, and left running continuously until the air coming out of the top of the storage has a clean, fresh smell. The only time drying fans are to be turned off during this phase is if ambient air exceeds 85% relative humidity for more than a few hours.

³⁴ Stored Grain Information Hub (2013) Dealing with high moisture grain. Factsheet. GRDC, <http://storedgrain.com.au/dealing-with-high-moisture-grain/>

VIDEOS

WATCH: [GCTV5: Aeration drying—getting it right](#)



MORE INFORMATION

[Dealing with high moisture grain](#)

Phase two of drying

By monitoring the temperature and moisture content of the grain in storage and referring to an equilibrium moisture table, such as Table 6, a suitable relative humidity trigger point can be set. As the grain dries, the equilibrium point will fall, so the relative humidity trigger point will need to be reduced to dry down the grain further. Reducing the relative humidity trigger point slowly during phase two of the drying process will help keep the difference in grain moisture from the bottom to the top of the stack to a minimum, by ensuring the fans get adequate run time to push each drying front right through the grain stack.

Table 6: *Equilibrium moisture content for wheat.*

Relative humidity (%)	Temperature			Grain moisture content (%)
	15	25	35	
30	9.8	9.0	8.5	
40	11.0	10.3	9.7	
50	12.1	11.4	10.7	
60	13.4	12.8	12.0	
70	15.0	14.0	13.5	

Note: values may be different for triticale grain.
Source: GRDC

Supplementary heating

Heat can be added to aeration drying in proportion to the airflow rate. Higher airflow rates allow more heat to be added as it will push each drying front through the storage quick enough to avoid overheating the grain close to the aeration ducting. As a general guide, inlet air shouldn't exceed 35°C.

Cooling after drying

Regardless of whether supplementary heat is added to the aeration drying process, the grain should be cooled immediately after it has been dried. Cool to the desired level.³⁵

13.4.4 Aeration controllers

Aeration controllers can manage both aeration drying and cooling, as well as maintenance functions, in up to 10 separate storages (Photo 12).³⁶ The unit takes into account the moisture content and temperature of grain at loading and the desired grain condition after time in storage, and automatically selects the correct type of aeration needed to obtain the desired grain moisture and temperature.³⁷

Research has shown that, with the support of an aeration controller, aeration can rapidly reduce stored grain temperatures to a level that helps maintain grain quality and inhibits insect development. During trials, where grain was harvested at 30°C and 15.5% MC, grain temperatures rose to 40°C within hours of being put into storage. An aeration controller was used to rapidly cool grain to 20°C and then hold the grain between 17°C and 24°C from November to March.

Before replicating similar results on their farm, growers need to:

- Know the capacity of their existing aeration system.
- Determine whether grain requires drying before cooling can be carried out.

³⁵ Stored Grain Information Hub (2013) Dealing with high moisture grain. Factsheet. GRDC, <http://storedgrain.com.au/dealing-with-high-moisture-grain/>

³⁶ Stored Grain Information Hub (2014) Aeration cooling for pest control. Factsheet. Revised. GRDC, <http://storedgrain.com.au/aeration-cooling/>

³⁷ GRDC (2007) New generation in aeration controller. Ground Cover, Issue 57. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-57-Grain-Storage-Supplement/New-generation-aeration-controller>

- Understand the effects of relative humidity and temperature when aerating stored grain.
- Determine the target conditions for the stored grain.

VIDEOS

WATCH: [Grain storage with Philip Burrill: using aeration coolers](#)



Photo 12: Automatic aeration controllers are the most effective way to cool grain and are designed to manage many storages from a central control unit.

Source: GRDC

13.5 Grain protectants for storage

It is recommended that a protectant be used when storing triticale, given the softness of the grain.³⁸ The widespread resistance of the lesser grain borer (*Rhyzopertha dominica*) to grain protectants is decreasing with the availability of products based on deltamethrin (e.g. K-Obiol® EC Combi) and spinosad (e.g. Conserve™ On-Farm).

K-Obiol® EC Combi

K-Obiol® EC Combi is a synergised grain protectant for use on cereal grains, malting barley and sorghum.³⁹ It is not suitable for oil seeds or pulses. It can be used in any type of storage, sealed or unsealed. It is suitable for use by grain growers and grain accumulators. Like all protectants, it is a liquid and must be evenly applied as a dilution to the grain as it is fed into the storage. It is for use on un-infested grain and is not recommended for eradicating insect pests when they have infested grain.

The active constituent is deltamethrin. Piperonyl butoxide is added as a synergist, i.e. to increase the effectiveness of the deltamethrin. As K-Obiol® EC Combi is based on deltamethrin, there are none of the insect-resistance problems that growers have with other protectants at this stage.

Because protectants are residual, grain end users may be concerned that the grain does not contain excessive levels of chemicals. This would generally only come about with incorrect treatment or double treatment as the grain moves along the supply chain. To protect the end user, and ultimately Australian grain growers, a product stewardship program has been developed to help ensure correct use of the product, including minimising the development of insect resistance and increasing the usable life of the chemical.⁴⁰

38 Waratah Seed Company (2010) Triticale: planting guide. Waratah Seed Company, http://www.porkcra.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

39 Bayer (n.d.) K-Obiol. Bayer, <https://www.environmentalscience.bayer.com.au/K-Obiol/About%20K-Obiol>

40 GRDC Stored Grain Information Hub. K-Obiol Combi. GRDC, <http://storedgrain.com.au/k-obiol-combi/>

SECTION 13 TRITICALE

TABLE OF CONTENTS

FEEDBACK

 MORE INFORMATION

Grain protectants prevent pests

Conserve™ On-farm

Conserve™ On-Farm is a Dow AgroSciences grain protectant that has three active ingredients that control most major insect pests of stored grain, including the resistant lesser grain borer (LGB).⁴¹ It provides six to nine months of control and has no WHP. MRLs have been established with key trading partners, and there are no meat residue bioaccumulation problems.

Conserve™ On-Farm is a combination of two parts that are mixed together for application. Using Part A and Part B together is very important in order to successfully control the complete spectrum of insects. They comprise:

- Part A—1 x 5 L of chlorpyrifos-methyl and S-methoprene, which controls all stored grain insect pests other than the LGB
- Part B—2 x 1 L of spinosad, which is very effective on the LGB, including resistant strains, but has little to no effect on other key species.⁴²

41 Dow AgroSciences (n.d.) Conserve. Dow AgroSciences, <http://www.conserveonfarm.com.au/en>

42 GRDC Stored Grain Information Hub. Conserve. GRDC, <http://storedgrain.com.au/conserve-farm/>

Environmental issues

Key messages

- Triticale appears to be more sensitive to frost damage than other cereals. Dry sowing for a portion of the crop is one option that has proven very successful and can be considered for triticale as well as other cereals.
- Among the cereals, triticale has the best adaptation to waterlogged soils and those with high pH (alkaline soils).
- Triticale is also tolerant of low pH (acid) soils, grows well on sodic soils, and tolerates soils high in boron.
- Farmers appreciate the ability of triticale to tolerate periods of drought through the growing season, and at the other extreme, its tolerance of waterlogging. There is limited research into triticale's ability to tolerate heat stress, but it is likely to have similar responses as wheat and rye.
- The crop is highly tolerant to soil with high concentrations of aluminium and to saline soils.

Due to the effects of climate change, both heat stress and frost are likely to play an increasing role in farming in the future, and growers will need to take steps to manage the risks and decrease their impact on crops. ¹ A survey conducted in 2015 revealed that grain growers and advisers rate grain filling heat as a greater risk than frost. ²

Despite these results, triticale, being a derivative of rye, is still assumed to be relatively resistant to abiotic stress. Its high productivity is most likely derived from high rates of carbon assimilation linked to stomatal physiology and, probably, low respiration rate. Triticale retains good to excellent adaptation to conditions of limited water supply and problem soils which involve salinity, low pH, defined mineral toxicities and deficiencies and waterlogging. ³

MORE INFORMATION

[The abiotic stress response and adaptation of triticale](#)

[Agronomist's guide to information for managing weather and climate](#)

14.1 Frost issues for triticale

Key points:

- Frost events can have major and sudden impacts on cereal yields.
- Frost doesn't cause extensive damage every year, but some areas are more prone to it and can feel frequent damage.
- There has been an increase in frost frequency in many areas in the last 20 years.
- Minor agronomic tweaks might be necessary in some frost prone areas.
- In the event of severe frost, monitoring needs to occur up to two weeks after the event to detect the full extent of the damage. ⁴
- Triticale has been estimated as one of the cereals most susceptible to frost. Crop susceptibility to frost from most to least susceptible is triticale, wheat, barley, cereal rye, and oats. ⁵
- It is estimated that frost costs the Australian grains industry about \$360 million annually in direct and indirect yield losses. ⁶

¹ R Barr (2016) Diversity the key to balancing frost-heat risks. GRDC, <https://grdc.com.au/Media-Centre/Media-News/South/2016/01/Diversity-the-key-to-balancing-frost-heat-risks>

² D Grey, J Nuttal, K Barlow (2015) South east Australian grain growers and advisors rate grain filling heat as a greater risk than frost. 17th Australian Agronomy Conference, 20–24 September, http://agronomyaustraliaproceedings.org/images/sampledata/2015_Conference/pdf/agronomy2015final00094.pdf

³ A Blum (2014) The abiotic stress response and adaptation of triticale: a review. Cereal Research Communications, 42 (3), 359–375.

⁴ D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here>

⁵ GRDC (2009) Managing the risk of frost. Factsheet. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk>

⁶ N Lee (2015) Frost ratings new tool to manage costly issue. GRDC, <https://grdc.com.au/Media-Centre/Media-News/National/2015/02/Frost-ratings-new-tool-to-manage-costly-issue>

SECTION 14 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Spring radiation frost is of significant importance in Australia, as it causes large yield and revenue losses to the national economy: it is estimated to cost about \$360 million a year in unfulfilled or lost yield potential.⁷ Winter cereals are most susceptible to low temperatures during the reproductive stage as reproductive parts are not protected by the leaf sheaths and ice can nucleate directly on them. As a result, complete or serious yield losses are felt when frost occurs between the booting and grain ripening stages (Photo 1).⁸ Identification of winter cereals with reproductive frost tolerance is a priority for frost research in Australia.



Photo 1: Frosted cereal grain head.

Source: GRDC

Once heads and grain have been frosted, small discoloured grain may be produced (Photo 2).⁹ In addition to direct yield loss, frost also results in economic losses by causing the crop quality to drop because it has lower organic matter digestibility and lower metabolisable energy. Frost can cause reductions in grain size, decrease flour extraction, decrease dough strength and baking quality, and cause increases in flour ash and α -amylase activity.

⁷ R Barr (2016) Diversity the key to balancing frost heat risks. GRDC, <https://grdc.com.au/Media-Centre/Media-News/South/2016/01/Diversity-the-key-to-balancing-frost-heat-risks>

⁸ N Lee (2014) Frost publication addresses hot research topic. GRDC, <https://grdc.com.au/Media-Centre/Media-News/West/2014/03/Frost-publication-addresses-hot-research-topic>

⁹ S Tshewang (2011) Frost tolerance in triticale and other winter cereals at flowering. Master's thesis. University of New England, https://e-publications.unen.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22



Photo 2: Comparison of healthy (left) and frost-damaged (right) H20 triticale grain.

Source: Tshewang 2011

Counterintuitively, crops grown in warmer climates, such as Australia’s northern cropping region, are at greater risk of frost injury because they develop faster, which increases the risk of heading and grain filling coinciding with the frost season: while July and August are theoretically the optimum flowering months for Northern Region crops, they are also the region’s highest frost-risk months. Long-term climate data show that there are typically multiple severe frosts in July and August, so growers need to delay crop sowing to ensure crops flower after this period. However, delaying flowering costs growers considerable yield benefits. Even under the best management, crop losses due to frost are estimated to average about 10% in the Northern Region. That figure is even higher in the northern part of the Northern grain region as potential yield is also reduced due to late sowing. Variety guides and decision-support tools can help growers match the best time for planting different varieties to optimise yields with an acceptable frost risk. There is little useful difference in frost resistance between current cultivars, so choosing the variety with the optimum flowering date for a particular sowing opportunity is more important.

