Effect of water stress and nitrogen on canopy development and radiation interception of lentil

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Abstract

Two experiments were conducted in 1990-91 and 1991-92 to study the effects of water stress and nitrogen on leaf initiation and growth, canopy development and radiation interception of lentil (*Lens culinaris* Medik.). Results from the glasshouse experiment showed that for leaves 1 - 12 water stress delayed leaf appearance by 4 - 10 days while nitrogen at all rates from 50 - 150 kg/ha reduced the time taken for leaves to appear. Time to the onset of senescence of the early leaves was delayed with both water and nitrogen. Senescence of leaf 1 was delayed 5 days with the fully irrigated compared to the stressed plants. Nitrogen delayed senescence of leaf 1 by up to 7 days even under severe water stress. The field studies back up results from the glasshouse. Nitrogen applications of 100 kg N/ha gave increases in intercepted PAR of 10 and 21% over 0 N for a May and a September sowing respectively. These increases were due to statistically significant increases in leaf area index. Maximum leaf area index of the May sowing was 6.7 with 0 N/ha and 13.6 with 100 kg N/ha. For the September sowing maximum LAI was 4.0 with no N and 6.0 with 100 kg N/ha. Both total DM and seed yield were also greater with N from 5.3 and 7.9 t/ha of TDM in the May sowing at 0 and 100 kg N/ha respectively to 1.3 and 1.5 t seed/ha at 0 and 100 kg N/ha. While nitrogen has been shown to decrease nodule weight in lentils, these results suggest that nitrogen may give small increases in seed yield in some seasons.

Introduction

There has been much agronomic research done on lentil in Canterbury. McKenzie and Hill reported on development (1989), water use (1990) and solar radiation interception (1991) of lentil in Canterbury. Also, Turay *et al.* (1991) reported on the effects of starter nitrogen on early lentil growth. McKenzie and Hill (1990) detailed a computer simulation model of lentil growth and development. This model, while capable of accurately predicting growth and yield of lentil in Canterbury, does a poor job of modelling canopy growth. In the model, leaf growth is not considered. Canopy expansion is a relative function of daily thermal time. Canopy senescence is empirically based on a parabolic decline with increasing thermal time.

To improve the lentil model a subroutine is required to mechanistically model lentil leaf and canopy development. The aim of this series of experiments was to provide the data to model nitrogen and water stress effects on leaf initiation, growth and senescence.

Materials and Methods

Experiment number one was a glasshouse pot trial examining leaf appearance, leaf duration and senescence as affected by water stress and nitrogen level. The experiment was a randomized complete block factorial design with 5 replicates. Seeds of lentil cv. Olympic were germinated, then sown into 150 mm diameter, 150 mm tall pots containing N free potting mix. Four levels of irrigation (full, 3/4 full, 1/2 full and 1/4 full irrigation were factorially combined with four levels of applied nitrogen (0, 50, 100 and 150 kg N/ha) to give 16 treatments. The experiment was repeated three times to allow sequential sampling. The plants were grown under natural autumn daylight with temperatures ranging from 17-25°C.

Days to emergence of leaves and branches were counted as was time to senescence for the first four mainstem leaves. The three repeats were harvested at either 34, 59 or 84 days after planting. At harvests one and two leaf area was measured using a LICOR model LI 3100 area meter. At all harvests, total DW, total leaf number and total branch number were measured.

The field trial was conducted on a Templeton silt loam at the Lincoln University Henley site. The experiment was a split plot randomized complete block factorial design with sowing date as main plots. Olympic lentils were sown on either 23 May or 16 September 1991. Subplots were a factorial combination of tree nitrogen levels (0, 50 or 100 kg N/ha) and two irrigation levels (0 or full irrigation). There were 4 replicates. Plots were 2.1 by 10 m. Nitrogen was applied a calcium ammonium nitrate (28% N) prior to sowing.

Plots were sampled approximately once a month during the winter. In spring sampling was increased to approximately fortnightly where one 0.1 m^2 quadrat was cut per plot. Solar radiation interception was measured using a miniature tube solarimeter and integrator. At final harvest, yield was measured from cuts of two 0.5 m^2 quadrats.

