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The growth and seed yield of five linseed (*Linum usitatissimum* L.) varieties as influenced by nitrogen application

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Key words: Linseed, alpha linolenic acid, nitrogen fertilization, essential fatty acids

1 SUMMARY

Objective: The linseed plant produces linseed, an excellent source of health-promoting omega-3 fatty acid, alpha linolenic acid. Currently, there is negligible production of this crop in Kenya. This study aimed to determine the growth and yield potential of five linseed varieties at different nitrogen fertilizer levels in Juja, Central Kenya.

Methodology and results: Five linseed varieties namely Summit, S19/21, Raja, Jawhar and S19/12 were evaluated at 0, 75 and 150KgN/ha fertilizer levels in Juja area, Kenya. Effect of the fertilizer on number of leaves, height, tillering, dry weight, number of heads and seed yield were evaluated in two planting seasons. Numbers of leaves, height, tillering and dry weight were not significantly affected by nitrogen application ($P>0.05$). Raja yielded higher head and seed yield than the other varieties in both seasons ($P<0.05$). The highest head yield was obtained at 75KgN/ha during the February-June season while it was 150KgN/ha during the July-December season.

Conclusion: Nitrogen fertilization up to 150KgN/ha does not result in significant differences in growth of Summit, S19/21, Raja, Jawhar and S19/12 and can so be considered a moderate consumer of nitrogen. Raja yields more highly compared to the other four varieties. Hence, it can be recommended for adoption in the study area as well as for future research and breeding programs.

2 INTRODUCTION

Linseed plant is a rich source of both edible and non-edible oil. It accounts for approximately 1% of the world's oilseed supplies (Smith and Jimmerson, 2005). The industrial linseed oil is an important ingredient in the manufacture of paint, varnish and linoleum (Matheson, 1976). Edible linseed oil is important as a rich source of α -linolenic acid (ALA), an essential ω -3 polyunsaturated fatty acid that has many health benefits but is not

readily available in most people's diet (Wood, 1997; Flax Council of Canada, 2004). The increasing popularity of linseed as a functional (health-promoting) food is not only due to its high content of ALA but also due to the presence of some soluble and insoluble fibre and lignans, and its suitability for use in bread, breakfast cereals and other food products (Morris, 2003). After oil extraction, the seed cake may be processed into a high protein

animal feedstock (Martin *et al.*, 1976; Sankari, 2000; Morris, 2003). Linseed oil may be

especially useful as a cheap source of ω -3 fatty acids in fish feed formulations (Bell *et al.*, 2004).



Plate 1: Photos showing (a) growing linseed crop in JKUAT fields, and, (b) seeds of Raja harvested from a crop grown in JKUAT fields during the February-June season 2012.

Despite the potential uses of linseed oil especially for human consumption and livestock and fish feed, linseed production in Kenya is still marginal. While earlier research showed that various introductions of this crop could do well in Kenya (Riungu, 1988; Ndireru, 1997), its current production is negligible, if any, perhaps due to lack of information on proper field management practices among other causes. Nitrogen plays the most important role in building the protein structure (Frink *et al.*, 1999). Excess N in combination with adequate moisture and high plant populations can increase mutual leaf shading that decreases light intensity in canopy, leading to decrease in photosynthate supply and subsequent square shed in cotton (*Gossypium hirsutum* L.) (Cothren, 1999). Nitrogen is the most important nutrient in linseed production, especially when grown under irrigation (Hocking *et al.*, 1987). Seed yield of linseed is

highly related to N and water availability and when water availability is not limited, N deficiency is the main cause of seed yield reduction (Hocking and Pinkerton, 1991). A significant number of studies have been published on linseed husbandry in other countries (Dybing, 1964; Khan and Bradshaw, 1976; Hocking *et al.*, 1987; Hocking and Pinkerton, 1991; Diepenbrock *et al.*, 1995; Hocking, 1995; Foster *et al.*, 1998; Lisson and Mendham, 2000; Easson and Molloy, 2001; Couture *et al.*, 2002) but there is limited information on linseed production in Kenya. There is particularly no available information on the response of linseed to management strategies like nitrogen (N) fertilization to optimize growth and seed yield.

This study was conducted with the aim of evaluating the growth and yield of five linseed cultivars at different nitrogen fertilizer levels.

3 MATERIALS AND METHODS

The experiments were conducted in Jomo Kenyatta University of Agriculture and Technology (JKUAT) -Juja research fields. JKUAT stands at an altitude of 1416 m above sea level, (1° 10' S, 37° 7' E) in Kiambu County,

Kenya, approximately 35 km north of Nairobi City. Before setting up the experiment, soil tests were conducted to determine initial levels of soil pH, electrical conductivity and % nitrogen according to the standard procedure as



documented in Okalebo *et al.* (2002). Experiments were laid out as split plots in randomized complete block design with three N-fertilizer levels {0Kg N/ha (control), 75Kg N/ha and 150Kg N/ha} as main plots, and five linseed varieties {Summit (V1), S19/21 (V2), Raja (V3), Jawhar (V4) and S19/12 (V5)} as sub-plots in two seasons (February-June 2012 season and July-December 2012 season). Land was ploughed to a fine tilth and plots measuring 3m x 3m prepared. Drills of 20cm apart and 2cm deep were made along each of the plots. Seeds were evenly spread along the drills and then covered with a thin layer of soil. Germinated seeds were kept weed free. Application of treatment N-fertilizer was done as CAN (26% N), commenced thirty days after planting and was done in three equal splits, being 2 weeks apart from each other. Plant height, number of primary branches on a randomly selected plant from each plot as well

as the number of leaves on the central branch were determined, starting from the 21st day after planting and at weekly intervals for nine consecutive weeks. The plant was oven dried at 70±1°C for 24hrs then weighed to determine dry matter accumulation. Plant maturity was determined as the period when more than 50 % of the capsules on a plant had turned brown and seeds rattled in the capsules when they were shaken (Matheson, 1976). Number of capsules/plant was estimated from counts on five sample-plants/plots. Capsules were removed by hand, seed was manually extracted and cleaned and the total number of seeds/sample recorded. Data was subjected to analysis of variance (ANOVA) using PROC GLM in SAS 9.1.3 portable version to identify main effects, interactions in response to N and the means were separated using LSD procedure at the 0.05 level of significance, and graphs plotted using SigmaPlot 12.0.