Recommendations for northern farmers are to:

- use several cultivars and planting dates to spread the frost risk;
- determine the correct sowing window for the district for each cultivar;
- consider early sown cultivars with a longer growing season when favourable seasonal conditions are expected; and
- take into account the topography of the farm. Lower areas will be more prone to damage—sow these areas last;
- consider shorter-season cultivars when below-average rain for the season is forecast.¹⁰

14.1.1 Frost risk in Queensland: a grower’s experience

Severe frosts are common on Brian Gibson’s property at Dulacca, in Queensland. The property can lose half of its yield to frost, and grain quality can drop from prime hard to feed grade overnight. Over the past decade or more, a trend towards warmer weather from May to June has meant that cereal crops have been induced

¹⁰ J Paterson (2014) Frost curbs early sowing in north. In Frost. Ground Cover Supplement. Issue 109, March–April 2014. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS109>

to head sooner, exposing them to the risk of frost in August. Mr Gibson said that thermometers placed at head height monitored minimum temperatures, and gave him a good indication of where the frost line was. One of his strategies is to plant above this line on the elevated country, which is usually 2–3°C warmer than lower areas, and to select slower-growing varieties with a longer coleoptile length, as these flower after the frost risk has passed.¹¹

14.1.2 Triticale and frost

Triticale has been rated as susceptible to frost damage (Photo 3). One study reported that triticale is the most susceptible crop, followed by wheat, barley, rye and oats. While species difference in frost tolerance do exist, frost damage is also determined by other factors such as crop growth stage and environmental conditions.

One of the reasons why a greater area is not devoted to triticale on most farms is the poor tolerance to frost at flowering: in one study, growers said that frost susceptibility was one of the main constraints of triticale production and expansion.¹²



Photo 3: Frost-damaged grain head of H20 triticale plant (left); and cold damage to triticale leaf (right),

Sources: left, S Tshewang 2011; right, Florida Downunder

IN FOCUS

Frost tolerance in triticale and other winter cereals at flowering

A series of experiments was conducted to evaluate the relative reproductive frost tolerance in different commercial triticale genotypes, and how they compared with two other winter cereals, wheat and barley. Eight triticales (cv. Bogong(b), Tahara, H20, H151, H418, H426, JRCT 74 and JRCT 400), four bread wheats (cv. Kite, Ventura, Young and Wyalkatchem), one durum wheat (cv. Bellaroi) and one barley (cv. Kaputar) were tested over two years (2009 and 2010). In addition, the roles of cold hardening and potassium fertilisation in frost tolerance were also investigated using the triticale variety H426. The plants were grown in a glasshouse and treated to a single overnight natural frost at flowering (± 5 days). The damage was assessed by counting the number of fertile grains at maturity.

¹¹ J Paterson (2014) Frost curbs early sowing in north. In Frost. Ground Cover Supplement. Issue 109, March–April 2014. GRDC, <https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS109>

¹² J Roake, R Trethowan, R Jessop, M Fittler (2009) Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

SECTION 14 TRITICALE

TABLE OF CONTENTS

FEEDBACK

The collated results of two years showed a difference in frost tolerance between the different triticale varieties. However, the difference was not huge and varietal responses were mainly determined by frost temperature. Temperatures particularly below -3.9°C were found to be destructive (Figure 1). At -4.2°C , there was little effect on barley floret survival, while triticale and wheat were severely affected (Figure).¹³

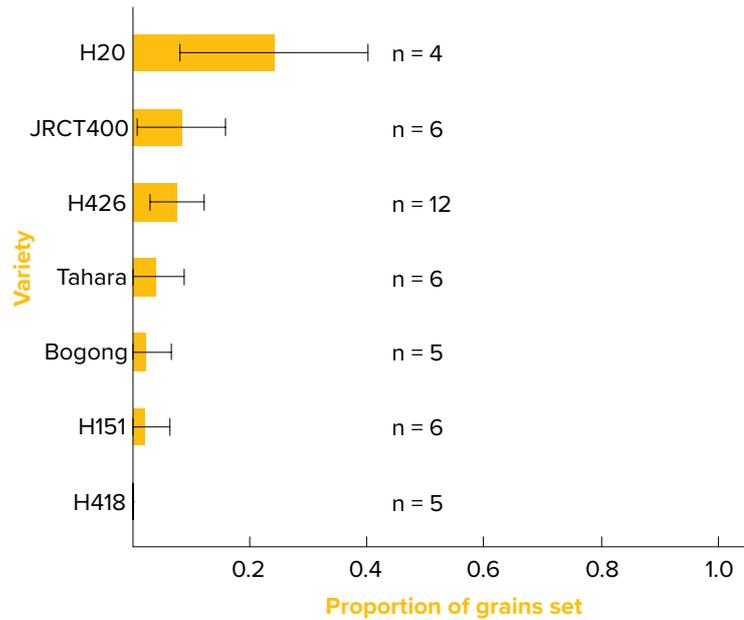


Figure 1: Proportion of grains that set in different triticale varieties at -4.2°C (2009). Bars are the lower and upper 95% confidence interval. N = the number of heads frosted.

Source: S Tshewang 2011

¹³ S Tshewang (2011) Frost tolerance in triticale and other winter cereals at flowering. Master's thesis. University of New England, https://e-publications.unen.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

SECTION 14 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: [Plant frost mechanisms—explained.](#)



MORE INFORMATION

[Frost and plant physiology: Q&A with Glenn McDonald](#)

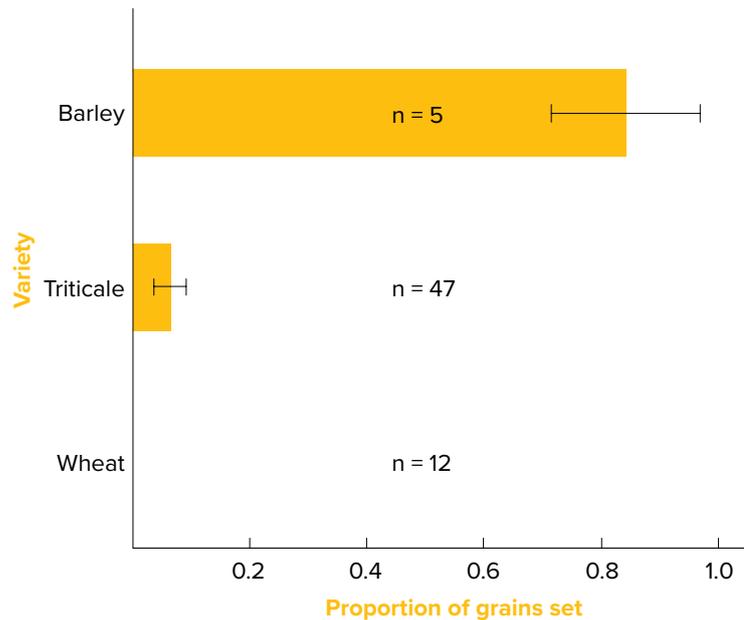


Figure 2: Proportion of grains that set in different species at -4.2°C (2009). Bars are the lower and upper 95% confidence interval. N = number of heads frosted.

Source: S Tshewang 2011

14.1.3 Conditions that lead to frost

Clear, calm and dry nights following cold days are the precursor conditions for a radiation frost (or hoar frost). These conditions are most often met during winter and spring where high pressures follow a cold front, bringing cold air from the Southern Ocean and settled, cloudless weather (Figure 3).¹⁴ When the loss of heat from the earth during the night decreases the temperature at ground level to zero, a frost occurs. Wind and cloud reduce the likelihood of frost by decreasing the loss of heat to the atmosphere. The extent of frost damage is determined by how quickly the temperature gets to zero, how long it stays below zero, and the how far below zero it falls.

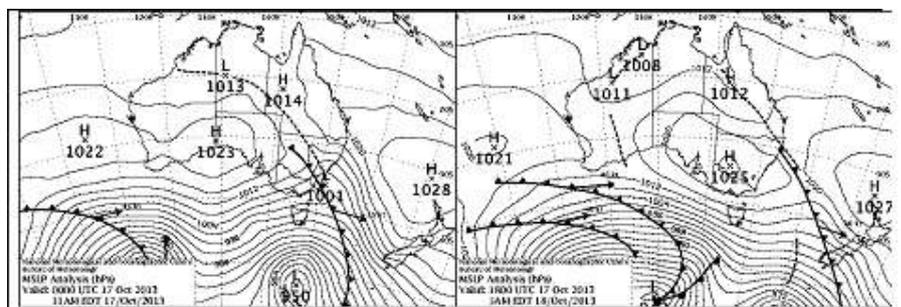


Figure 3: A cold front passes through, injecting cold air in from the Southern Ocean the day before a frost (left). Overnight, the high-pressure system stabilises over south-east Australia, meaning clear skies and no wind leading to a frost event (right).

Source: GRDC

¹⁴ D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here>

VIDEOS

WATCH: [GCTV20: Frost's emotional impact—is it greater than its economic impact?](#)



Though temperatures (particularly in winter and spring) are getting warmer, frost is still a major issue, and likely to remain so. CSIRO researchers found that in some areas of Australia the number of frost events is increasing (with the greatest increase in August), and that central western NSW, the Eyre Peninsula, Esperance and the northern Victorian Mallee were the only major crop growing areas to be less affected by frost from 1961 to 2010 (Figure 4).¹⁵ This increase is thought to be caused by the latitude of the subtropical ridge of high pressure drifting south (causing more stable pressure systems) and the existence of more El Niño conditions during this period.¹⁶

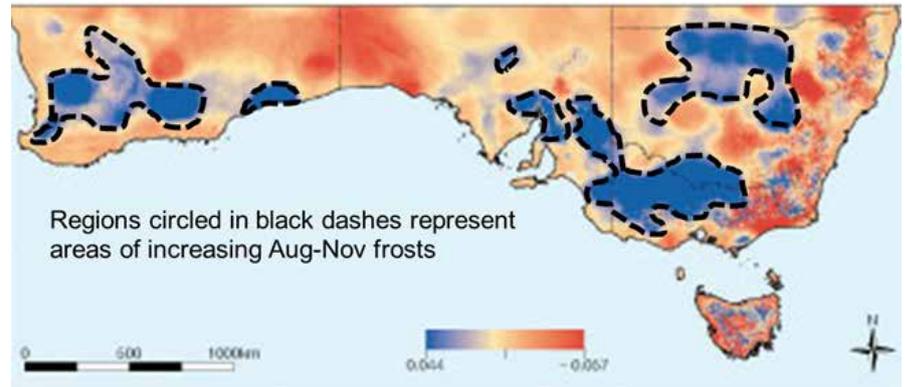


Figure 4: Region of increasing August–November frost events.

Source: GRDC

14.1.4 Diagnosing stem and head frost damage in cereals

Table 1 shows how to diagnose frost damage to stems and heads. Although the information given is for wheat, it applies equally to triticale.¹⁷

¹⁵ D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here>

¹⁶ D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here>

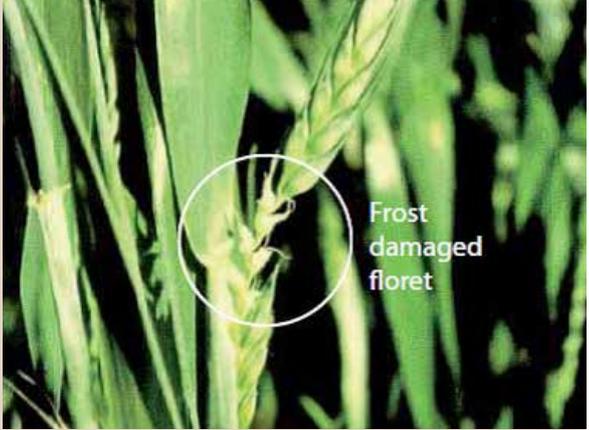
¹⁷ R Barr (2014) Frost-damage concern for south-eastern Australia. GRDC, <https://grdc.com.au/Media-Centre/Media-News/South/2014/09/Frost-damage-concern-for-southeastern-Australia>

SECTION 14 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Table 1: Symptoms of frost during early growth stages.

Crop growth stage	Inspection details	Frost symptoms in wheat	Example
Vegetative (before stem extension)	Examine leaves	Leaves are limp and appear brown and scorched	
Elongation (before and after head emergence)	Pull back leaf sheath or split stem to inspect damage	<p>Stem has a pale green to white ring that usually appears sunken, rough to touch, and soft to squeeze</p> <p>Stem or nodes can also be cracked or blistered</p> <p>Stems can be damaged on the peduncle (stem below head) or lower in the plant</p> <p>If the head has emerged it is likely that the flowering parts or developing grain has sustained damage</p> <p>If the head is in the boot then ongoing monitoring is required to assess the level of damage</p>	 

SECTION 14 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Crop growth stage	Inspection details	Frost symptoms in wheat	Example
<p>Flowering and post-flowering</p> <p>(Flowering is the most vulnerable stage, because exposed florets cannot tolerate low temperatures and are sterilised)</p>	<p>Peel back the lemma (husk), inspect the condition of the florets (floral organs) in the head</p>	<p>Grain will not form in frosted florets</p> <p>Some surviving florets may not be affected</p> <p>Pollen sacs (or anthers, normally bright yellow) but become dry, banana-shaped and turn pale yellow or white</p>	

Source: GRDC

What to look for in the paddock

- Symptoms may not be obvious until 5–7 days after the frost.
- Heads on affected areas have a dull appearance that becomes paler as frosted tissue dies (Photo 4).¹⁸
- At crop maturity severely frosted areas remain green longer.
- Severely frosted crops have a dirty appearance at harvest, due to blackened heads and stems and discoloured leaves.
- sample plants in the lowest parts of the paddock first, as this is where the damage will be the worst.