All data were analysed using analysis of variance.

Results

Weather during the field experiments is shown in Figure 1. The important months of November and December, when most crop DM is produced were both wetter and colder than long term means. Rainfall over late winter and early spring was much lower than the long term means.

In the glasshouse experiment leaf emergence was strongly influenced by both irrigation and nitrogen level. Water stress increased the time to emergence for all leaves from leaf 1 to leaf 12. Leaf 1 was delayed a mean of 3.1 days and leaf 12 11.4 days (Table 1). The effects of nitrogen on leaf emergence were similar to irrigation with low N plants showing a 3.9 d delay in emergence of leaf 1 (Table 1).

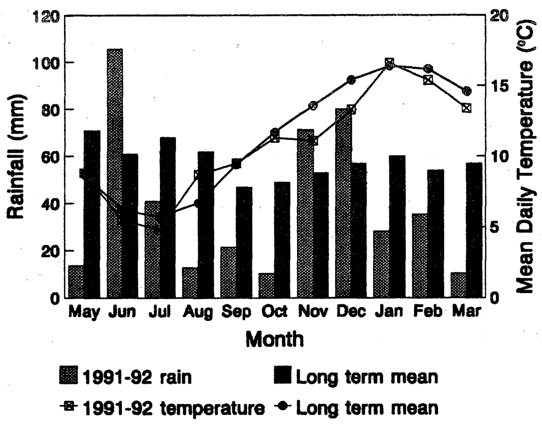

Figure 1. Rainfall (bars) and mean daily temperature (symbols) for the 1991-92 lentil growing season in Canterbury, New Zealand. Long term means from 1931-1980.

While the interaction between these treatments was not significant a regression of leaf number against days to emergence for 150 kg N and full irrigation and for 0 kg N and 0 irrigation gave different slopes and intercepts (Fig. 2). (Slopes different at $p < 0.001$ (t test. $t_{calc} = 5.75$) with 20 d.f.).

Branch emergence had very similar trends to leaf emergence. Under the fully irrigated treatment branch 1 appeared 1.6 days earlier than with the 1/4 fully irrigated plants. The high nitrogen rate also caused more rapid branch emergence at 4.6 days for branch 1 and 6.9 days for branch 1 with 0 nitrogen.

Leaf senescence was also affected by both factors (Table 2). Leaf duration, equivalent to number of days to senescence minus number of days to emergence was 17% shorter under 1/4 full irrigation than under full irrigation. The highest N rate reduced leaf duration compared with 50 and 100 kg N/ha. However at 100 kg N/ha leaf duration was 47% longer than the duration at 0 kg N/ha.

At final harvest (84 days after planting), DM production was reduced from 10.4 g/plant at full irrigation to 3.3 plant at 1/4 full irrigation (Table 3). Nitrogen also gave large DM increases with 44 g DM/plant at 0 N and 9.1 g/plant at 100 kg N/ha.

The increases in DM with irrigation and nitrogen were similar to the effects of these factors on total leaf number and leaf area per plant (Table 3).

In the field experiment, there was no effect of irrigation because rainfall during the growing season was

Table 1. The effect of irrigation and nitrogen on leaf emergence of lentil.

	Days to emergence		
	Leaf 1	Leaf 6	Leaf 12
Irrigation			
full	4.9	21.4	47.5
3/4 full	5.5	23.6	50.3
1/2 full	6.0	25.8	53.0
1/4 full	8.0	31.7	58.9
SEM	0.17	0.90	0.93
Significance	***	***	***
Nitrogen (kg N/ha)			
0	8.8	31.6	57.9
50	7.0	26.2	52.7
100	5.1	23.6	48.8
150	4.9	21.1	48.4
SEM	0.17	0.90	0.93
Significance	***	***	***

above average. However, nitrogen and sowing gave highly significant effects on all parameters studied. The May sown plants produced 67% and 36% more seed and DM respectively than did the September sown plants. Harvest index was 29% higher at the early sowing and maximum leaf area index was double that of the late sowing (Table 4).

