A preliminary investigation into root-shoot growth relationships of lentils (*Lens culinaris* Medik)

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Abstract

An experiment was conducted in 1989/90 which examined the effects of irrigation and rhizobium inoculation on the growth of lentil cv. Titore. The plants were grown in 80 cm deep pots which enabled total recovery of roots.

Results showed that lentils partition a large proportion of early photosynthate to the root, with root/shoot dry weight ratios at 32 days after sowing (DAS) of approximately 4.3. By final harvest, root/shoot ratio had declined to 0.36. Root/shoot ratio was not affected by the treatments. Root growth was analysed functionally using a Gompertz curve. Root dry matter (DM) accumulated rapidly with maximum growth rates of 16 $g/m^2/d$.

There were significant treatment effects on nodule score, final DM yield and seed yield. Fully irrigated plants produced 736 and 320 g/m^2 of DM and seed respectively while non-irrigated plants produced 509 and 193 g/m^2 of DM and seed respectively. Inoculation with *Rhizobium leguminosarum* gave a doubling of nodule score at 46 DAS. However, by 56 DAS this difference had disappeared and all plants were well nodulated. The early difference in nodule score was accompanied by increased shoot production in the inoculated plants. However the increase was temporary and all plants produced similar shoot DM by 56 DAS.

***Additional key words:** root/shoot ratio,* Lens esculenta, *nitrogen, nodules, inoculation*

Introduction

Lentils are an important crop in Canterbury with usually 2-4000 ha sown in the region. It is an ideal crop for the Canterbury region as it yields well on shallow dryland farms. When grown under rain shelters, lentils have shown the ability to survive on soil moisture for as long as 7 months (McKenzie, 1987). Seed yields are usually higher in dry than in wet years. McKenzie and Hill (1990) found that field lentils are tolerant of water stress in Canterbury.

While work from the Indian sub-continent has shown lentils usually respond positively to irrigation (Sharma and Prasad, 1984; Saraf and Baitha, 1985), in Canterbury results are less consistent. Irrigation may in a dry season result in increased vegetative growth, but often seed yield is not increased (McKenzie and Hill, 1990). Previous work by McKenzie (1987) suggested that lentils have a root system capable of extracting soil moisture from a depth of 80 cm. Lentil plants under severe water stress are capable of extracting from 75-80% of the total water content held at field capacity (McKenzie, 1987). The tolerance to drought of the lentil plant may be due to a large root system which is efficient at utilising soil moisture. Additionally it seems likely that plants under severe water stress may increase the proportion of assimilate sent below ground in an attempt to reach new sources of soil moisture.

This experiment was conducted to study the effects of water stress and rhizobium inoculation on root and shoot growth of lentils. The objectives were to determine: 1) root/shoot ratios under water stress; 2) harvest index under water stress; and 3) the effect of water stress and rhizobial inoculation on nodulation.

Materials and Methods

The trial was a randomized complete block factorial design consisting of 4 treatments. These were a factorial combination of 1) irrigation, full or nil and 2) Rhizobium, inoculated or nil. There were six replicates for each of the six harvest dates making a total of 144 pots.

Seed of lentil cv. Titore was sown on 26 October 1989 into 80 cm deep 15 cm diameter pots filled with

50% full nutrient potting mix, 25% vermiculite and 25% perlite. Plants were thinned to 5 per pot on 17 November. Rhizobium inoculum was applied as a solution on 18 November. The pots were located in a pit to simulate field conditions. Headlands were sown two days after planting with cv. Titore at 150 plants/m^2. The pots were covered by a movable 4 m x 4 m square rain shelter and all watering was done by hand.

Nodulation was quantified using a scoring system. One was equivalent to a few small nodules, two was equivalent to a many small nodules, three was equivalent to many small and large nodules.