Photo 4: Frost damage in cereal.

Photo: Jim Kuerschner

¹⁸ R Barr (2014) Frost-damage concern for south-eastern Australia. GRDC, <https://grdc.com.au/Media-Centre/Media-News/South/2014/09/Frost-damage-concern-for-southeastern-Australia>

What to look for in the plant

- Before flowering:
- Freezing of the emerging head by cold air or water is caught next to the flag leaf or travels down the awns into the boot. Individual florets or the whole head can be bleached and shrivelled, stopping grain formation. Surviving florets will form normally.
- Stem frost by a small amount of water that has settled in the boot and frozen around the peduncle. Symptoms include paleness or discolouration, roughness at the affected point on the peduncle, and blistering or cracking of nodes and leaf sheath. Stems may be distorted.
- Flowering head:
- The ovary in frosted flowers feels spongy when squeezed and turns dark in colour. In normal flowers the ovary is bright white and feels crisp when squeezed. As the grain develops it turns green.
- Anthers are dull-coloured and are often banana-shaped. Normal anthers are green to yellow before flowering, or yellow turning white after flowering.
- Grain:
- Frosted grain at the milk stage is white, turning brown, with a crimped appearance. It is usually spongy when squeezed and doesn't exude milk or dough. Healthy grain is light to dark green and plump, and exudes white milk or dough when squeezed (Photo 5).
- Frosted grain at the dough stage is shrivelled and creased along the long axis, rather like a pair of pliers has crimped the grain (Photo 6).¹⁹



Photo 5: A normal cereal head (left) compared to frost-damaged cereal showing discoloured and deformed glumes and awns.

Source: DAFWA

¹⁹ DAFWA (2015) Diagnosing stem and head frost damage in cereals. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-stem-and-head-frost-damage-cereals>

SECTION 14 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

VIDEOS

WATCH: [GCTV15: Frost ratings](#)



WATCH: [GCTV15: The frost ranking challenge](#)



WATCH: [GCTV12: Frost susceptibility ranked](#)

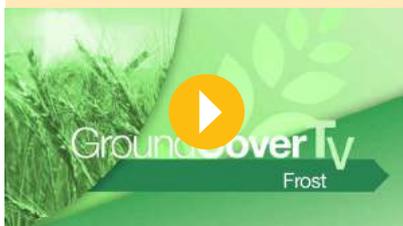


Photo 6: Frosted hollow grain dries back to a typically shrivelled appearance.

Source: [GRDC](#)

14.1.5 Managing frost risk

Key points:

- The widening of the frost 'season' has been exacerbated by changes in grower practices.
- Since the risk, incidence and severity of frost varies between and within years, as well as across landscapes, growers need to assess their individual situation regularly.
- The occurrence of frost and damage to grain crops is determined by a combination of factors including: temperature; humidity; wind; topography; soil type, texture and colour; crop species and variety; and how the crop is managed.
- The greatest losses in grain yield and quality are observed when frosts occur between the booting and grain-ripening stages of growth.
- Frost damage is not always obvious and crops should be inspected 5–7 days after a suspected frost.
- Methods to deal with the financial and personal impact of frost also need to be considered in the farm management plan.
- Careful planning and zoning, and choosing the right crops, are the best options to reduce frost risk.²⁰

Significant frost damage has occurred several times in triticale crops in recent years in the eastern cropping regions. Because triticale suffers more from frost damage than wheat, it should generally be sown later. Although the risk of frosting, particularly in low-lying paddocks, can be reduced by not planting too early, heat stress during grainfill will, potentially, become more of a factor the longer the sowing date is delayed.

Newer varieties, which have more tolerance to the cold, combined with the ability to cope with drier seasons, give growers a significant improvement in variety choice. In regions where spring frosts are a likely problem, a delay 7–10 days in sowing compared with main-season wheat varieties should reduce exposure to frosts. The

²⁰ GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk>

avoidance of frost-prone areas (e.g. low lying paddocks and creek areas) will also reduce possible frosting.²¹

The variability in the incidence and severity of frost means that growers need to adopt a number of strategies as part of their farm management plan. These include pre-season, in-season, and post-frost strategies.

There are two types of pre-season management tactics available for growers:

1. at the level of farm management planning; and
2. within identified frost zones of a farm.

Farm management planning tactics

Step 1: Assess personal approach to risk

Consider your personal approach to risk in your business; every individual will have a different approach. As part of this process, identify and measure the extent of the risk, evaluate risk-management alternatives and tailor the risk advice according to your attitude to and level of comfort with risk. The risk of frost can promote conservative farming practices, which should be carefully and regularly reviewed in light of the latest research.

Step 2: Assess frost risk of property

Carefully consider the risk of your property incurring frosts due to the location. Use historical seasonal records and forecasts. Because cold air will flow into lower areas, spatial variability (topography and soil type) across the landscape should also be considered. Temperature-monitoring equipment, such as Tinytags, iButtons and weather stations, can determine temperature variability across the landscape.

Step 3: Diversify the business

A range of enterprise options should be considered as part of a farm-management plan so as to spread financial risk in the event of frost damage. Options are subject to the location of the business and skill set of the manager, but the largest financial losses with frost have occurred where growers have a limited range of enterprises or crop types. Intensive-cropping systems, especially those focused on canola and spring wheat, are more at the mercy of frost than a diversified business, as both crops are highly susceptible to frost.

Step 4: Zone property and paddock

Paddocks or areas in paddocks that are prone to frost can be identified through past experience, and the use of precision tools such as topographic, electromagnetic and yield maps, and temperature monitors to locate susceptible zones. This can help determine the appropriate management practice to use to mitigate the incidence of frost. Be aware that frost-prone paddocks can be high-yielding areas on a farm when frosts do not occur.

Frost zone management tactics

Step 1: Consider enterprise within a zone

The use of identified frost zones should be carefully considered, for example using them for grazing, hay or oat production, and avoiding large-scale exposure to frost of highly susceptible crops like peas or expensive crops like canola. It may be prudent to sow annual or perennial pastures on areas that frost regularly, in order to avoid the high costs of crop production.

²¹ RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy, Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report.pdf

SECTION 14 TRITICALE

TABLE OF CONTENTS

FEEDBACK

VIDEOS

WATCH: Frost Initiative: Do micronutrients reduce frost risk?



WATCH: MPCN: Copper and frost relationship investigated



Step 2: Review nutrient management

For high-risk paddocks, set fertiliser (nitrogen, phosphorus, potassium) and seeding rates to achieve realistic yield targets, rather than for top yields. By doing this, the grower should minimise their financial exposure, reduce frost damage and increase whole-paddock profitability over time. Nutrients not applied in these paddocks could be reallocated to lower-risk areas of the farm.

While high levels of nitrogen (N) increase yield potential, N also promotes the production of vegetative biomass and increases the susceptibility of the crop to frost. Using conservative N rates at seeding and avoiding late top-ups results in less crop damage.

It is best if crops are not deficient in potassium or copper, as insufficient amounts of these elements may increase susceptibility to frost events. The levels of these nutrients can be assessed from initial soil tests and with plant-tissue testing. Copper deficiency can be ameliorated with a foliar spray pre-flowering and as late as the booting stage to optimise yield, even in the absence of frost. Potassium plays a role in maintaining cell-water content in plants, and it has been shown that plants deficient in potassium are more susceptible to frost. Soils that are deficient in potassium could benefit from increasing potassium levels at the start of the growing season. However, it is unlikely that there will be a benefit of extra potassium applied to plants that are not potassium-deficient.

There is no evidence that applying other micronutrients has any impact to reduce frost damage.

Step 3: Modify the soil heat-bank

The soil heat-bank helps reduce the risk of frost (Figure 5).²² Farmers can manipulate the way heat-banks operate, to store heat absorbed during the day and release it during the night into the crop canopy, to reduce the impact of a frost.

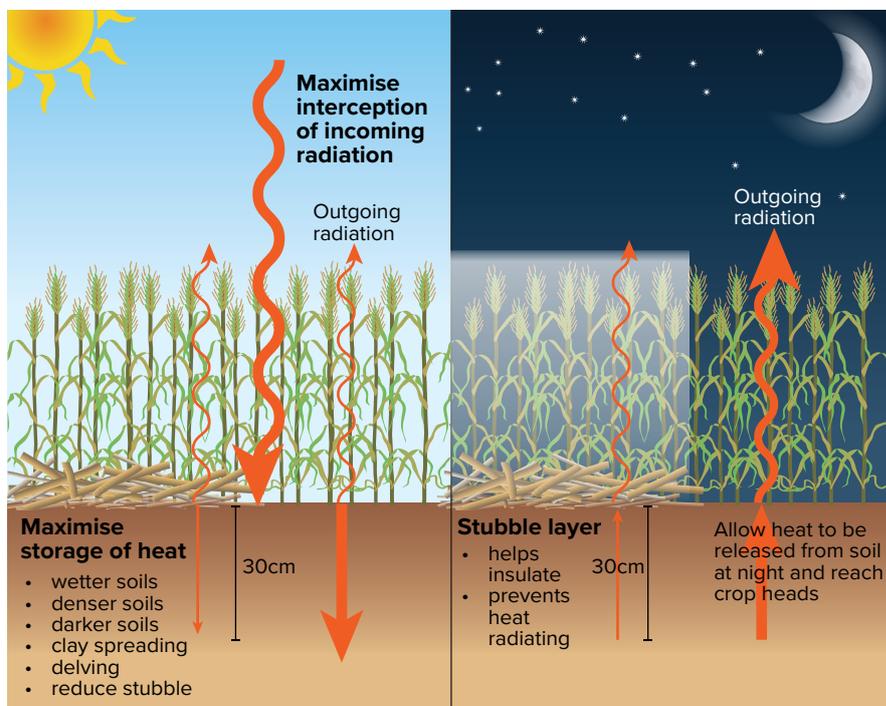


Figure 5: The soil heat-bank captures heat during the day and radiates that heat into the crop canopy overnight, to warm flowering heads and minimise frost damage.

Source: GRDC

22 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk>

SECTION 14 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Agronomic practices that may assist with storing heat in the soil heat-bank include:

- Practices that alleviate non-wetting sands, such as clay delving, mouldboard ploughing or spading, have multiple effects, and include increasing heat storage, nutrient availability and infiltration rate.
- Rolling sandy soil and loamy clay soil after seeding can reduce frost damage. It also prepares the surface for hay cutting should that be necessary.
- Reducing the amount of stubble—stubble loads above 1.5 t/ha in low-production environments (2–3 t/ha) and 3 t/ha in high-production environments (3–5 t/ha) generally increase the severity and duration of frost events, and have had a detrimental effect on yield under frost. However, reducing stubble can also be detrimental through increasing evaporation losses, decreased mineralisation etc.
- Halving the normal seeding rates can reduce frost severity and damage by creating a thinner canopy and more tillers, which result in a spread of flowering time. However, weed competitiveness can be an issue.

IN FOCUS

Stubble reduces frost severity

In a 2012 trial at Wickepin, WA, yields of wheat were 0.7 tonnes per hectare higher in burnt stubble high in the landscape (where there was moderate frost risk) and 0.3 t/ha higher in burnt stubble lower in the landscape where the frost risk is higher. Wheat in the high stubble plots had almost 85% sterility, while plants beyond the stubble had 20–30% sterility, indicating that the high stubble load increased the frost damage. Temperature data showed substantially colder temperatures in plots with high stubble. This is because stubble can insulate the soil surface, which lowers the amount of heat absorbed into the soil compared with paddocks without stubble. Less heat is radiated from the soil in stubble paddocks at night, which lowers the canopy temperature and leads to greater frost severity, duration and damage.²³ Reducing the amount of stubble is likely to reduce the risk of frost damage in triticale. .

23 B Biddulph in J Paterson (2014) Groundcover Supplement Issue 109: Frost - Stubble lifts frost severity. https://grdc.com.au/_data/assets/pdf_file/0028/75835/qcs109highres-pdf.pdf

SECTION 14 TRITICALE

[TABLE OF CONTENTS](#)
[FEEDBACK](#)

Table 2: Yield and yield component data for Nyabing. Where frost induced sterility (FIS), harvest index (HI) 100 grain weight (100GW) and screenings.

Position Stubble	Additional*	Low landscape	Removed	High landscape		LSD 0.05
		Standing		Standing	Removed	
Stubble biomass in August	3.5	2.6	0.5	2.6	0.5	0.5
Average minimum canopy temperature during September–October frosts	–2.4	–2.0	–1.8	–1.1	–1.3	0.16
Hours below zero	45	33	32	22	24	
Yield (t/ha)	0.6	1.0	1.8	1.9**	2.5**	0.40
FIS (%)	87	33	35	20	13	4.0
Screenings (%) <2 mm	56	9	9	13	13	5.5

*Additional stubble plot was unreplicated and was only located low in the landscape. **Yield estimated from small plot trial harvester cuts with two replicates per plot.