4 RESULTS

Initial soil tests indicated that the soil had a pH of 6.2, electrical conductivity of 0.12 and 0.10%N that is classified as low according to Okalebo *et al.*, 2002. There were no interaction effects and therefore the data presented is on the main factors. There were no significant variations in production of leaves by cultivars in February-June 2012 as well as in July-December 2012 (Fig. 1a, b). In the February-June season, S19/12 produced the highest number of leaves and Jawhar the least while in the July-December season, all the cultivars produced equal number of leaves. Application of nitrogen did not result in significant variations in production of leaves in both seasons (Fig. 1c,

d). Cultivars varied in production of tillers in both seasons (Fig 2). Raja produced 14 and 6 tillers at the eleventh week in the February-June and July-December seasons respectively compared to a range of 6-8 and 2-4 in the other cultivars. Cultivars tillered more during the February-June season compared to the July-December season (Fig. 2a, b). Tillering was not significantly affected by the amounts of nitrogen fertilizer applied (Fig. 2c, d). During the February-June season, the control produced the lowest number of tillers while the two nitrogen treatments produced equal numbers of tillers.

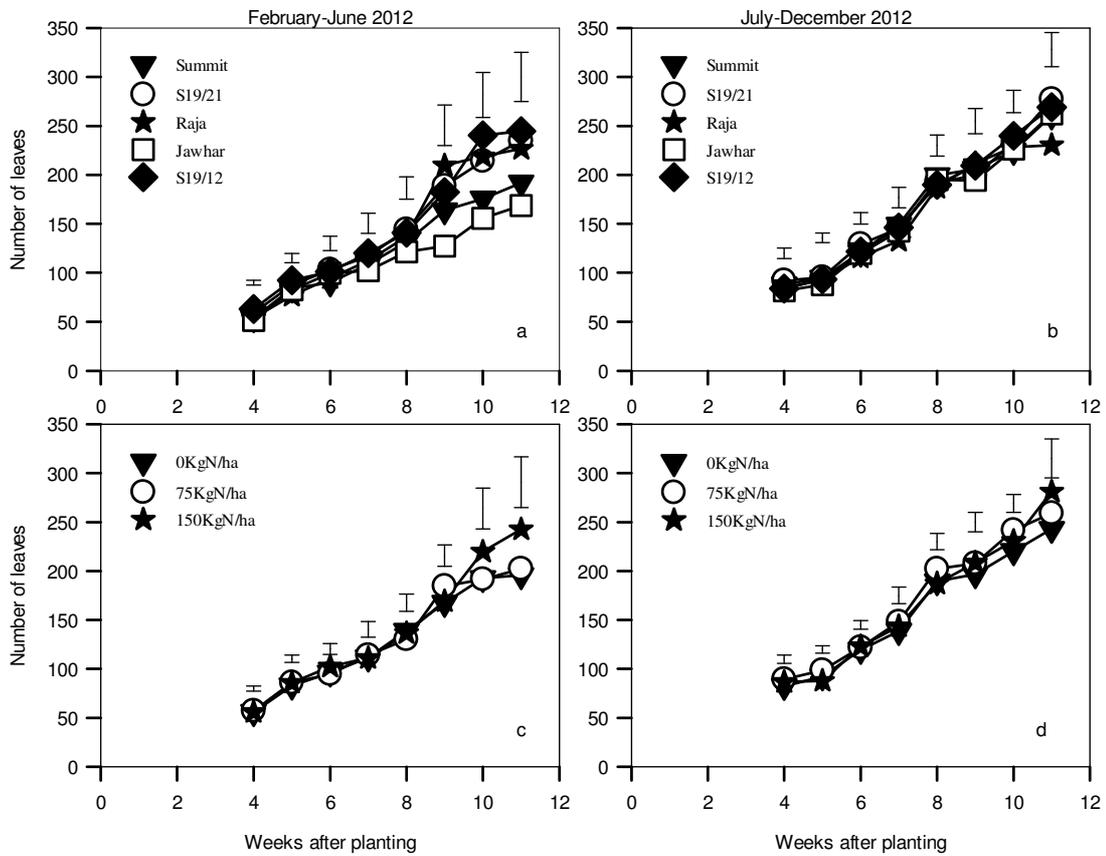


Figure 1: The number of leaves of five linseed cultivars as influenced by nitrogen fertilizer levels during the February-June and July-December seasons 2012. Vertical bars show LSD_{0.5}.