Functional growth analysis

Generalized logistic curves with the form of Equation (1) were fitted to the growth analysis data:

$$y = \frac{C}{(1 + Te^{-b(x-m)})^{\frac{1}{T}}} \qquad (1)$$

where y is yield, C is the final above-ground crop weight and T, b and m are constants (Gallagher and Robson 1984). Values of C, T, b and m were used to calculate weighted mean absolute growth rate (WMAGR), duration of growth (DUR) and maximum crop growth rate (C_m) according to Equations (2), (3) and (4), respectively.

$$WMAGR = \frac{bC}{2(T+2)} \qquad (2)$$

$$DUR = \frac{2(T+2)}{b} \qquad (3)$$

$$C_m = \frac{bC}{(T+1)^{(\frac{T+1}{T})}} \qquad (4)$$

Functional growth analysis was made using the MLP programme from Rothamsted Experimental Station, UK (Ross *et al.* 1979). All statistics were calculated using the GENSTAT statistical package (Rothamsted Experimental Station 1980).

Results

Irrigation caused a significant increase in both seed yield and DM production (Table 1). Irrigated plants produced 320 g seed/m^2 while non-irrigated plants produced 40% less seed at 193 g/m^2. Inoculation had no significant effect. Harvest index (HI) was unaffected by any treatment and ranged from 0.35 - 0.41.

Crop growth was measured by fortnightly harvesting. The only treatment which affected DM production during the season was rhizobial inoculation. At 46 DAS inoculated plants produced 64% more DM/plant than did non-inoculated plants (Table 2). However, by 56 DAS, nodulation was approximately equal, and DM/plant was essentially the same for both inoculated and non-inoculated plants.

While root growth was unaffected by the treatments, overall mean root growth was rapid with a maximum of 16.2 g/m^2/d (Fig. 1). Average root growth was about 11.0 g/m^2/d. Root to shoot (R/S) ratios were very high early in the season (Fig. 2). At 32 DAS root to shoot ratio was about 4.3. This declined to about 0.36 by 90 DAS.

Inoculation had a significant effect on nodulation early in the season. At 46 DAS there were more nodules in the inoculated plants than in the non-

TABLE 1: Effect of irrigation and rhizobium on final yield of lentils. There were no significant interactions between treatments.

	Seed yield (g/m^2)	Dry weight (g/m^2)	Harvest Index
Irrigation:			
Full	320	736	0.41
Nil	193	509	0.35
SEM	32	71	0.029
Significance	*	*	NS
Rhizobium:			
Inoculated	280	707	0.39
Nil	232	538	0.37
SEM	32	71	0.029
Significance	NS	NS	NS
CV (%)	39.4	26.7	43.7

TABLE 2: Effect of rhizobium on shoot DM (g/plant) of lentils.

	Days after Sowing				
	32	46	56	77	90
Inoculated	0.09	0.46	1.00	2.34	2.74
Nil	0.09	0.28	0.98	2.00	2.00
SEM	0.004	0.024	0.080	0.172	0.274
Significance	NS	***	NS	NS	NS

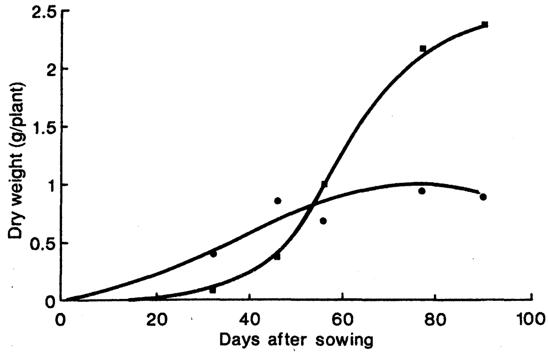

Figure 1: **Dry matter accumulation of roots (●) and shoots (■) of lentils in Canterbury, New Zealand, 1990.**

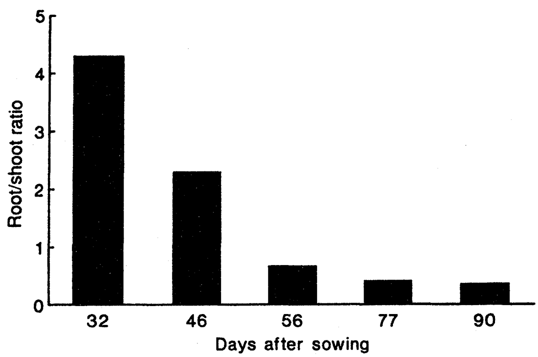

Figure 2: **Root to shoot ratios of lentils in Canterbury, N.Z., 1990.**

inoculated plants (Table 3). However, by 56 DAS there were no differences between treatments.