Source: [GRDC](#).

MORE INFORMATION

[Yield Prophet®](#)

[Flower Power](#)

Step 4: Select appropriate crops

Crop selection is an important factor to consider for frost-prone paddocks. Crops grown for hay are harvested for biomass, so the problem of grain loss from frost does not arise. Pasture rotations are a lower-risk enterprise, and oats are the most frost-tolerant crop during the reproductive stage. Barley is more tolerant than wheat at flowering, but it is not known if barley and wheat have different frost tolerance during grainfill. Canola is an expensive crop to risk on frost-prone paddocks, due to high input costs.

Yield Prophet® and Flower Power are useful tools to match the flowering time of varieties to your own farm conditions.

Step 5: Manipulate flowering times

When cereals are sown in frost-risk areas, a good tactic is to ensure the flowering window of the cropping program is spread widely. This can be done by using more than one variety and manipulating sowing date and planting varieties with different phenology drivers so that crops flower over a wide period during the season. It should be noted that flowering later than the frost may result in lower yields in seasons with hot, dry finishes, as plants will be subjected to heat and moisture stress.

Staging sowing dates over a 3–6-week period is recommended. If sowing just one variety, this would provide a wide flowering window. If sowing more than one variety: sow grazing cereal first; then a long-season cereal or a day-length-sensitive cereal; then an early-maturing cereal last. A whole farm planting program like this is planned so that flowering occurs over a two-week period, potentially exposing it to more frost risk but maximising the yield potential in the absence of frost. Even with this strategy in place, it is possible to have more than one frost event that causes damage.

i MORE INFORMATION

[Managing the costs of frosts](#)

[Groundcover supplement: Frost.](#)

Flowering over a wide window will probably mean that some crop will be frosted, but the aim is to reduce extensive loss rather than prevent it altogether.

Sowing at the start of a variety's preferred window will achieve higher yields at the same cost as sowing late. Sowing time remains a major driver of yield in all crops, so the primary objective with this tactic is to achieve a balance between crops flowering after the risk of frost has passed and before the onset of heat stress. The loss of yield from sowing late to avoid frost risk is often outweighed by the gains from sowing on time to reduce heat and moisture stress in spring.

Trials have shown that blending a short-season variety with a long-season variety is an effective strategy. However, the same effect can be achieved by sowing one paddock with one variety and the other with another variety to spread risks.

To minimise frost risk there needs to be a mix of sowing dates, crop types and maturity types to be able to incorporate frost avoidance strategies into the cropping system. In years of severe frost, regardless of which strategy is adopted it may be difficult to prevent damage.

Step 6: Fine-tune cultivar selection

As few cereal varieties are tolerant of frost, consider using varieties that have lower susceptibility to frost during flowering as a means of managing frost risk to the cropping program while maximising yield potential. There is no point selecting less-susceptible varieties for the whole cropping program if there is an opportunity cost of lower yield without frost.

Preliminary ranking information on current wheat and barley varieties for susceptibility to reproductive frost is available from the [National Variety Trials website](#). A new variety should be managed based on how known varieties of similar ranking are currently managed.

14.1.6 New insight into frost events and management

Key points:

- Growers need to consider carefully whether earlier sowing is justified in seasons where warmer temperatures are predicted.
- Warmer temperatures may reduce the frequency of frosts, but also increase the rate of crop development so that crops arrive at the susceptible, post-heading stages earlier.
- Situation analysis of the national impact of frost indicates substantial losses in all regions, averaging approximately 10% using current best practice.
- There can be even greater losses in yield when crops are sown late.
- Continued research into reducing frost risk remains a high priority, despite temperatures increasing overall.
- Variety guides and decision-support software are useful for matching cultivars to sowing opportunities.
- Current variety ratings based on floret damage may not provide a useful guide to frost damage of heads and stems.
- Crops become most susceptible to frost once awns emerge.
- If crop temperature at canopy height drops below -3.5°C after awn emergence, crops should be assessed for damage.
- Consider multiple sowing dates and or crops of different phenology to spread risk.

The first nationwide assessment of the comparative impact of frost in different Australian cropping regions provides important insights into how to manage frost risk in our cropping environments.

SECTION 14 TRITICALE

TABLE OF CONTENTS

FEEDBACK

Climate data from 1957 to 2013 were used to assess the frequency and severity of frost for each region of the Australian cropping belt.²⁴ Night-time minimum temperatures have been observed to increase over much of the Australian cropping region during that period. However, when researchers analysed the climate data they learned that frost risk and frost impact did not reduce over the whole cropping area during that time. The effect has been that warmer temperatures have accelerated plant development, causing crops to reach the frost-susceptible, heading stages more rapidly. So, counterintuitively, planting earlier or even at the conventional date during warmer seasons may sometimes increase frost risk.

The researchers used historical climate data from a grid database and for 60 locations that represent each of the four major cropping regions of Australia to determine the frequency and severity of frost (Figure 6 top panel). They used the crop-simulation model Agricultural Production Systems simulator program (APSIM) to estimate yields (Figure 6 bottom panel). Expert knowledge combined with data from frost trials was used to estimate crop losses. The computer simulation allowed them to predict crop losses for all Australian cropping regions, using damage information from a limited number of frost trial sites. It also allowed them to simulate potential yields using sowing dates optimised for yield in the hypothetical absence of frost risk, something that had not been achieved in experiments before.

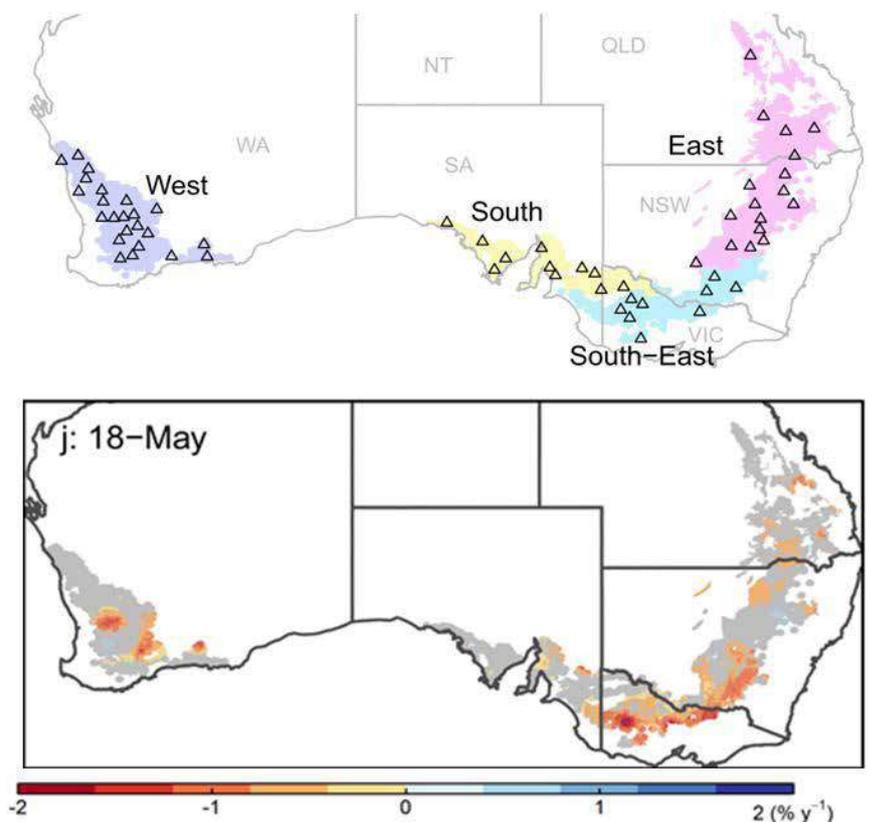


Figure 6: Maps showing sites and regions for which climate data were analysed for the frequency and severity of frosts (top panel) and annual percentage change in yield loss due to frost from 1957 to 2013 (bottom panel). In the lower map, negative values (yellow to red) represent areas where yield loss became worse over recent decades. Estimations in the lower panel were for the cultivar Janz, sown 18 May and are based on a ~5 km × 5 km grid of climatic data. (Gridded climate data may not reflect local climatic conditions of particular paddocks within each grid, as frost events are highly spatially variable.)

Source: GRDC

24 J Christopher, B Zheng, S Chapman, A Borrell, T Frederiks, K Chenu (2016) An analysis of frost impact guidelines to reduce frost risk and assess frost damage. GRDC Update Paper, GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/An-analysis-of-frost-impact-plus-guidelines-to-reduce-frost-risk-and-assess-frost-damage>

SECTION 14 TRITICALE

TABLE OF CONTENTS

FEEDBACK

The study revealed that estimated yield losses due to direct frost damage averaged close to 10% nationally for all crop maturity types, following current sowing guidelines (Figure 7). To estimate the loss of yield potential due to late sowing, which is necessary in many areas to manage frost risk, a theoretical optimal sowing date (as early as the 1 May) was used. When lost yield potential from delayed sowing (indirect cost of frost) was added to direct damage, estimated yield losses approximately doubled to 20% nationally (see Figure 7 'direct + indirect' impact). In the eastern grains region (Queensland to central NSW), losses were even greater, with estimated yield losses due to direct damage and delayed sowing (indirect losses) of 34%, 38% and 23% for early-, mid- and late-flowering cultivars, respectively (Figure 7).

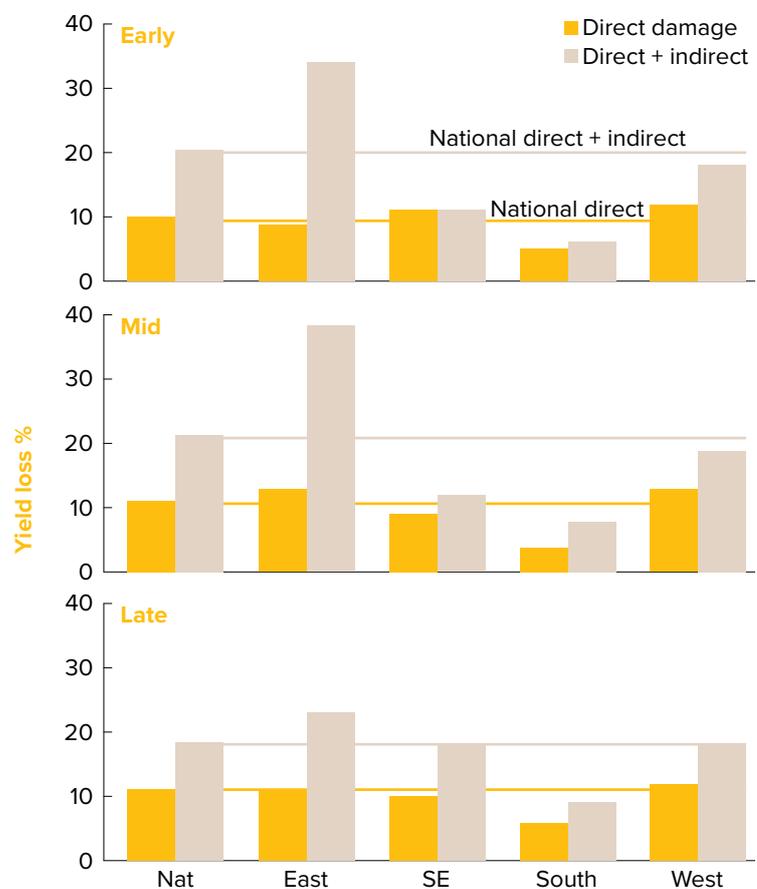


Figure 7: Estimated wheat yield losses (%) due to frost damage for crops sown at the current best sowing date (direct frost damage), and crop losses due to both direct damage and delayed sowing currently necessitated to manage frost risks (direct + indirect) for early-, mid- and late-flowering crops.

Source: GRDC

In some areas in each region, simulated frost impact has significantly increased between 1957 and 2013 (Figure 6, bottom panel, yellow, orange and tan areas). The estimated date of last frost has come later in some areas, but earlier in others. However, even in areas where it has come significantly earlier, higher temperatures have also increased the rate of development to frost-susceptible heading stages. The modelling suggests that crop heading dates have been brought forward more rapidly than the date of last frost, leading to an overall modelled increase in frost impact in many areas.

Over time, these trends may have implications for growers making planting decisions. They indicate that sowing early to increase yield potential may not always be the best course of action in warmer seasons, even when a lower frequency of frost events is anticipated. By increasing the rate of crop development, warmer temperatures cause the crop to develop more rapidly to the frost-susceptible, heading stages, which may actually increase frost risk.

These results indicate that continued research to reduce frost risk remains a high priority, despite increasing temperatures due to climate change. Counterintuitively, percentage yield losses are greatest in the Northern Region with the greatest yield losses actually due to delayed sowing rather than frost per se.