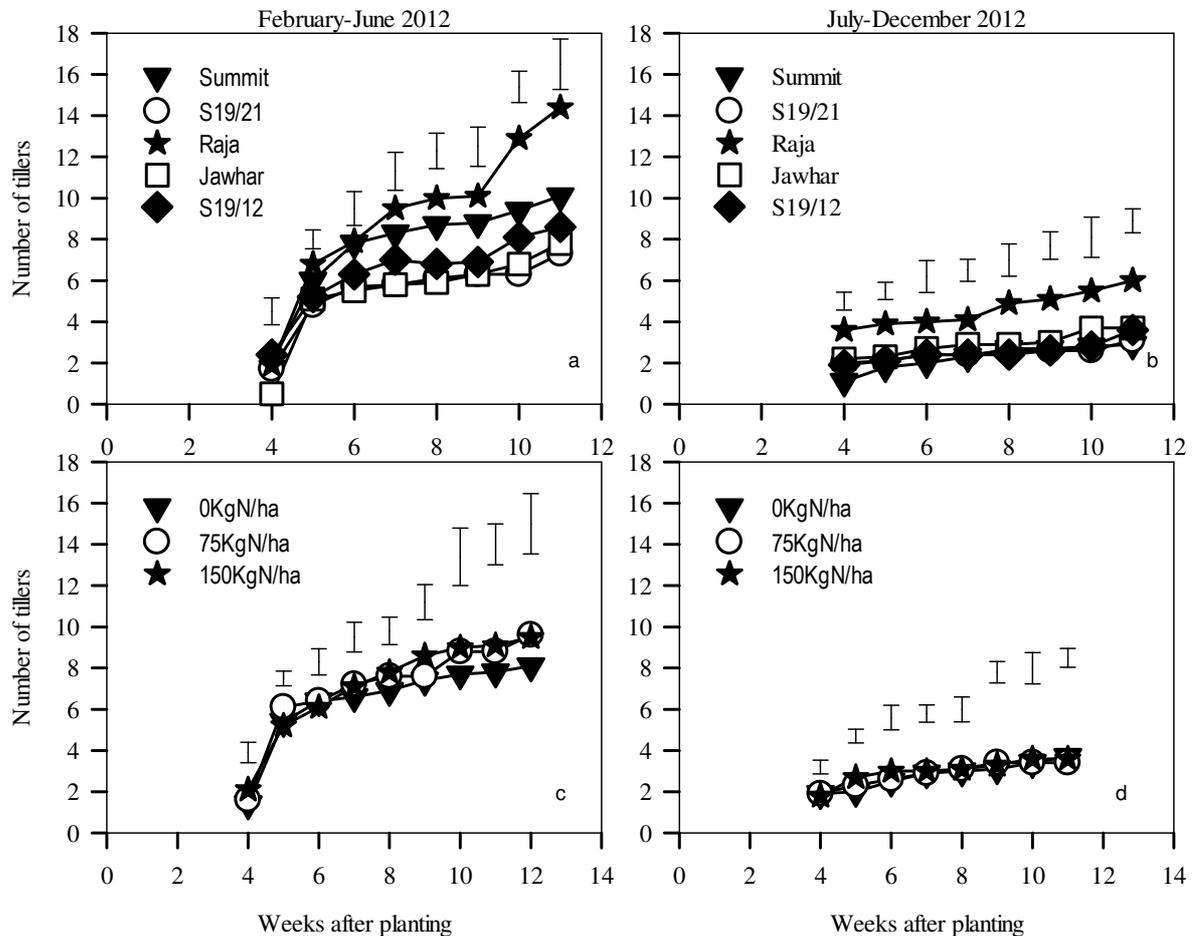


Figure 2: The number of tillers of five linseed cultivars as influenced by nitrogen fertilizer levels during February-June and July-December seasons 2012. Vertical bars show LSD_{0.5}.

Plant height was not significantly different among the linseed cultivars in both seasons (Fig. 3a, b). Increase in height across the varieties was more rapid during the July-December season compared to the February-June season. S19/12 attained the greatest height during the February-June season while it was S19/12 and S19/21 during the July-December season. In both seasons, Raja was the shortest cultivar. Upon fertilization with the different levels of nitrogen, the height attained by the plants did not differ significantly (Fig. 3c, d). The initial height increase was slow. During the February-June season, plants under 0KgN/ha as well as those under 150KgN/ha treatments attained similar heights while those under the 75KgN/ha treatment became the tallest. On

the other hand, the control gave the shortest plants while the other two nitrogen levels gave the tallest plants during the July-December season. Dry matter accumulation was significantly higher in Raja compared to all the other cultivars in both seasons (Fig. 4a, b). Dry matter accumulation in the different cultivars during the February-June season ranged from 0-11.4g while it ranged from 0-7.1g during the July-December season. The initial increase in biomass was slow at the beginning but rose sharply from the 7th week in both seasons. There were no significant differences in accumulation of biomass upon addition of the different N-fertilizer levels in both seasons (Fig. 4c, d). The rate of increase was slow at first and increased with time. A sharp increase in both

seasons however occurred at around the 10th week after the last split of fertilizer had been added. Addition of fertilizer caused a dry weight increase of upto 8.5g during the February-June season and 4.9g during the July-December season. There was a significant linear relationship between increase in number of leaves and dry matter accumulation during the

July-December season (Fig. 5d, e, f). This relationship was however not there during the February-June season (Fig. 5a, b, c). For the different varieties and seasons, a unit increase in number of leaves was accompanied by an increase in dry weight at varied proportions depending on the cultivars as shown in table 1.

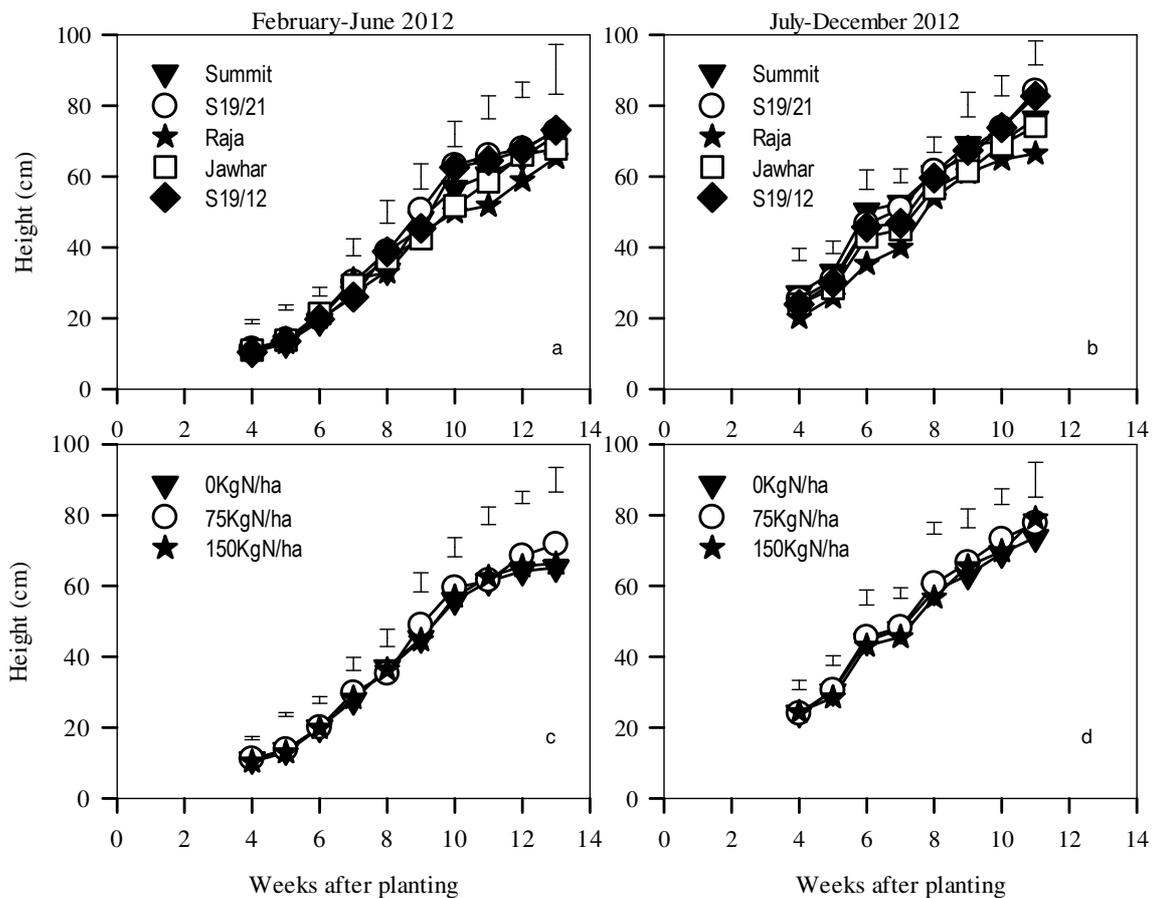


Figure 3: Height of five linseed cultivars as influenced by nitrogen fertilizer levels during February-June and July-December seasons 2012. Vertical bars show $LSD_{0.5}$.