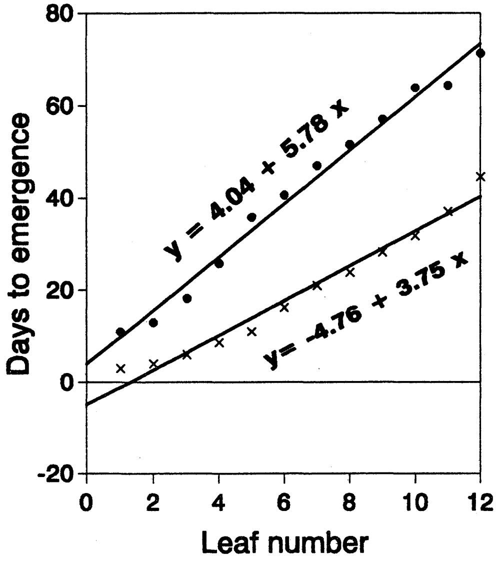

Figure 2. Days to emergence of leaves one to twelve of lentil cv. Olympic in Canterbury (• = 0 kg N/ha and no irrigation, x = 150 kg N/ha and full irrigation).

Table 2. The effect of irrigation and nitrogen on duration of leaf life.

	Duration of growth (days)			
	Leaf 1	Leaf 2	Leaf 3	Leaf 4
Irrigation				
Full	43.2	44.5	46.9	50.9
3/4 full	42.8	44.8	49.0	49.0
1/2 full	40.4	41.6	43.5	46.6
1/4 full	35.8	38.2	39.4	41.2
SEM	0.95	0.87	1.05	0.94
Significance	***	***	***	***
Nitrogen				
0	34.2	36.4	37.2	36.9
50	43.3	44.4	45.2	47.5
100	50.3	52.5	53.5	57.4
150	34.4	35.9	42.9	45.9
SEM	0.95	0.87	1.05	0.94
Significance	***	***	***	***

Table 3. The effect of irrigation and nitrogen on dry matter production per plant at 84 days after planting, and number of leaves per plant and leaf area at 59 days after planting.

	DM (g/plant)	No. of leaves per plant	Leaf area (cm^2/plant)
Irrigation			
full	10.4	137	428
3/4 full	8.2	117	301
1/2 full	5.5	82	189
1/4 full	3.3	47	77
SEM	0.33	6.3	24.3
Significance	***	***	***
Nitrogen (kg N/ha)			
0	4.4	63	154
50	6.4	89	236
100	7.6	110	272
150	9.1	120	333
SEM	0.33	6.3	24.3
Significance	***	***	***

Table 4. Effects of nitrogen and sowing date on yield, harvest index and leaf area index at DAS of lentil.

	Seed yield (g/m^2)	Dry matter	Harvest index	Leaf area index
Sowing Date				
May	304	692	0.45	9.6
September	182	507	0.35	4.8
SEM	5.7	13.2	0.014	0.23
Significance	***	***	**	***
Nitrogen (kg/ha)				
0	198	530	0.36	5.3
50	230	601	0.38	6.4
100	301	667	0.45	9.8
SEM	7.0	16.2	0.17	0.49
Significance	***	***	**	**
Interactions	NS	NS	*	***

While the effect of nitrogen was smaller than that of sowing date 100 kg N/ha gave increases of 52%, 26%, 25% and 85% respectively for seed yield, DM production, HI and LAI.

The significant interaction of nitrogen and sowing date on LAI (Table 5) showed that the largest gain in LAI with nitrogen was in the May sowing where LAI increased by 103% from 0 - 100 kg N/ha. In the September sowing the increase in LAI from 0 to 10 kg N/ha was only 50%. The only other significant interaction was with H.I. H.I. did not change with changing N applications in the May sowing, however with the September sowing 0 N plots had a H.I. of 0.28 while the 100 kg N/ha plots produced a H.I. of 0.44.

There was a strong relationship in the September sowing between maximum DW production and intercepted solar radiation (r^2 = 0.93). The calculated utilisation coefficient was 1.91 g DM/MJ PAR intercepted.