14.1.7 Guidelines to reduce frost risk and assess frost damage

Matching variety to planting opportunity

The current best strategy to maximise long-term crop yields is to aim to time crop heading, flowering and grainfilling in the short window of opportunity after the main frost risk period has passed and before day-time maximum temperatures become too high.

It is essential that varieties are sown within the correct window for the district, as outlined in variety guides.

Planting in the optimum window does not guarantee that crop loss due to frost will be averted, nor does it always prevent drastic yield reduction due to late-season heat and drought stress. However, planting a variety too early gives a much higher probability of crop loss.

With seasonal temperature variation, the days to flowering for each variety will change from season to season, as discussed above.

Current variety ratings based on floret damage may not provide a useful guide. Floret damage ratings are yet to be correlated with more significant head and stem damaging frosts.

Measuring crop temperature

Temperatures taken in the crop are useful in determining whether the crop may have been exposed to damaging temperatures. A historic comparison of on-farm and district minimum temperatures also allows growers to fine-tune district management recommendations to better suit their property and individual paddocks. District recommendations are based on one, or at best, a few sites, for each district, and may not correlate well with the experience of individual growers. Thus, in many instances, the recommendations likely err on the side of caution.

Stevenson screen temperatures measured at Bureau of Meteorology stations do not fully explain frost risk, either. In crops, the temperature can vary several degrees from the temperature measured in the screen. On nights of still, cold air, clear skies, and low humidity, temperatures can drop rapidly, resulting in radiant frost (Figure 8). Temperatures in a crop can vary widely, due to differences in topography, micro-environments and recording methods.

SECTION 14 TRITICALE

TABLE OF CONTENTS

FEEDBACK

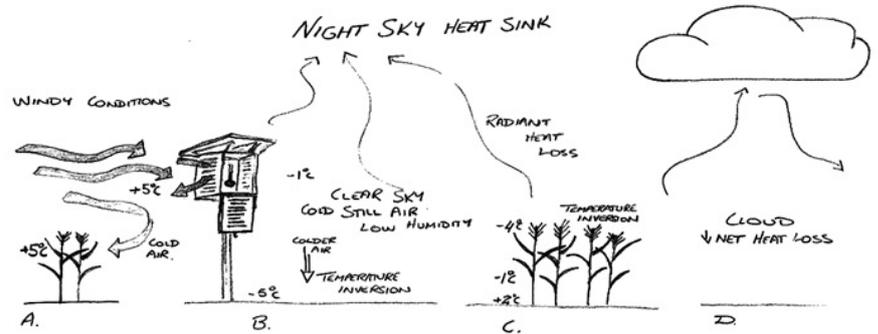


Figure 8: If clear skies and still, cold, dry air coincide, heat can be lost rapidly to the night sky, resulting in a radiant frost. Minimum air temperatures measured at head height can be several degrees colder than reported ‘screen’ temperatures. Some indicative temperatures are illustrated for (A) windy conditions, (B) clear, still conditions in an open area, (C) clear, still conditions in a crop, and (D) cloudy conditions.

Source: GRDC

Measurements taken using exposed thermometers at canopy height (Photo 7) give a much more accurate indication of the likelihood of crop damage.²⁵



Photo 7: Canopy temperature measured using a calibrated minimum–maximum thermometer. For best results, a minimum of two or three field thermometers are required to give representative temperatures for a crop. In undulating country, more thermometers should be used to record temperatures at various heights in the landscape.

Source: GRDC

14.1.8 What to do with a frosted crop

Once a frost has occurred, especially at or after flowering, the first step is to inspect the affected crop and collect a random sample of heads to estimate the yield loss incurred.

²⁵ J Christopher, B Zheng, S Chapman, A Borrell, T Frederiks, K Chenu (2016) An analysis of frost impact guidelines to reduce frost risk and assess frost damage. GRDC Update Paper. GRDC, <https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/An-analysis-of-frost-impact-plus-guidelines-to-reduce-frost-risk-and-assess-frost-damage>

In the event of severe frost (Photo 8),²⁶ monitoring needs to occur for up to two weeks after the event to ensure all the damage is detected. After the level of frost damage is estimated, the next step is to consider options for the crop (Table 2).²⁷



Photo 8: *Crops in severely frosted areas such as this mature later and are often stained or discoloured.*

Source: DAFWA

Option 1: Take through to harvest

If the frost is prior to or around growth stage GS 31 to GS 32, most cereals can produce new tillers to compensate for damage, provided spring rainfall is adequate, so it may be worth keeping the crop and harvesting it. Tillers already formed but lower in the canopy may become important. Naturally, tiller response, depends on the location and severity of the damage. Compensatory tillers will mature later, but where soil-moisture reserves are high, or it is early in the season, they may contribute to grain yield.

A later frost is more concerning, as there is less time for compensatory growth. The grain yield needed to recover the costs of harvesting should be determined using gross margins.

Option 2: Cut and bale

Cutting and baling is an option when late frosts occur during flowering and through grain fill. Assess crops for hay quality within a few days of a frost and be prepared to cut a larger area than you had intended to before the start of the season. Producing hay can also be a good management strategy to reduce stubble, weed seedbank

²⁶ DAFWA (2015) Diagnosing head and stem frost damage in cereals. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-stem-and-head-frost-damage-cereals>

²⁷ R Barr (2014) Frost damage concern for south-eastern Australia. GRDC, <https://grdc.com.au/Media-Centre/Media-News/South/2014/09/Frost-damage-concern-for-southeastern-Australia>

and disease loads for the coming season. This may allow more rotational options in the following season to recover financially from frost, for example to go back to cereal on cereal in paddocks cut early for hay. However, as hay making can be an expensive exercise, growers should have a clear path to market or a use for the hay on the farm before committing to this option.

Option 3: Grazing, manuring and crop-topping

Grazing is an option after a late frost, when there is little or no chance of plants recovering, or when hay is not an option. Spraytopping for weed seed control may also be incorporated into this option, especially if the paddock will be sown to crop the next year. Ploughing in the green crop is an option to return organic matter and nutrients to the soil, manage crop residues and weeds, and improve soil fertility and structure. Brown manuring can also be considered in this toolbox. It involves spraying out the crop with a non-selective herbicide such as Glyphosate, hence negating the detrimental effects of ploughing country. The economics need to be considered carefully.²⁸

Depending on the degree of damage, the grain may still make valuable stockfeed (Table 3). Severely frosted grain can have metabolisable energy (ME) of approximately 1 MJ/kg lower than unfrosted grain. Provided allowance is made for this, the grain is useful in a feed ration.²⁹

Table 3: Management options for frost-damaged crops, with advantages and disadvantages.

Options	Advantages	Disadvantages
Harvest	Salvage remaining grain More time for stubble to break down before sowing Machinery available	Cost may be greater than return Need to control weeds Threshing problems Removal of organic matter
Hay, silage	Stubble removed Additional weed control	Costs \$35–50/t to make hay Quality may be poor Nutrient removal
Chain, rake	Retains some stubble (which reduces erosion risk) Allows better stubble handling	Raking costs \$5/ha Time taken
Graze	Feed value	Inadequate stock to use feed Remaining grain may cause acidosis Stubble may be difficult to sow into
Spray	Stops weeds seeding Preserves feed quality for grazing Gives time for final decisions Retains feed Retains organic matter	With a thick crop, difficulty getting chemicals onto all of the weeds May not be as effective as burning Boom height limitation Costs \$5/ha plus cost of herbicide Some grain still in crop

28 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk>

29 Jessop RS, Fittler M. (2009). Triticale production manual—an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report.pdf

SECTION 14 TRITICALE

TABLE OF CONTENTS

FEEDBACK

MORE INFORMATION

GRDC factsheet, [Managing frost risk](#)

VIDEOS

WATCH: [GCTV3: Frost R&D](#)



WATCH: [GCTV16: National Frost Initiative](#)



Options	Advantages	Disadvantages
Plough	<ul style="list-style-type: none"> Recycles nutrients and retains organic matter Stops weed seedset Green manure effect 	<ul style="list-style-type: none"> Requires offset disc to cut straw Soil moisture needed for breakdown and incorporation of stubble
Swathe	<ul style="list-style-type: none"> Stops weed seedset Windrow can be baled Regrowth can be grazed Weed regrowth can be sprayed 	<ul style="list-style-type: none"> Relocation of nutrients to windrow Low market value for straw Poor weed control under swathe Costs \$20/ha to swathe Costs \$5/ha per herbicide to spray
Burn	<ul style="list-style-type: none"> Recycles some nutrients Controls surface weed seeds Permits re-cropping with disease control Can be done after rain 	<ul style="list-style-type: none"> Potential soil and nutrient losses Fire hazard Organic matter loss

Source: GRDC

Useful tools

- [AgExcellence Alliance](#) has an annotated list of several weather and farming apps.
- Plant-development apps, e.g. [MyCrop](#), DAFWA [Flower Power](#)
- [Temperature monitors](#)
- [Yield Prophet®](#)

14.1.9 National Frost Initiative

The objective of the GRDC's National Frost initiative is to provide the Australian grains industry with targeted research, development and extension solutions to manage the impact of frost and maximise seasonal profit. It funds multidisciplinary projects in these areas:

- Genetics—developing more frost-tolerant wheat and barley germplasm, and ranking current wheat and barley varieties for susceptibility to frost.
- Management—developing best-practice crop canopy, stubble, nutrition and agronomic management strategies to minimise the effects of frost, and searching for innovative products that may minimise the impact of frost.
- Environment—predicting the occurrence, severity and impact of frost events on crop yields and at the farm scale to enable better risk management.³⁰

14.2 Drought and heat stress

Key points:

- Heat and drought stress is a key yield-limiting factor in crop production. Heat stress has been shown to adversely affect yield as early as growth stage 45.
- Post-flowering heat stress is most common in the northern region.
- Delayed sowing increases the chance of the crop being exposed to heat stress, particularly at the vulnerable pre-flowering growth stages.

Drought is one of the major environmental factors that reduces grain production in the rain-fed and semi-arid regions of Australia (Photo 9). The direct effects of heat stress are estimated to cost grain growers about \$1.1 billion nation-wide. Due to the

³⁰ GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, <https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk>

effects of climate change, both heat stress and frost are likely to increase in the future, and will require growers to take steps to manage the risks.³¹



Photo 9: Drought conditions in 2015 left a dry landscape prone to dust storms.

Photo: Brad Collis,
Source: GRDC.

Triticale has been variably rated for its resilience in drought, with one study ranking cereal in terms of highest-yielding under drought conditions as, in descending order: barley, triticale, durum wheat, bread wheat and oats.³² Triticale is well adapted to conditions where water is limited.

Overseas data indicate that under dry conditions triticale's biomass production falls, but that the biomass of wheat normally falls much further, so triticale's relative advantage is likely to become more pronounced during droughts.

These data are backed up by a study in a Mediterranean climate, in which researchers found that yields of wheat dropped significantly (by 25%, 54% and 87%) under drought stress, while those for triticale showed only a slight, and statistically insignificant, amount (by 8%) in comparison to the irrigated control. It is suggested that the greater drought resistance of triticale can be attributed to the earliness of its heading and to the greater capacity of its roots to extract water from the soil.³³

In another study, in 1988–89 in Mexico, 24 early triticale lines were tested in under drought stress (mean yield of 1,720 kg/ha–1) and normal conditions (mean yield of 7,180 kg/ha–1) and compared with the best standard wheat cultivar available. Under drought conditions, triticale had a yield advantage over wheat.³⁴

In 2009, laboratory experiments indicated that the varieties Tickit and Credit were able to accumulate more carbohydrates (sugars) in their stems and to translocate them to the grain compared with varieties used commonly in New South Wales, such as Everest and Kosciusko. The better translocation capacity may be related to improved drought tolerance. More detailed field assessment of water relations

31 R Barr (2016) Diversity the key to balancing frost heat risks. GRDC, <https://grdc.com.au/Media-Centre/Media-News/South/2016/01/Diversity-the-key-to-balancing-frost-heat-risks>

32 C López-Castañeda, RA Richards (1994) Variation in temperate cereals in rainfed environments II. Phasic development and growth. *Field Crops Research*, 37 (1), 63–75.

33 F Giunta, R Motzo, M Deidda (1993) Effect of drought on yield and yield components of durum wheat and triticale in a Mediterranean environment. *Field Crops Research*, 33 (4), 399–409.

34 A Blum (2014) The abiotic stress response and adaptation of triticale: a review. *Cereal Research Communications*, 42 (3), 359–375.

SECTION 14 TRITICALE

TABLE OF CONTENTS

FEEDBACK

in triticale compared with wheat is needed, especially with the likelihood of drier conditions associated the current projections on climate change.³⁵

Heat-stress affects crop and cereal production in all regions of the Australian wheatbelt. It can have significant effects on grain yield and productivity, with potential losses equal to, and potentially greater than, other abiotic stressors such as drought and frost. Controlled-environment studies have established that a 3–5% reduction in the grain yield of wheat can occur for every 1°C increase in average temperature above 15°C. Field data suggest that yield losses can be in the order of 190 kg/ha for every 1°C rise in average temperature, in some situations having a more severe effect on yield loss than water availability.