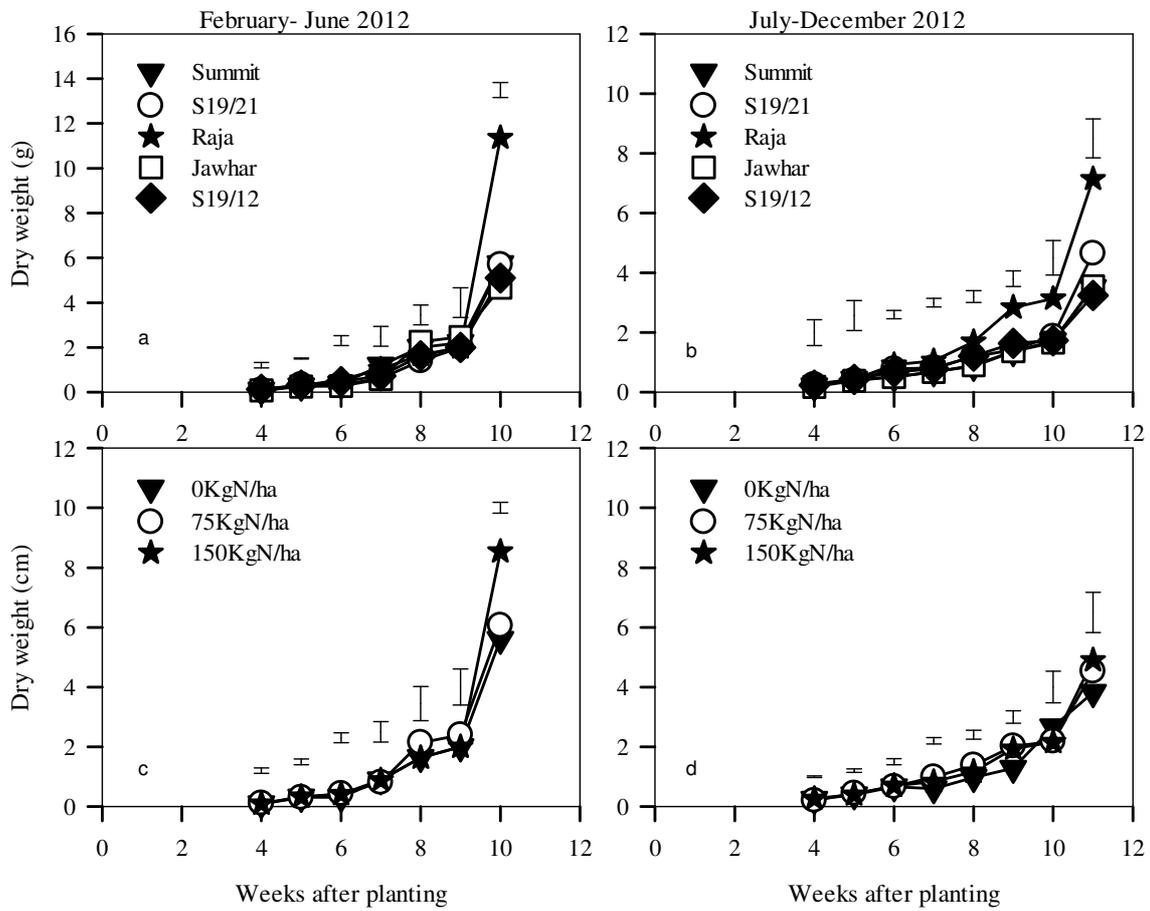


Figure 4: Accumulation of biomass by five linseed cultivars as influenced by nitrogen fertilizer levels during the February-June and July-December seasons 2012. Vertical bars show LSD_{0.5}.