Table 5. The interaction of nitrogen and sowing date on leaf area index of lentil at DAS.

	Nitrogen (kg N/ha)		
Sowing date	0	50	100
May	6.7	8.4	13.6
September	4.0	4.5	6.0

Discussion

There has been little information published on leaf growth of lentils. The glasshouse experiment has provided considerable data for modelling leaf and canopy growth. Saxena and Hawtin (1981) reported leaf appearance rates for cv. ILL4400 and ILL4401 in Tel Hadia, Syria. Leaf appearance was curvilinear for both cultivars when winter sown and approximately linear when spring sown. Timing of leaf appearance was delayed with water stress only in the spring sowings.

These results have shown that both water stress and nitrogen availability can delay leaf appearance (Table 1). Furthermore as shown in Table 2 duration of leaf life was reduced with water stress and with low nitrogen levels. Interestingly, the highest N rate of 150 kg N/ha also reduced the duration of leaf life. This was more marked at the earliest leaves and the effect decreased with leaves 3 and 4. It seems likely that the single N application of 150 kg N/ha at sowing was large enough to produce temporary salt stress.

Leaf appearance rates in this work were linear (Fig. 2). Rate of appearance was increased by full irrigation and nitrogen when compared to nitrogen and low irrigation. This indicates the importance of accounting for these parameters when modelling leaf and canopy growth of lentils.

Growth and yield of lentils in the field were similar to previous reports (McKenzie and Hill, 1990). Generally, lentils in Canterbury are highest yielding when sown in autumn or early spring. This is due to increased crop duration and greater solar radiation interception. There have however been no reports of increases in yield with the addition of nitrogen. This work suggests that at least in a wet cool growing season lentils may not fix adequate nitrogen for their own use and may produce higher seed yields with the addition of fertilizer nitrogen.

However, these results support the findings of Saxena and Hawtin (1981) who reported that leaf area per plant was very susceptible to water stress and even with winter sown lentil crops rained plants showed an 11% reduction in leaf area per plant compared to irrigated plants. In spring sowing in Tel Hadia, Syria, leaf area of rained plants was less than half of that of irrigated plants.

These authors however, reported little effect of irrigation on the number of leaves per plant. This work showed that at least for cv. Olympic grown in pots, severe water stress can reduce the number of leaves per plant (Table 3).

The reduction in leaf area with water stress is very common. Cell expansion is driven by turgor pressure and is very sensitive to water stress for many different plant species (Boyer, 1970). While the field trial found no effect of irrigation on leaf area, this was due to above average rainfall. The glasshouse clearly showed that leaf area of lentil is sensitive to water stress.

The effects of nitrogen on leaf area were as strong or stronger than those of water stress both in the glasshouse and in the field.

Nitrogen has been shown to increase area of individual leaves in most plants. Indeed, even very early forming leaves such as leaves 2, 3 and 4 have been shown to give large increases in area in response to applied N for cereals (Andrews *et al.*, 1991 and legumes (McKenzie, unpublished data). Andrews *et al.* (1991) reported that final leaf area for a range of cereals and grasses increased markedly over the range of applied nitrate levels from 0.1 to 20 mol/m^3. Most of the response occurred in the range of 0.1 - 1.0 mol/m^3 NO_3^-, this is equivalent to nitrate concentrations in the interstitial water of most agricultural soils (Haynes *et al.*, 1986). Hence, it is likely that applied N will give smaller increases in leaf area in the field. Field results presented here showed both an increase in LAI with the addition of nitrogen from 0 to 100 kg N/ha (Table 4) and a corresponding increase in intercepted solar radiation in the September sowing. The utilisation coefficient in the September sowing of 1.9 g DM/MJ PAR was similar to that found by McKenzie and Hill, 1991. The results for intercepted solar radiation in the May sowing were unreliable due to a weed problem.

Conclusions

1. Water stress and low fertility can delay leaf appearance, reduce leaf area and reduce duration of leaf life.
2. Nitrogen may under some circumstances boost lentil seed yield, but further work is required in this area.

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