Plants are more sensitive to elevated temperatures during the reproductive stages of growth, with physiological responses including premature leaf senescence, reduced photosynthetic rate, reduced seedset, reduced duration of grainfill, and reduced grain size, all of which lead, ultimately, to reduced grain yield. Even without temperature increases as a result of climate change, elevated temperatures are a normal, largely unavoidable occurrence during the reproductive phase of Australian crops in September and October.³⁶

In some cereals, heat stress can be identified by the withering and splitting of leaf tips (Photo 10). The tips can also turn brown to grey in colour. In this situation, some or all grains fail to develop in a panicle.³⁷



Photo 10: *Withered and split tips in heat stressed cereal.*

Source: DAFWA

Heat stress is a key yield-limiting factor in crop production. The results of recent trials suggest that variety selection and early sowing are still the most effective means to reduce the risk of a crop being damaged by excessive heat. A later sown crop will have an increased likelihood of being exposed to the heat stress at more sensitive growth stages, particularly pre-flowering, and will have greater consequences to the potential grain yield.³⁸

³⁵ RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report.pdf

³⁶ P Telfer, J Edwards, H Kuchel, J Reinheimer, D Bennett (2013) Heat stress tolerance of wheat. GRDC Update Paper. 7 February 2013. GRDC, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Heat-stress-tolerance-of-wheat>

³⁷ DAFWA (2016) Diagnosing heat stress in oats. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-heat-stress-oats>

³⁸ P Telfer, J Edwards, D Bennett, H Kuchel (2013) Managing heat stress in wheat. Mallee Sustainable Farming, <http://www.msfp.org.au/wp-content/uploads/Managing-heat-stress-in-wheat.pdf>

14.2.1 Managing heat and drought stress

Because drought can be unpredictable and can last for extended periods of unknown length, it is difficult to prepare for it. See the links below for some tips on managing drought.

In drought, it is important to not ignore the signs and to have a plan, act early, review and then plan again, and revise the plan with each action as you play out your strategy.

Step One: Check the most limiting farm resources:

- funds available;
- surface/subsoil moisture for crop leaf and root growth;
- need to service machinery—breakdowns cost time, money and frustration.

Step Two: Set action strategies, considering:

- breakeven position of each strategy chosen;
- windows of opportunity to adopt management practices that will be profitable during drought;
- available resources and the implications for ground cover, chemical residues, etc., of carrying out each strategy;
- when situations are changing, conditional and timely fall-back options.

Step Three: Monitor and review performance, position and outlook by:

- using your established network to stay informed about key factors that affect your drought strategies;
- being proactive about the decisions made;
- being prepared for change;
- remembering that the impact falls very heavily not only on the decision makers but on the whole farm family.³⁹

Soil management following drought

The principal aim after rain should be to establish either pasture or crop as a groundcover on your bare paddocks as quickly as possible. This is especially important on the red soils, but is also important for the clays. After drought, many soils will be in a different condition to what is considered to be their 'normal' condition. Some will be bare and powdery on the surface, some will be further eroded by wind or water, and some will have higher levels of nitrogen (N) and phosphorus (P) than expected. Loss of effective ground cover (due to grazing or cultivation) leaves the soil highly prone to erosion by wind and water. Research by the former Department of Land and Water Conservation's Soil Services showed that erosion due to drought-breaking rain can make up 90% of the total soil loss in a 20–30 year cycle. Following a drought, available N and P levels in the soil are generally higher than in a normal season. However, most of the N and P is in the topsoil, so if erosion strips the topsoil much of this benefit is lost.⁴⁰

14.3 Waterlogging and flooding issues for triticale

Key points:

- Waterlogging occurs when roots cannot respire due to excess water in the soil profile.

MORE INFORMATION

Make sure to consider the impacts of [herbicide residues following drought](#).

[Winter cropping following drought](#)

[Soil management following drought](#)

[DPI NSW Drought Hub](#)

[Drought planning](#)

[Managing drought](#)

39 Meaker G, McCormick L, Blackwood I. (2007). Primefacts: Drought planning. NSW DPI. http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0008/96236/drought-planning.pdf

40 Jenkins A. (2007). Primefacts: Soil management following drought. NSW DPI. http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0012/104007/soil-management-following-drought.pdf

SECTION 14 TRITICALE

TABLE OF CONTENTS

FEEDBACK

- Though cereals can be more prone to waterlogging than other crop types, triticale has been found to be more tolerant of waterlogged conditions than wheat.⁴¹
- Water does not have to appear on the surface for waterlogging to be a problem.
- Improving drainage from the inundated paddock can decrease the period at which the crop roots are subjected to anaerobic conditions.
- While raised beds are an expensive management strategy, they are also the most effective at improving drainage.

Waterlogging occurs whenever the soil is so wet that there is insufficient oxygen in the pore spaces for plant roots to be able to respire adequately (Photo 11).⁴² Other gases detrimental to root growth, such as carbon dioxide and ethylene, also accumulate in the root zone and affect the plants.

Plants differ in their demand for oxygen, so there is no universal level of soil oxygen that can be used to identify what constitutes waterlogged conditions. In addition, a plant's demand for oxygen in the root zone will vary with its stage of growth.⁴³



Photo 11: The 2016 July wet had a big impact on producers in Murrumburrah.

Photo: Harden Murrumburrah Express

41 CJ Thomson, TD Colmer, ELJ Watkin, H Greenway (1992) Tolerance of wheat (*Triticum aestivum* cvs Gamenya and Kite) and triticale (*Triticosecale* cv. Muir) to waterlogging. *New Phytologist*, 120 (3), 335–344. See also KV Cooper, RS Jessop, NL Darvey. In M Mergoum, H Gómez-Macpherson (eds) (2004) *Triticale improvement and production*. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, <http://www.fao.org/docrep/009/y5553e/y5553e00.htm>

42 Harden Murrumburrah Express (2016) Farmers feel the wet with crops under water. 19 August. Harden Murrumburrah Express, <http://www.hardenexpress.com.au/story/4106306/crops-still-water-logged/>

43 Soilquality.org. Waterlogging. Soilquality.org., <http://soilquality.org.au/factsheets/waterlogging>

Many wetland plants are specially adapted to cope with life in waterlogged soils: they have a combination of a high volume of aerenchyma (soft plant tissue containing air spaces) and a barrier to prevent radial oxygen loss (ROL) from roots. The lack of a barrier to ROL in dryland cereals presumably contributes to their sensitivity to soil waterlogging.⁴⁴

Among the cereals, triticale has been reported to be more tolerant of waterlogged conditions than wheat.⁴⁵ Some farmers have noted that triticale also outperforms barley in areas prone to waterlogging.⁴⁶ At one farm, the variety Rufus was completely under water for 4–5 days and still yielded 1.34 t/ha. It also carried no rust, and the straw was baled for sale to dairy producers.⁴⁷

Researchers in WA explored the responses of two genotypes of wheat (*Triticum aestivum* cvs Gamenya and Kite) and one genotype of triticale (*Triticosecale* cv. Muir) to waterlogging. They put plants that were 23 to 36 days old in a stagnant solution and in waterlogged soil. The stagnant nutrient solutions decreased shoot fresh weight of Gamenya by 21% compared with aerated plants, while shoot fresh weight of Muir was unaffected. Reductions in nodal root fresh weight under stagnant conditions were also less for Muir than Gamenya.⁴⁸

Australian researchers have found that seed size is related to waterlogging tolerance. On average, larger seeds resulted in greater plant growth for triticale cultivars, and larger seeds lead to increased plant biomass and adventitious nodal root mass under waterlogged conditions.⁴⁹

14.3.1 Where waterlogging occurs

Waterlogging occurs:

- Where water accumulates or drains poorly in areas such as valleys, at the change of slope, or below rocks.
- In duplex soils, particularly sandy duplexes with less than 30 cm sand over clay.
- With deeper-sown crops.
- In crops with low levels of nitrogen.
- In very warm conditions when oxygen is more rapidly depleted in the soil.⁵⁰

Waterlogging greatly increases crop damage from salinity. Germination and early growth can be much worse on marginally saline areas after they have been waterlogged.

Identifying problem areas

The best way to identify problem areas is to dig holes about 40 cm deep in winter and see if water flows into them (Photo 12). If it does, the soil is waterlogged. Some farmers put slotted PVC pipe into augured holes. They can then monitor the water levels in their paddocks. Digging holes for fence posts often reveals waterlogging.

Symptoms in the crop of waterlogging include:

- Yellowing of crops and pastures.
- Presence of weeds such as toad rush, cotula, dock and Yorkshire fog grass.⁵¹

44 Al Malik., AKMR Islam, TD Colmer. [Physiology of waterlogging tolerance in wheat, hordeum marinum and their amphiploid](#)

45 CJ Thomson, TD Colmer, ELJ Watkin, H Greenway (1992) Tolerance of wheat (*Triticum aestivum* cvs Gamenya and Kite) and triticale (*Triticosecale* cv. Muir) to waterlogging. *New Phytologist*, 120(3), 335–344.

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50 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA. <https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals>

51 Soilquality.org. Waterlogging_Soilquality.org. <http://soilquality.org.au/factsheets/waterlogging>



Photo 12: In areas prone to waterlogging, water will fill a hole dug in the soil.

Source: Soilquality.org

14.3.2 Symptoms and causes

Waterlogging occurs when the soil profile or the root zone of a plant becomes so saturated with water that there is no longer enough oxygen in the soil (which becomes anaerobic). In rain-fed situations, this happens when more rain falls than the soil can absorb or the atmosphere can evaporate. The lack of oxygen causes plants' root tissues to decompose. Usually this occurs from the tips of roots, and causes the roots to appear as if they have been pruned. The consequence is that the plant's growth and development is stalled. If the anaerobic circumstances continue for a considerable time (e.g. days to weeks) the plant will eventually die.

Most often, however, waterlogging does not last this long. Once a waterlogging event has passed, plants recommence respiring. As long as soil conditions are moist, the older roots close to the surface allow the plant to survive. However, further waterlogging-induced root pruning and/or dry conditions may weaken the plant to the extent that it may not recover, and may eventually die.

Many farmers do not realise that a site is waterlogged until water appears on the soil surface. However, by this stage, plant roots may already be damaged and yield potential severely affected.

What to look for in the paddock

- Poor germination or pale plants in areas where water collects, particularly on shallow duplex soils (Photo 13).⁵²
- Wet soil and/or water-loving weeds are present.
- Early plant senescence.

52 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals>



Photo 13: *Pale plants in waterlogged areas.*

Source: DAFWA

What to look for in the plant

- Waterlogged seed will be swollen and may have burst.
- Seedlings may die before emergence, or be pale and weak if they do emerge.
- Waterlogged plants appear to be nitrogen-deficient, with pale plants, poor tillering, and older leaf death.
- If waterlogging persists, roots (particularly root tips) cease growing, become brown, and then die (Photo 14).
- Plants that may be more sensitive to spring drought (Photo 14) because the seminal roots, which are important for accessing deep subsoil moisture, have been damaged.

Plants are particularly vulnerable from seeding to tillering, with seminal roots being more affected than the nodal roots, which form later.



Photo 14: *Waterlogged roots, particularly seminal roots and tips, become brown and then die.*

Source: DAFWA

How waterlogging can be monitored

Waterlogging can be monitored by:

- Regularly checking water levels using bores or observation pits, but keep in mind that water tables can vary greatly over short distances.
- Digging a hole in the paddock and watching for the appearance of water in it—plants can become waterlogged if there is a water table within 30 cm of the surface. There may be no indication on the surface that the soil is waterlogged. Also observe plant symptoms and paddock clues.⁵³

Other impacts of waterlogging and flood events

Heat from stagnant water

Stagnant water, particularly if it is shallow, can heat up in hot, sunny weather and kill plants in a few hours. Remove excess water as soon as possible after flooding to give plants the best chance of survival.

Chemical and biological contaminants

Floodwater may carry contaminants, particularly from off-farm run-off. You should discard all produce, particularly leafy crops, that have been exposed to run-off.

Make sure you take food-safety precautions and test soils before replanting, even if crops look healthy. Contaminants will reduce over time, with follow-up rainfall and sunny weather.

53 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals>

VIDEOS

WATCH: [GCTV3: Big Wet—Managing strategies after flooding](#)



WATCH: [Over the Fence: Raised beds boost yields at Winchelsea](#)



MORE INFORMATION

[Cropping on raised beds in southern NSW](#)

Iron chlorosis or nitrogen deficiency

Floods and high rainfall can leach essential nutrients from the soil, which can affect plant health. Nutrients such as iron and nitrogen can be replaced through the use of fertiliser.