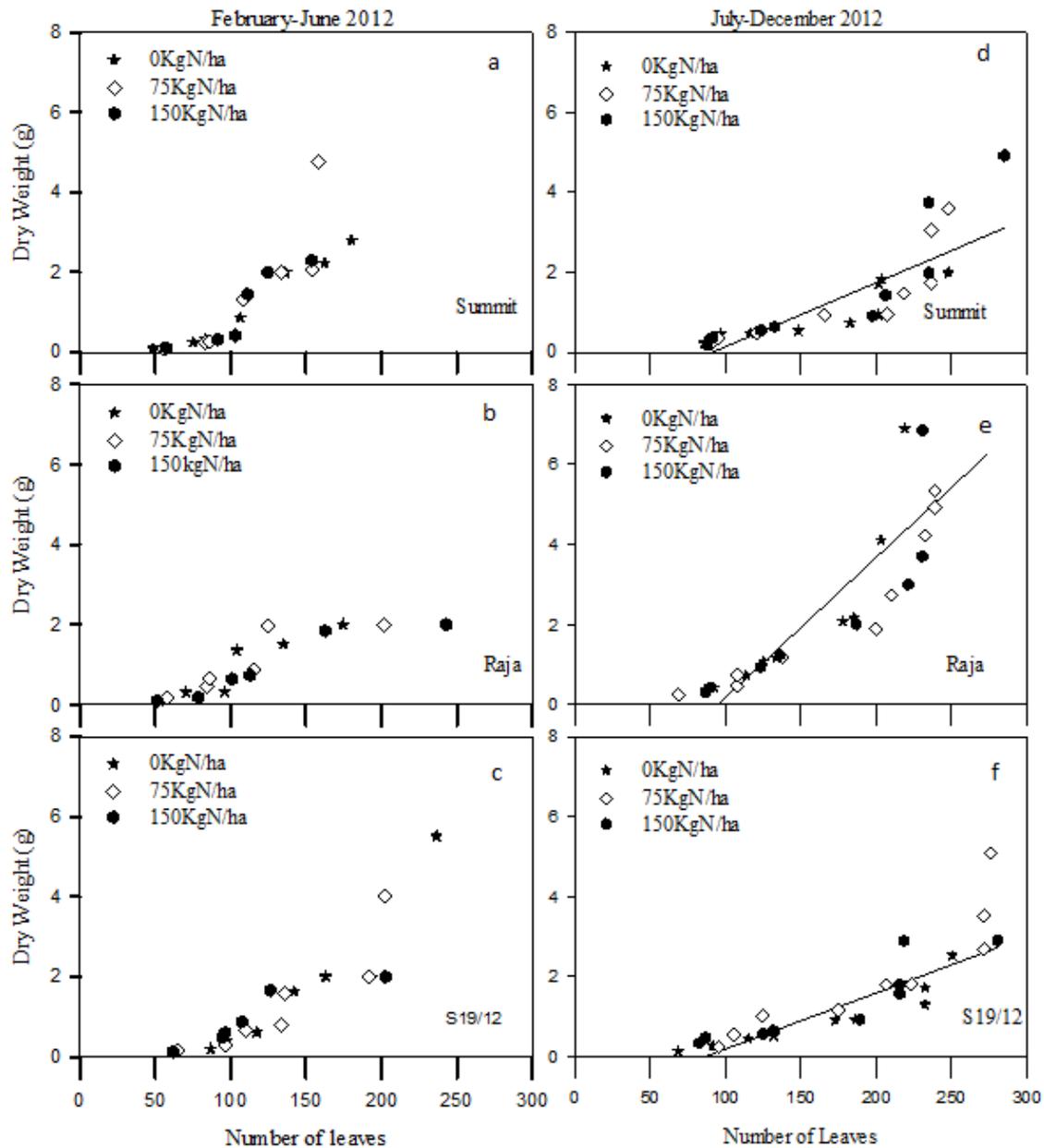


Figure 5: Number of leaves vs dry weight regressions of linseed during the February-June and July-December seasons 2012.

During the February-June season, there was no relationship between tillering ability and accumulation of dry matter in all varieties (Fig. 6a, b, c). However, a significant relationship existed during the July-December season as shown in figure 6d, e, f. During this season, an increase in number of tillers was accompanied

by an increase in dry weight at proportions that depended on the cultivars as shown in table 2. A unit increase in tillers resulted in 3.5, 3.2, 3.3, 3.6 and 3.3 times increase in dry matter accumulation for Summit, S19/21, Raja, Jawhar and S19/12 respectively.



Table 1: The slope and intercepts and their 95% confidence intervals for the linear functions in Fig 5

Variety	February-June					July-December				
	Slope	Std err	Intercept	Std err	R ²	Slope	Std err	Intercept	Std err	R ²
Summit	25.6	-	73.5	-	0.7522	62.5	0.00431	91.2	0.0079	0.0077
S19/21	33.3	-	84.9	-	0.6948	50.0	0.0039	97.9	0.00768	0.00768
Raja	20.8	-	79.7	-	0.5614	28.6	0.00104	95.1	0.00372	0.0041
Jawhar	21.7	-	75.3	-	0.8226	58.8	0.00503	88.8	0.0097	0.01
S19/12	40.0	-	79.0	-	0.8016	71.4	0.00629	86.1	0.0108	0.0102

Table 2: The slope and intercepts and their 95% confidence intervals for the linear functions in Fig 6.

Variety	February-June					July-December				
	Slope	Std err	Intercept	Std err	R ²	Slope	Std err	Intercept	Std err	R ²
Summit	2.0	-	4.1	-	0.5947	0.9	-	1.1	-	0.6977
S19/21	1.4	-	3.1	-	0.3467	0.4	-	1.9	-	0.8893
Raja	2.0	-	3.8	-	0.5006	0.5	-	3.4	-	0.9291
Jawhar	1.8	-	2.3	-	0.4339	0.6	-	2.1	-	0.8927
S19/12	1.5	-	3.8	-	0.4389	0.6	-	1.7	-	0.7396

Table 3: The slope and intercepts and their 95% confidence intervals for the linear functions in Fig 7.

Variety	February-June					July-December				
	Slope	Std err	Intercept	Std err	R ²	Slope	Std err	Intercept	Std err	R ²
Summit	0.5	-	20.5	-	0.8473	0.3	-	7.0	-	0.6147
S19/21	0.4	-	13.7	-	0.7327	0.3	-	2.0	-	0.6394
Raja	0.3	-	5.9	-	0.6418	0.3	-	2.1	-	0.8727
Jawhar	0.4	-	15.2	-	0.8703	0.3	-	4.7	-	0.9097
S19/12	0.3	-	12.6	-	0.8507	0.3	-	2.2	-	0.7533

Table 4: The slope and intercepts and their 95% confidence intervals for the linear functions in Fig 8

Variety	February-June					July-December				
	Slope	Std err	Intercept	Std err	R ²	Slope	Std err	Intercept	Std err	R ²
Summit	10.1	-	12.8	-	0.9298	18.5	0.0021	32.3	0.00354	0.9214
S19/21	11.5	-	15.7	-	0.9863	16.1	-	31.4	0.00143	0.9593
Raja	5.0	-	17	-	0.9343	8.5	0.00027	25.9	0.00097	0.9770
Jawhar	9.3	-	16.3	-	0.9419	16.7	0.00155	29.2	0.00285	0.9750
S19/12	12.0	-	13.4	-	0.9487	20.8	0.00197	26.6	0.00358	0.9353