Discussion

In Canterbury, lentils have been shown to be very tolerant of drought (McKenzie, 1987; McKenzie and Hill, 1990). However, under rain shelters McKenzie and Hill (1990) found a linear decrease of lentil yield with increasing maximum potential soil moisture deficit. It is therefore surprising that there was only a

TABLE 3: Effect of irrigation and rhizobium on nodule scores of lentils. (0 = no nodules, 1 = few small nodules, 2 = many small nodules, 3 = many small and large nodules). There were no signifcant treatment interactions.

	46 DAS	56 DAS	77 DAS
Irrigation:			
Full	1.5	2.1	2.5
Nil	1.2	1.6	2.3
SEM	0.19	0.26	0.13
Significance	NS	NS	NS
Rhizobium:			
Inoculated	1.9	1.9	2.3
Nil	0.8	1.9	2.5
SEM	0.19	0.26	0.13
Significance	***	NS	NS
CV (%)	47.3	48.2	19.2

small increase in yield with irrigation in this experiment. While both seed and dry matter production were about 40% lower without irrigation than with irrigation, there were no significant irrigation effects during the growing season. The reason for the relative lack of response lies with the growing medium and husbandry. All pots contained a mixture of 50% potting mix, 25% perlite and 25% vermiculite. This mixture was watered to field capacity at sowing. Clearly, the pots held adequate water for plant growth over most of the season. Therefore, significant deficits did not build up until towards the end of the season.

Surprisingly rhizobial inoculation did not give increased production. Lentils are nodulated by *Rhizobium leguminosarum* (Islam, 1981). While some authors have reported increased yields with inoculation (Saxena and Rana, 1977), *R. leguminosarum* is present in all Canterbury soils due to the large areas sown to peas each year. As shown in Table 3 by 56 DAS all plants were well nodulated. Clearly inoculation is not necessary in Canterbury for vigorous nodulation.

The increased nodulation at 46 DAS was accompanied by a temporary increase in plant above ground shoot production (Table 2). The response should have been due to fixed N, however, the non-inoculated plants had attained similar production by 56 DAS. It is clear that additional work needs to be done on nodulation and DM response.

Growth analysis

There are very few reports on growth rates of lentil roots. McKenzie and Hill (1990) reported that lentil shoots can grow at rates of 230 kg/ha/d. This compares very favourably with maximum shoot growth rates obtained in this trial of 252 kg/ha/d. Early in the season root growth was more rapid than shoot growth (Fig. 1). However, maximum root growth rates only reached 162 kg/ha/d. Conditions for growth were excellent. The growing medium provided a friable but firm structure which was readily penetrated by even fine roots. Comparing these results with other work is difficult since most other studies measure either root length (Hoogenboom *et al.*, 1987) or root mass (Matthew *et al.*, 1988).

Root/shoot ratio

The root/shoot ratio was very high early in the season at about 4.3 32 DAS. While few reports of root/shoot ratios exist, this is higher than that reported by Andrews *et al.*, (1986) in *Vicia faba*. At 49 DAS only cv. Herz Freya had a root/shoot ratio significantly greater than 1. As reported by McKenzie (1987) lentils produce an extensive root system early in their life cycle. This work clearly supports and quantifies that finding. The extensive root system would seem to provide one explanation for the tolerance of this species to water stress. When grown in the field, lentils are capable of extracting up to nearly 80% of the water a soil held at field capacity (McKenzie, 1987). The large root structure produced early in the growing season (Figs. 1 and 2) gives a benefit to the plant if drought conditions develop. Later in a growing season root senescence may occur and carbohydrates may be transported above ground. The final root sample was taken 90 DAS, when roots had stopped growing but had not begun dying. By final harvest however, root degeneration was evident. Further work is required to determine if root carbohydrates are transported to the shoot and if so how much.

This work needs to be repeated with the imposition of severe water stress. However, the results have clearly quantified the below ground growth of lentils. More work needs to be done assessing the effects of soil fertility on both growth and nodulation.

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