Soils with high clay content

Soils with a high clay content can become compacted and form a surface crust after heavy rainfall or flooding. Floodwater may also deposit a fine clay layer on top of the soil. The clay layer dries into a crust, which prevents oxygen penetration into the soil (aeration). This layer should be broken up and incorporated into the soil profile as soon as possible.

Pests and diseases

Many diseases are more active in wet, humid conditions, and pests can also cause problems then, too. Apply suitable disease control measures as soon as possible and monitor for pests.⁵⁴

14.3.3 Managing waterlogging

Key points:

- Sow waterlogging-tolerant crops such as oats and faba beans.
- Sow as early as possible with a higher cereal seeding rate.
- Drainage may be appropriate on sandy duplex soils on sloping sites.
- Raised beds are more effective on relatively flat areas and on heavier-textured soils, but areas need to be large enough to justify the machinery costs.⁵⁵

Draining

Drainage is usually the best way of reducing waterlogging. Good drainage is essential for maintaining crop health. Wet weather provides a good opportunity to improve the drainage of your crop land, as it allows you to identify and address any problem areas. Drain waterlogged soils as quickly as possible, and cultivate between rows to aerate the soil.

Other management options to reduce the impact of waterlogging include: choice of crop, seeding, fertiliser and weed control.

Drainage problems after flooding

After significant rain or flooding, inspect the crops as soon as it is safe to do so and mark areas (e.g. with coloured pegs) that are affected by poor drainage. If possible, take immediate steps to improve the drainage of these areas so that the water can get away (e.g. by digging drains).

Irrigation after waterlogging

To avoid the recurrence of waterlogging, time irrigation by applying small amounts often until the crop's root system has recovered.

Ways to improve drainage

In the longer term, look for ways to improve the drainage of the affected areas. Options might include:

- re-shaping the layout of the paddock
- improving surface drainage
- installing subsurface drainage

54 Queensland Government (2016) Managing risks to waterlogged crops. Queensland Government, <https://www.business.qld.gov.au/industry/agriculture/crop-growing/disaster-recovery-for-crop-farming/saving-crops-floods/managing-risks-waterlogged-crops>

55 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, <https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals>

If the drainage can't be improved, consider using the area for some other purpose (e.g. as a silt trap).⁵⁶

Choice of crop species

Some species of grains crop are more tolerant of waterlogging than others. Grain legumes and canola are generally more susceptible to waterlogging than cereals, especially triticale, and faba beans.

Seeding crops early and using long-season varieties help to avoid crop damage from waterlogging. Crop damage is particularly severe if plants are waterlogged between germination and emergence. Plant first those paddocks that are susceptible to waterlogging. However, if waterlogging delays emergence and reduces cereal plant density to fewer than 50 plants/m², re-sow the crop.

Seeding rates

Increase sowing rates in areas susceptible to waterlogging to give some insurance against uneven germination, and to reduce the dependence of cereal crops on tillering to produce grain. Waterlogging depresses tillering. High sowing rates will also increase the competitiveness of the crop against weeds, which will take advantage of stressed crops.

Nitrogen fertiliser

Crops tolerate waterlogging better if the soil has a good nitrogen status before waterlogging occurs. Applying nitrogen at the end of a waterlogging period can be an advantage if nitrogen was applied at or shortly after seeding because it avoids loss by leaching or denitrification. However, nitrogen cannot usually be applied from vehicles when soils are wet, so consider aerial applications.

If waterlogging is moderate (7–30 days), then nitrogen application after waterlogging events when the crop is actively growing is recommended where basal nitrogen applications were 0–50 kg N/ha. However, if waterlogging is severe (greater than 30 days), then the benefits of nitrogen application after waterlogging are questionable. But this recommendation requires verification in the field at a range of basal nitrogen applications using a selection of varieties.

Weeds

Weed density affects a crop's ability to recover from waterlogging. After the water has drained, they will compete with the crop for water and the small amount of remaining nitrogen. The waterlogged parts of a paddock are often weedy, and require special attention if the yield potential is to be achieved.⁵⁷

MORE INFORMATION

[Should waterlogged crop be top-dressed with N fertiliser?](#)

VIDEOS

WATCH: [The 2012 N story and planning for 2013](#)



⁵⁶ Queensland Government (2016) Improving drainage of crop land. Queensland Government, <https://www.business.qld.gov.au/industry/agriculture/crop-growing/disaster-recovery-for-crop-farming/saving-crops-floods/improving-drainage-crop-land>

⁵⁷ DAFWA (2015) Management to reduce the impact of waterlogging in crops. DAFWA, <https://www.agric.wa.gov.au/waterlogging/management-reduce-impact-waterlogging-crops>

Marketing

The final step in generating farm income is converting the tonnes produced into dollars at the farm gate. This section provides best in class marketing guidelines for managing price variability to protect income and cash-flow.

15.1 Price determinants for feed grains in northern markets.

Stock feed markets are the biggest consumers of grain domestically in Australia.

Domestic stock feed grain consumption in Northern Australia is equivalent to approximately 45% of the total winter crop produced in NSW and Qld. Furthermore the domestic market in Victoria traditionally will draw grain in from NSW to support domestic stock feed markets as well as bulk and container export programs. Further drawing on stocks in Northern markets.

The biggest stock feed market in northern Australia is the beef industry representing 45% of all stock feed demand in these markets, followed by the poultry industry at 30%.

Whilst the poultry industry remains a strong source of demand for feed grains in northern markets intensive livestock industries such as poultry and pig meat continue to experience geographic relocation. Whilst to some extent Qld has been able to benefit from a shift in pig meat production away from NSW, the stronger trend across both these industries is a move away from East Coast markets to South Australia and Western Australia.

This geographic shift is being driven by the availability of land, of feed grains and a more favourable regulatory environment.

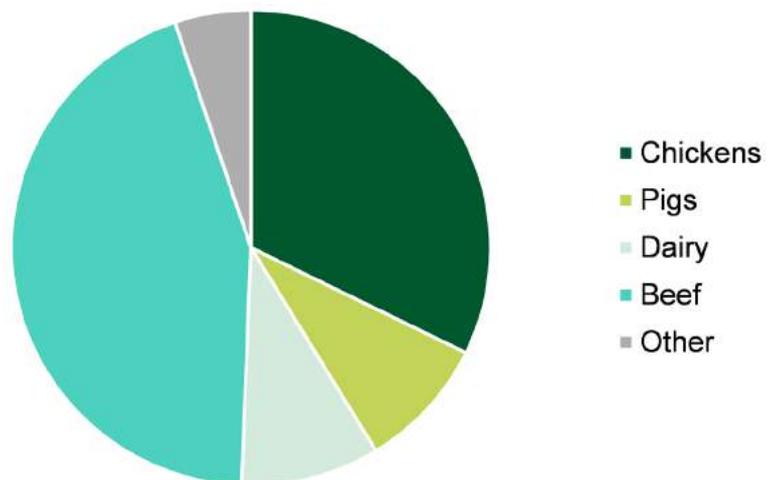


Figure 1: Sources of demand for stock feed in Northern Australia

The key drivers of prices for feed grains in Northern markets include;

- Rate of exports and remaining supply of feed grains for domestic markets.
- Commodity prices in the consuming industry (ie meat prices – especially for beef)
- Consumption trends in domestic livestock markets.
- Livestock health
- Seasonality / supply of pasture and fodder vs grains.

- Imports of alternate feed sources (ie soy bean meal)
- Prices of competing feed grains.
- Regulatory changes

15.2 Executing tonnes into cash

When it comes to accessing domestic stock feed markets there are several ways this can be approached.

1. Sale to a feed miller or manufacturer
2. Sale direct to farm or end user.
3. Sale to a trader or merchant who on sells this grain to the stockfeed market.

Each organisation will differ in terms of how they manage grain purchases, the professionalism of the enterprise and management around grain requirements and grain purchases, documentation and record keeping.

Hence it is particularly prudent when making sales into these markets to be vigilant in maintaining records of contracts, even when they are executed by phone. It is strongly advised that the seller keeps a written record of the particulars of the contract including price, quantity, quality, delivery and payment terms to protect yourself in the event of a dispute with your counterparty as to the details of the sale agreement.

It is even better practice to send a contract confirmation to the buyer in the event they don't provide one to you, or even as well as. Grain Trade Australia provide standard form contract documents which can be completed by either party and returned to the buyer by email as confirmation of the verbal contract. This way, any mis-understandings that may have taken place on the phone can be quickly identified and rectified immediately whilst the conversation is still fresh in both your minds rather than waiting until delivery to identify a problem.

15.2.1 How to sell for cash

Like any market transaction, a Cash grain transaction occurs when a bid by the buyer is matched by an offer from the seller. Cash contracts are made up of the following components with each component requiring a level of risk management:

Price

Future price is largely unpredictable hence devising a selling plan to put current prices into the context of the farm business is critical to manage price risk.

Quantity and Quality

When entering a cash contract you are committing to delivery of the nominated amount of grain at the quality specified. Hence production and quality risk must be managed.

Delivery terms

Timing of title transfer from the grower to the buyer is agreed at time of contracting. If this requires delivery direct to end users it relies on prudent execution management to ensure delivery within the contracted period.

Payment terms

In Australia the traditional method of contracting requires title of grain to be transferred ahead of payment; hence counterparty risk must be managed.

SECTION 15 TRITICALE

TABLE OF CONTENTS

FEEDBACK

GTA Contract No.3 CONTRACT CONFIRMATION

GTA Trade Rules and Dispute Resolution Rules apply to this contract

This Contract is confirmation between:



Grain Trade Australia is the industry body ensuring the efficient facilitation of commercial activities across the grain supply chain. This includes contract trade and dispute resolution rules. All wheat contracts in Australia should refer to GTA trade and dispute resolution rules.

BUYER

Contract No: _____
 Name: _____
 Company: _____
 Address: _____

Buyer ABN: _____
 NGR No: _____

SELLER

Contract No: _____
 Name: _____
 Company: _____
 Address: _____

Seller ABN: _____
 NGR No: _____

Quantity (tonnage) and quality (bin grade) determine the actuals of your commitment. Production and execution risk must be managed.

Price is negotiable at time of contracting. Price basis or price point is important as it determines where in the supply chain the transaction will occur and so what costs will come out of the price before the growers net return.

Timing of delivery (title transfer) is agreed upon at time of contracting. Hence growers negotiate execution and storage risk they may have to manage.

Whilst the majority of transactions are on the premise that title of grain is transferred ahead of payment this is negotiable. Managing counterparty risk is critical.

The Buyer and Seller agree to transact this Contract subject to the following Terms and Conditions:

Commodity: _____ GTA Commodity Reference: _____
 Grade: _____ Inspection: _____ (Origin - Destination)
 Quantity: _____ Tolerance: _____ (Refer over)
 Packaging: _____ Weights: _____ (Origin - Destination)
 Price: _____ Excl/Inc/Free GST _____
 Price Basis: _____

Delivery/Shipment Period: _____ (Delivered, Shipped, Free In Store, Free On Board, Ex-Farm, etc.)
 Delivery Point and Conveyance: _____ (Road, Rail, Delivered Container Terminal, Freight, Rated Basing Point, Loading Weight requirements if applicable)

Payment Terms: The buyer agrees to pay the seller within _____, In the absence of a declaration, payment will be 30 days end of week of delivery.

Levies and Statutory Charges: Any industry, statutory or government levies which are not included in the price shall be deducted as required by law.

Disclosures: Is any of the crop referred to in this contract subject to a mortgage, Encumbrance or lien and/or Plant Breeders Rights and/or EPR liabilities and/or registered or unregistered Security Interest? NO YES (Please appropriate box) If "yes" please provide details:

Other Special Terms and Conditions:

All Contract Terms and Conditions as set out above and on the reverse of this page form part of this Contract. Terms and Conditions written on the face of this Contract Confirmation shall overrule all printed Terms and Conditions on the reverse with which they conflict to the extent of the inconsistency. This Contract comprises the entire agreement between Buyer and Seller with respect to the subject matter of this Contract.

Recipient Created Tax Invoice (RCTI). To assist with the processing of the Goods and Services Tax compliance, the buyer may prepare, for the seller, a Recipient Created Tax Invoice (RCTI). If the seller requires this service they are required to sign this authorisation.

Please issue a RCTI (Please)

Incorporation of GTA Trade & Dispute Resolution Rules: This contract expressly incorporates the GTA Trade Rules in force at the time of this contract and Dispute Resolution Rules in force at the commencement of the arbitration, under which any dispute, controversy or claim arising out of, relating to or in connection with this contract, including any question regarding its existence, validity or termination, shall be resolved by arbitration.

Buyer's Name: _____ PRINT NAME
 Buyer's Signature: _____
 Date: _____

Seller's Name: _____ PRINT NAME
 Seller's Signature: _____
 Date: _____

This Contract has been executed and this form serves as confirmation and should be signed and a copy returned to the buyer/seller immediately.

2014 Edition

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Figure 2: Typical cash contracting as per Grain Trade Australia standards.