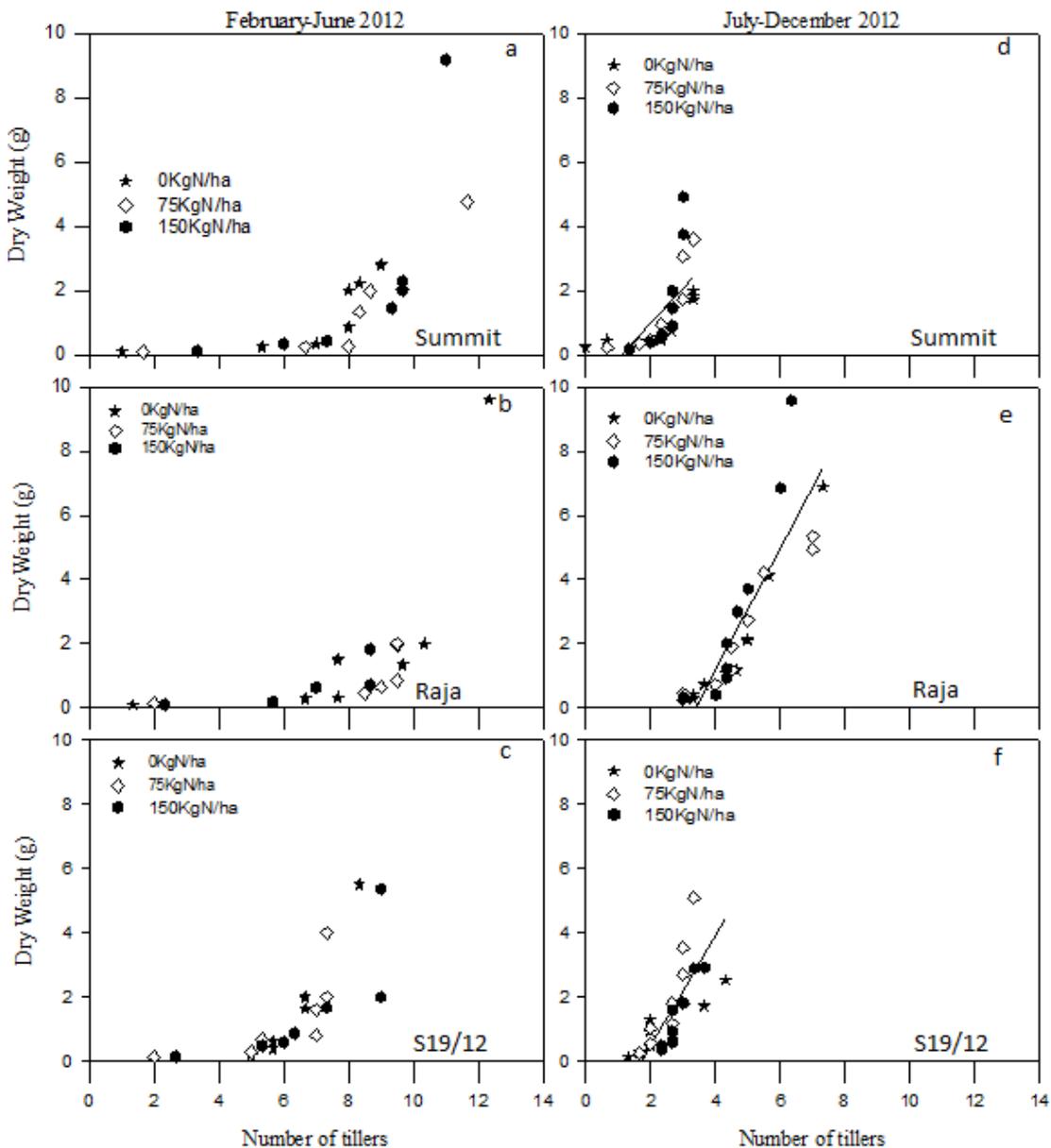


Figure 6: Number of tillers vs dry weight of linseed during the February-June and July-December seasons 2012.

Plant height showed a significant linear relationship with number of leaves (Fig. 7). There was an increase by 2.2-3.3 and 3.2-3.6 leaves per unit increase in height in the February-June (Fig. 7a, b, c) and July-December (Fig. 7d, e, f) There was an increase by 2.2-3.3 and 3.2-3.6 leaves per unit increase in height in the February-June and July December 2012 seasons, respectively. Nitrogen had no

significant effect on this relationship. In both seasons, an increase in plant height was accompanied by an increase in the number of leaves. This increase was however not dependent on the level of nitrogen fertilizer used. For the different varieties and seasons, a unit increase in height resulted in varied number of leaves (Table 3).

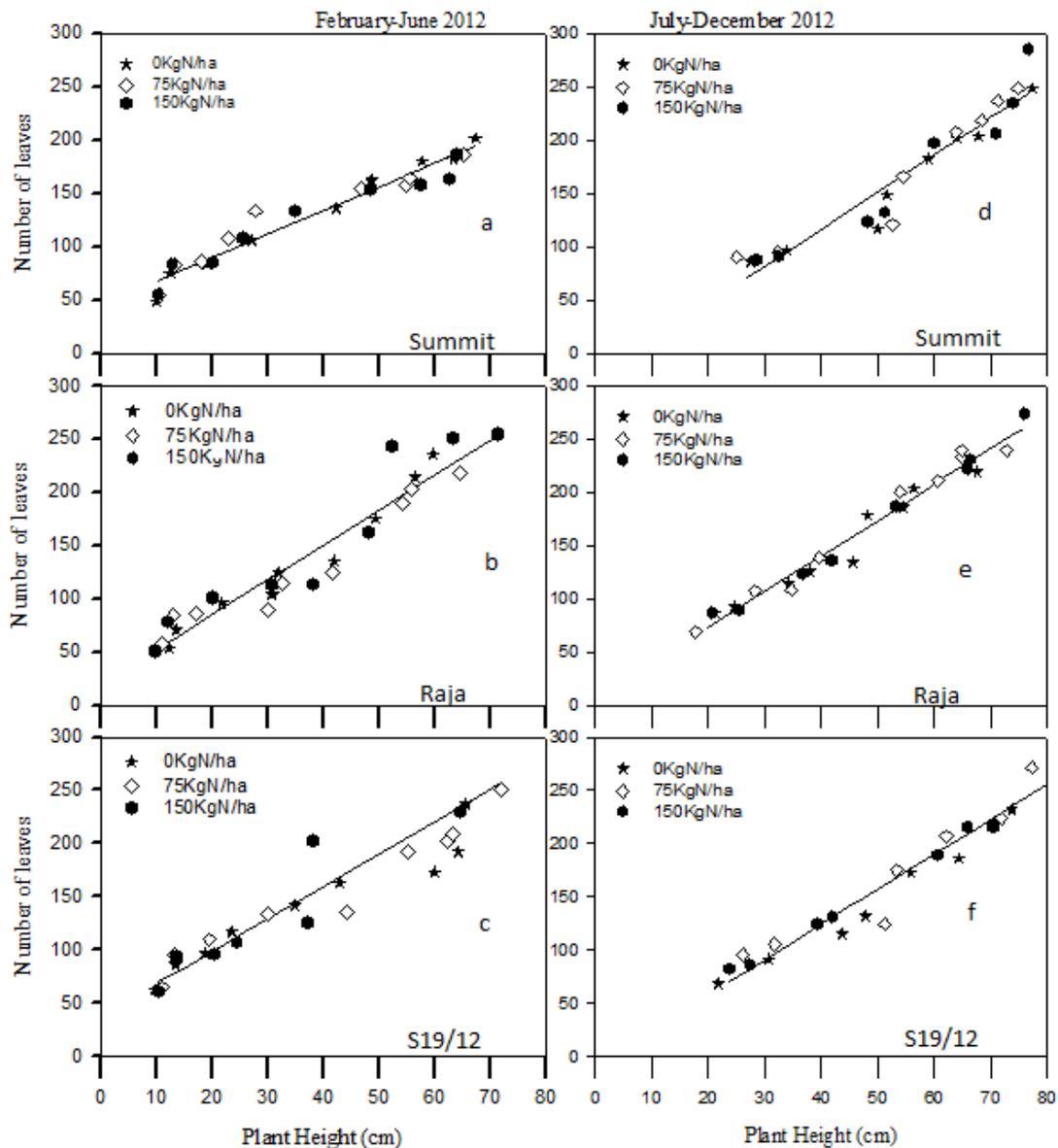


Figure 7: Plant height vs number of leaves of linseed during the February-June and July-December seasons 2012.

In both seasons, there was a linear relationship between the height of the linseed plants and increase in dry weight. As plant height increased so did the dry weight though this depended on the variety (table 4). This increase was independent of the level of N-fertilizer added. During the February-June 2012 season, a unit increase in height resulted in a 0.1 times increase in the dry matter of Summit, S19/21,

Raja, Jawhar and S19/12 respectively (Fig. 8a, b, c). Consequently, an increase in a single leaf resulted in a 0.1 times increase in dry weight for Summit, S19/21, Raja, Jawhar and S19/12 during the July-December season (Fig. 8d, e, f). Though the relationship for Raja during the February-June season was statistically significant, this relationship did not appear linearly real.

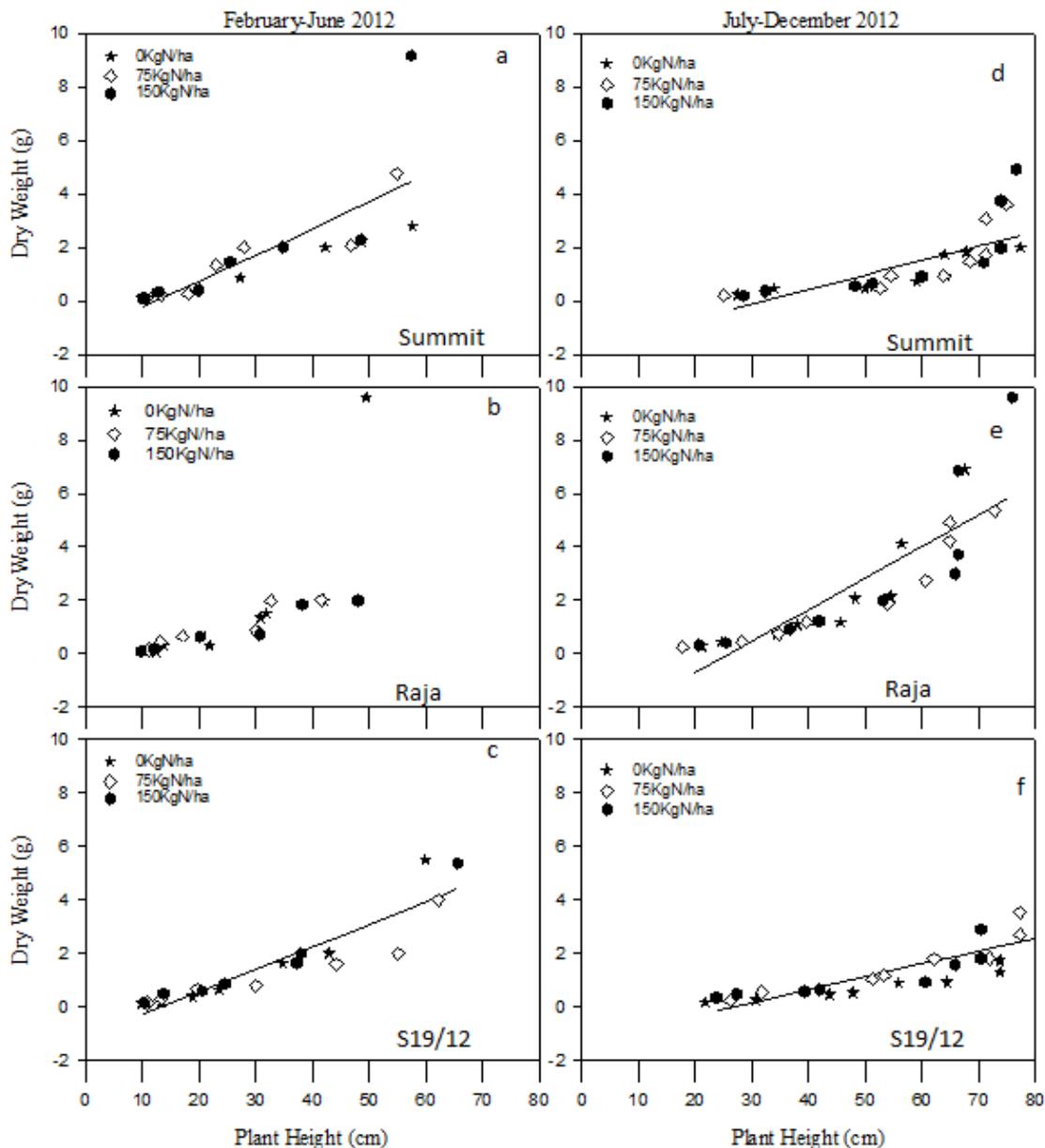


Figure 8: Plant height vs dry weight regressions for linseed during the February-June and July-December seasons 2012.

Summit and Raja produced significantly higher head yields in the February-June season. In the July-December season, while Raja still gave the highest head yield, Summit gave the lowest. S19/21, Jawhar and S19/12 did not significantly differ in head yield ($P > 0.05$) (table 5). In both seasons, production of heads was influenced by nitrogen fertilization rates with

75KgN/ha giving the highest head yield in the February-June season while it was 150KgN/ha in the July-December season. Seed yield per plant shows that Raja yielded significantly higher seed ($P < 0.05$) than the other varieties in both seasons (table 6). In the two seasons, the yield per plant between Summit, S19/21, Jawhar and S19/12 did not vary significantly. In



the February-June season, the control (0kg N) gave a significantly higher seed yield while in the June-December season, seed yield for the

different rates of N application was not significantly different (Table 6).

Table 5: Production of heads as influenced by linseed cultivars and different nitrogen fertilizer levels during the February-June and July-December 2012 seasons.

Variety	Number of heads per plant	
	February-June 2012	July-December 2012
Summit	211a	82c
S19/21	103b	135b
Raja	163a	232a
Jawhar	106b	132b
S19/12	111b	105b
LSD	65.715	20.213

Nitrogen (Kg/ha)	Number of heads per plant	
	February-June 2012	July-December 2012
0	119b	133b
75	150a	137a
150	146a	140a
LSD	50.845	3.114

**Values with same alphabet are not significantly different along the column while values followed by different alphabets are significantly different at 5% probability level.*

Table 6: A comparison of yield per plant for five linseed cultivars as influenced by nitrogen fertilizer levels during the February-June and July-December 2012 seasons.