15.2.2 Counterparty risk

Most sales involve transferring title of grain prior to being paid. The risk of a counterparty defaulting when selling grain is very real and must be managed. Conducting business in a commercial and professional manner minimises this risk.

Principle: “Seller beware” – There is not much point selling for an extra \$5/t if you don’t get paid.

Counterparty risk management includes:

1. Dealing only with known and trusted counterparties.
2. Conduct a credit check (banks will do this) before dealing with a buyer they are unsure of.
3. Only sell a small amount of grain to unknown counterparties.
4. Consider credit insurance or letter of credit from the buyer.
5. Never deliver a second load of grain if payment has not been received for the first.

If possible, do not part with title of grain before payment or request a cash deposit of part of the value ahead of delivery. Payment terms are negotiable at time of contracting,

Above all, act commercially to ensure the time invested in a selling strategy is not wasted by poor counterparty risk management. Achieving \$5/t more and not getting paid is a disastrous outcome.

15.2.3 Read market signals

The appetite of buyers to buy a particular commodity will differ over time depending on market circumstances. Ideally growers should aim to sell their commodity when buyer appetite is strong and stand aside from the market when buyers are not that interested in buying the commodity.

Principle: “Sell when there is buyer appetite” – When buyers are chasing grain, growers have more market power to demand a price when selling.

Buyer appetite can be monitored by:

1. The number of buyers at or near the best bid in a public bid line-up. If there are many buyers, it could indicate buyer appetite is strong. However if there is one buyer \$5/t above the next best bid, it may mean cash prices are susceptible to falling \$5/t if that buyer satisfies their buying appetite.
2. Monitoring actual trades against public indicative bids. When trades are occurring above indicative public bids it may indicate strong appetite from merchants and the ability for growers to offer their grain at price premiums to public bids.

15.2.4 Know the specifications of your grain

Feed ‘grades’ of grain as defined by bulk handler receival standards can have very broad quality specifications. For the lowest grades there is often no minimum tolerances on screenings or protein hence no two parcels are the same.

The important factor for the stock feed market however is not what ‘grade’ the grain is but its energy and protein components which ultimately determine conversion in to meat or other animal products. Hence by having your grain tested and knowing your specifications helps the buyer to know exactly what the value of the grain will be in the production system.

Without this information the buyer may base their pricing on the ‘minimum’ specification or likely worst case scenario, to protect themselves in the event they receive grain of the lowest quality allowable in the grade specifications. However knowing why your grain was downgraded and the specifications of the load, the

buyer may be able to pay premiums for the exact quality you are offering, above the minimum specification.

15.3 Ensuring access to markets for Northern Australian feed grains

Planning on where to store the commodity is important in ensuring access to the market that is likely to yield the highest return.

Animal industries such as pigs and poultry are highly intensive and tend to be geographically concentrated. Hence proximity to these markets can be an important determinant of market access. Some growers may not have access to these markets at all due to large distances between production and demand making the cost of transport prohibitive to profitably accessing these markets.

In Northern Australia some of the largest delivered markets include Brisbane (Qld), Darling Downs (Qld), Texas / North Star (NSW), Riverina (NSW). Hence once again proximity to these markets must be considered as part of any marketing plan to access demand from the stock feed industry.

15.3.1 Storage and Logistics

Return on investment from grain handling and storage expenses is optimised when storage is considered in light of market access to maximise returns as well as harvest logistics.

Storage alternatives include variations around the bulk handling system, private off farm storage, and on-farm storage. Delivery and quality management are key considerations in deciding where to store your commodity.

Commodities destined for the domestic end user market, (e.g feed lot, processor, or container packer), may be more suited to on-farm or private storage to increase delivery flexibility.

Storing commodities on-farm requires prudent quality management to ensure delivery at agreed specifications and can expose the business to high risk if this aspect is not well planned. Penalties for out-of-specification grain on arrival at a buyer's weighbridge can be expensive. The buyer has no obligation to accept delivery of an out-of-specification load. This means the grower may have to incur the cost of taking the load elsewhere whilst also potentially finding a new buyer. Hence there is potential for a distressed sale which can be costly.

On-farm storage also requires prudent delivery management to ensure commodities are received by the buyer on time with appropriate weighbridge and sampling tickets.

Principle: "Storage is all about market access" – Storage decisions depend on quality management and expected markets.

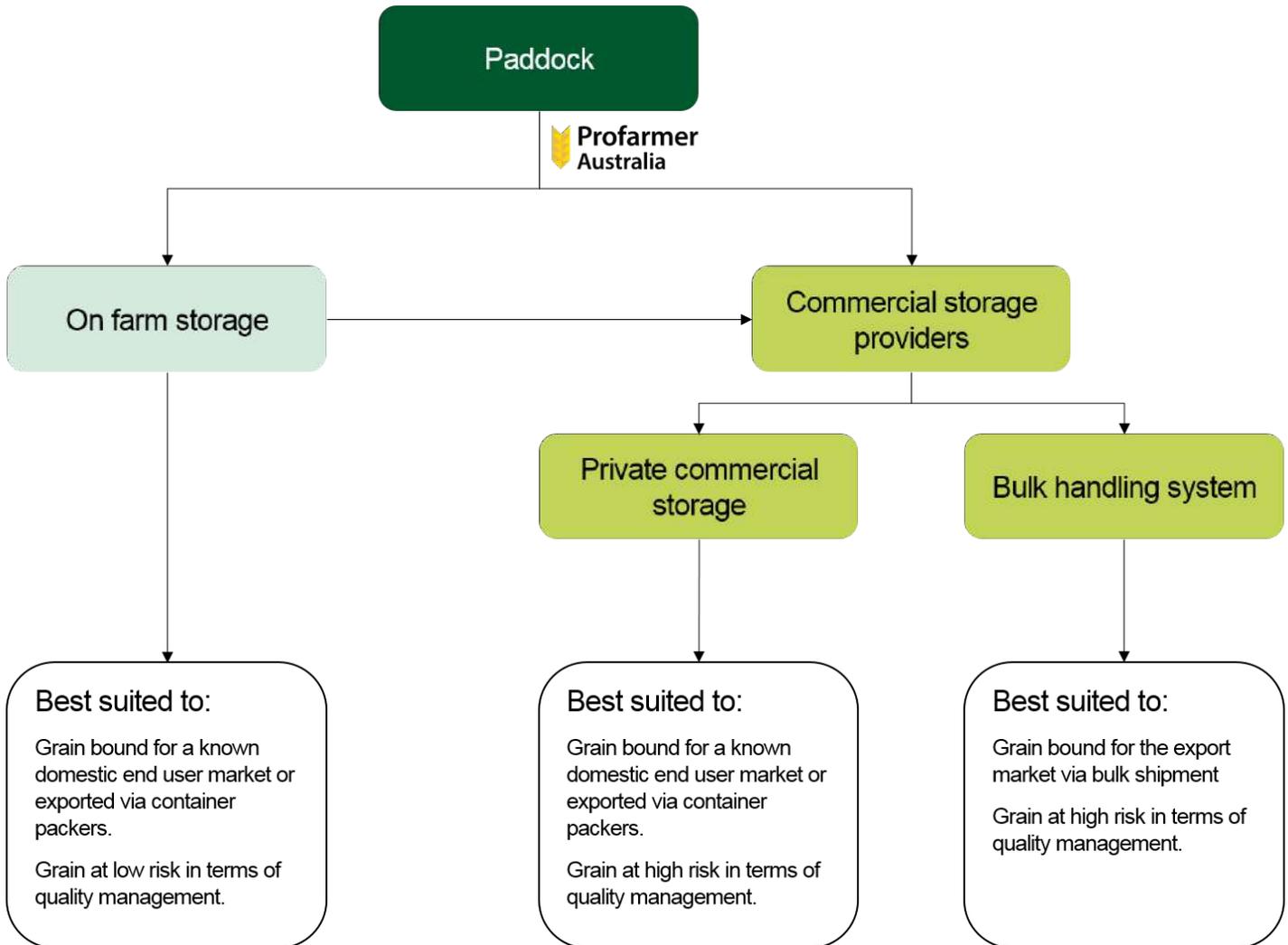


Figure 3: Grain storage decision making

Decisions around storage alternatives of harvested commodities depend on market access and quality management requirements.

15.3.2 Separate the delivery decision from the pricing decision

Organised stock feed buyers, with a clear outlook as to what their grain requirements will be across the season may seek to purchase their grain in advance of delivery. That is they may purchase grain in March for delivery between May and July. This provides the seller the opportunity to obtain price certainty immediately whilst delivery may not take place until some point in the future.

The benefit of this is that a seller can capture strong value when it presents, even though it may not be a convenient time to arrange delivery. Or you can create cash flow certainty for a known future commitment at today's price.

15.3.3 Cost of carrying grain

Storing grain to access sales opportunities post-harvest invokes a cost to "carry" grain. Price targets for carried grain need to account for the cost of carry.

Carry costs for canola are typically \$4-5/t per month consisting of:

1. monthly storage fee charged by a commercial provider (typically ~\$1.50-2.00/t per month)

SECTION 15 TRITICALE

TABLE OF CONTENTS

FEEDBACK

2. the interest associated with having wealth tied up in grain rather than cash or against debt (~\$2.50-\$3.00/t per month depending on the price of the commodity and interest rates.

The price of carried grain therefore needs to be \$4-5/t per month higher than what was offered at harvest.

The cost of carry applies to storing grain on farm as there is a cost of capital invested in the farm storage plus the interest component. \$4-5/t per month is a reasonable assumption for on farm storage.

Principle: “Carrying grain is not free” – The cost of carrying grain needs to be accounted for if holding grain and selling it after harvest is part of the selling strategy.

Principles revised

“Always keep written records” – thorough record keeping is everyone’s responsibility not just the buyers.

“Seller beware” – Know your counterparty

“Know your specs” – grades don’t always convey quality

“Separate the delivery decision from the pricing decision”

“Sell when there is buyer appetite” – When buyers are chasing grain, growers have more market power to demand a price when selling.

“Storage is all about market access” – Storage decisions depend on quality management and expected markets.

“Carrying grain is not free” – The cost of carrying grain needs to be accounted for if holding grain and selling it after harvest is part of the selling strategy.

Current and past research

Project Summaries

www.grdc.com.au/ProjectSummaries

As part of a continuous investment cycle each year the Grains Research and Development Corporation (GRDC) invests in several hundred research, development and extension and capacity building projects. To raise awareness of these investments the GRDC has made available summaries of these projects.

These project summaries have been compiled by GRDC's research partners with the aim of raising awareness of the research activities each project investment.

The GRDC's project summaries portfolio is dynamic: presenting information on current projects, projects that have concluded and new projects which have commenced. It is updated on a regular basis.

The search function allows project summaries to be searched by keywords, project title, project number, theme or by GRDC region (i.e. Northern, Southern or Western Region).

Where a project has been completed and a final report has been submitted and approved a link to a summary of the project's final report appears at the top of the page.

The link to Project Summaries is www.grdc.com.au/ProjectSummaries

Final Report Summaries

http://finalreports.grdc.com.au/final_reports

In the interests of raising awareness of GRDC's investments among growers, advisers and other stakeholders, the GRDC has available final reports summaries of projects.

These reports are written by GRDC research partners and are intended to communicate a useful summary as well as present findings of the research activities from each project investment.

The GRDC's project portfolio is dynamic with projects concluding on a regular basis.

In the final report summaries there is a search function that allows the summaries to be searched by keywords, project title, project number, theme or GRDC Regions. The advanced options also enables a report to be searched by recently added, most popular, map or just browse by agro-ecological zones.

The link to the Final Report Summaries is http://finalreports.grdc.com.au/final_reports

Online Farm Trials

<http://www.farmtrials.com.au/>

The Online Farm Trials project brings national grains research data and information directly to the grower, agronomist, researcher and grain industry community through innovative online technology. Online Farm Trials is designed to provide growers with the information they need to improve the productivity and sustainability of their farming enterprises.

Using specifically developed research applications, users are able to search the Online Farm Trials database to find a wide range of individual trial reports, project summary reports and other relevant trial research documents produced and supplied by Online Farm Trials contributors.

The Online Farm Trials website collaborates closely with grower groups, regional farming networks, research organisations and industry to bring a wide range of

SECTION 16 TRITICALE

TABLE OF CONTENTS

FEEDBACK

crop research datasets and literature into a fully accessible and open online digital repository.

Individual trial reports can also be accessed in the trial project information via the Trial Explorer.

The link to the Online Farm Trials is <http://www.farmtrials.com.au/>

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- The Australian Fodder Industry Association <http://www.afia.org.au/>
- The link below provides current financial members of Grain Trade Australia <http://www.graintrade.org.au/membership>
- A guide to grain contracts <http://www.australiangrainexport.com.au/docs/Grain%20Contracts%20Guide.pdf>
- Grain trade Australia contracts: <http://www.graintrade.org.au/contracts>
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