Variety	Average yield (g/plant)	
	February-June 2012	July-December 2012
Summit	8.938b	0.1493b
S19/21	1.513b	0.3038b
Raja	21.383a	3.2929a
Jawhar	0.837b	0.4200b
S19/12	1.343b	0.2366b

Nitrogen (Kg/ (Kg/ha)	Average yield (g/plant)	
	February-June 2012	July-December 2012
0	9.400a	0.8533a
75	4.047b	0.8101a
150	5.075b	0.9781a

**Any two means not sharing a letter common in a column differ significantly at 5% probability level according to the lsd test.*

6 DISCUSSION

There were visible colour differences between the control and the treatments (data not shown) although this was not expressed in the various growth parameters. This could have resulted from leaching of nitrogen due to above average

rainfall (>230mm) especially during the July-December season. Nitrogen could also have migrated from treatment plots to the control hence the non-significant response in most of the growth parameters (Erhart *et al.*, 2007). This



study did not establish significant differences in production of leaves by the linseed cultivars as well as across the N-fertilizer rates. Different linseed cultivars significantly differed in the number of tillers produced, with Raja producing the most side shoots. The difference in number of tillers per plant among the linseed cultivars may be attributed to genetic factors. The number of tillers per plant was not significantly affected by different levels of nitrogen fertilization though maximum number of tillers (upto 8.1) was recorded at the highest level of nitrogen fertilization (150KgNha⁻¹). Ali *et al* (2011) observed that Linseed cv. Chandni produced significantly higher number of tillers at 100KgN/ha than at 0, 50 and 75KgN/ha. Working with Linola and linseed at 0, 25, 50, 75 and 100KgN/ha, they found that maximum number of tillers per plant (4.93) was produced at 75KgN/ha while the least (2.13) was by linseed at 0KgN/ha. Hocking (1995) found that plants under adequate N-supply (140KgN/ha) produced about 3.7 tillers plant⁻¹ vs 0.8 for the most N-stressed. He therefore concluded that nitrogen stress reduced the number of tillers (secondary basal stems) and fruiting branches per plant and an adequate supply of N is required throughout the growth of linola crop. The level of nitrogen application was not found to significantly affect plant height. Height increased steadily with increasing level of nitrogen application and plants were slightly taller during the July-December season (79.1cm) compared to 71.7cm reached during the February-June season. This was probably due to the low initial nitrogen levels in the soil. Ali *et al.*, (2011) reported linear increase in height with increase in nitrogen with maximum height of 106.07cm at 75KgN/ha while the minimum of 91.77cm was at 0KgN/ha. The current difference in response to N-fertilization compared to earlier research is probably due to differences in cultivars used. N-fertilization prompted faster vegetative growth hence faster increase in height due to rapid increase in cell size. However, the highest nitrogen level (150kgNha⁻¹) caused massive lodging in some

plots. Similar effect of nitrogen on linseed cultivars was reported by Sharief *et al.* (2005) and Sakandar *et al.* (2011). The different cultivars reached significantly different heights of up to 73.1cmduring the February-June season and 84.1cm during the July-December season. The pattern of dry matter accumulation during the experimental period followed that typical of many cultivated species, with exponential, linear and decreasing phases (Gardner *et al.*, 1985). These phases were clearly visible and pronounced during both seasons of the experiment. During the early period of growth, all the treatments accumulated smaller weights but differences were visible. However, when the plants were well established in their specific environments they made the necessary adjustments to enable full exploitation of the available resources. The momentum of accumulation was maximum during the main growth period, and it declined at maturity. This later reduction in dry matter accumulation may be the result of senescence of leaves, complete dieback of basal branches and lodging during the maturity period, which was caused by heavy rains and especially during the July-December season. Nitrogen stress had no significant effect on biological yield of the tested linseed cultivars. Cultivars however varied in biomass accumulation in both seasons, with Raja accumulating much more biomass compared to the other cultivars. This can be attributed to the higher number of tillers produced by Raja. The biological yield consistently increased with increasing level of N especially after the third split of application due to continued increase in photosynthetic surfaces leading to increased photosynthetic assimilates. Biological yield is a major contributor to total output of any crop and depends upon species, growing season and nutrition. It is the product of growth rate and duration of the growth period, both of which indicate the potential for improvement in yield (Diepenbrock, 2000). The possible reason for the increase in biological yield with the increasing rates of N maybe that N increases vegetative growth resulting in more



photosynthesis and hence photosynthates, which increase the growth and development of crop and thus result in the increased biological yield. Additionally, the increase maybe due to the higher critical N demand of linseed for biomass formation (Colnenne *et al.*, 1998). These results are in line with the results of Uddin *et al.* (1992) who stated that biological yield of rapeseed increased with increasing rate of N up to 150 kg N ha⁻¹. Total dry matter accumulation has been shown to be a function of assimilating organs and the photosynthetic capacity of the leaf canopy (Bisco and Gallanher, 1977; Diepenbrock and Porksen, 1992). During the February-June season, an increase in number of leaves led to a linear increase in the dry weight, a relationship that did not exist during the July-December season. This is perhaps due to increased sites of photosynthetic assimilates production. In both seasons, number of leaves increased linearly with plant height. Leaves grew onto the elongating stem. Since the varieties grew in height at different rates, the rates at which the number of leaves increased were consequently different. The elongated stem translated to increased biomass. Cultivars differed in production of capsules per individual plants

7 CONCLUSION

The essence of growing any crop lies in its yield potential. Raja is a superior variety to the other four as it yielded more heads and consequently

with Raja and Summit producing the highest numbers in the February-June season and Raja in the July-December season. Nitrogen application at 75Kg^{ha}⁻¹ and 150Kg^{ha}⁻¹ produced higher numbers of capsules per plant in both seasons compared to 0KgN^{ha}⁻¹. Similar findings have been reported by other researchers where application of nitrogen caused increased production of capsules (Dybing, 1964; Gad and El-Farouk, 1978; Nayital and Singh, 1984; Hocking, 1995). This increase in number of capsules per plant due to increase in nitrogen might be attributed to increase in vegetative growth which resulted in more number of capsules being carried by each plant. Different nitrogen levels significantly affected seed yield per individual plant of linseed. Maximum seed yield of 9.4g^{plant}⁻¹ was obtained at 0 kg N ha⁻¹, which is opposite the results for number of capsules. However, lodging was observed in N fertilized plots, and this accounts for the poor seed yield in such plots. Koshta and Battawar (1981) reported that more than 60 kg N/ha caused extensive crop lodging with rain and reduced yield. Similarly, Hocking *et al.* (1997) reported that when water was not limiting lodging was a problem in linseed at high N rates.

more seed. Linseed is a low nitrogen user crop and moderate supply of nitrogen is sufficient.

8 ACKNOWLEDGEMENT

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