YIELD, ^{15}N-UPTAKE AND FERTILIZER USE EFFICIENCY OF IRRIGATED AND DRYLAND WHEAT AND LENTIL AS MEASURED THROUGHOUT THE GROWING SEASON UNDER VARIOUS LEVELS OF NITROGEN

C. van Kessel and N.J. Livingston
Department of Soil Science, University of Saskatchewan, Saskatoon

ABSTRACT

Laird-lentil and Neepawa-wheat were grown under irrigation in 1987 at the experimental Irrigation Farm at Outlook under three levels of N: 10 (N1), 50 (N2) and 100 (N3) kg of NH_4NO_3, double labelled with ^{15}N. A similar experiment was conducted at the same site under dryland conditions in close vicinity to the experiment under irrigation. Both experiments were laid out as a split-plot, with main plots arranged as RCBD. Main plot treatments were lentil and wheat, sub-plot treatments were N level. Treatments were replicated four times. Crops were harvested at 44, 52, 63, 72, 88 and 101 days after planting (DAP).

Dry weight of wheat was increased through N appliation and irrigation. Irrigated wheat yielded around 100 % more grain than dryland wheat (2539 and 1361 kg/ha, respectively). Irrigation significantly increased the total dry weight of irrigated lentil. However, this was not translated into higher grain yield because the irrigated lentil remained largely in the vegetative growth stage.

At 44 DAP, irrigated N3-lentil had accumulated significantly less N than irrigated N3-wheat (16.7 and 41.3 kg N/ha, respectively). At final harvest, total N uptake of N3-lentil, 157.5 kg N/ha, was significantly higher than for irrigated N3-wheat, 82.6 kg N/ha. Similar trends were found for dryland N3-wheat and N3-lentil with total N accumulation at final harvest of 48.7 and 89.4 kg N/ha for wheat and lentil, respectively. Comparable results were found for the other levels of applied N. There was no starter N effect (10 kg N/ha) on lentil yield. The highest N-accumulation for irrigated wheat occurred between 44 and 52 DAP; 2.8 kg N/ha/day. For irrigated lentil the highest N-accumulation occurred between 63 and 72 DAP; 6.8 kg N/ha/day. Under dryland conditions, N accumulations during comparable periods were 1.2 and 3.5 kg N/ha/day for wheat and lentil, respectively.

With total N accumulation, most of the fertilizer N-uptake by irrigated and dryland wheat occurred during the first 52 DAP. Similar results were also found for irrigated lentil. Dryland lentil, however, accumulated fertilizer-N until the end of the growing season. The difference between dryland and irrigated lentil can be explained by leaching below the lentil rooting zone of N-fertilizer under irrigated conditions. Irrigated N3-wheat had a higher fertilizer use efficiency (% FUE) than irrigated N3-lentil, 32.8 versus 19.4%. In contrast, dryland N3-wheat showed a lower FUE than dryland N3-lentil, 22.2 versus 36.4%.

N application reduced N_2-fixation activity at early growth stages for irrigated N3-lentil and throughout the growing season for dryland N3-lentil. During the total growing season irrigated N1-lentil fixed 124 kgN/ha, dryland N1-lentil 47 kg/ha.

INTRODUCTION

Nitrogen is a major element in all crops and N-fertilization is often required to guarantee optimum crop production. Most commercially grown legumes can fix N (Allen and Allen, 1981) and do not depend on the available soil or fertilizer N application to reach optimum production levels. Crop production under Saskatchewan dryland farming systems is often not limited by N but by available moisture. N-fertilizer recommendations for dryland crops take this production limiting factor into account and an average of 50 kg/ha is applied on stubble in the Dark Brown soil zone. Crop production under irrigated systems is not limited by lack of moisture but other growth factors such as N may become limiting. N recommendations for irrigated stubble are, in general, twice those for comparable dryland soils (Saskatchewan Soil Testing Laboratory).

N losses under irrigated farming systems can be significant. Losses due to nitrification (NO_2) and denitrification (NO_2 and N_2) can be as high as one third of the N applied (Ryden et al., 1979). Others have found much lower values and estimates of NO_2 evolution evolved from applied fertilizer during a cropping season of lower than 2% have been reported (Breitenbeck et al., 1980; Mosier et al., 1982). N gaseous losses also occur in dryland soils but drier conditions largely prevent denitrification activity; a possible exception may be during early spring when the top soil can be saturated with moisture and anaerobic conditions prevail (Aulakh and Rennie, 1986). In addition to gaseous losses, N can leach below the rooting zone where it becomes unavailable for plant uptake. Such losses are unlikely to happen under dryland conditions but can be of significance under irrigation (Smika et al., 1977). Through proper water managment, such losses can be minimized.

MATERIALS AND METHODS

The experimental site was located at the Experimental Irrigation Development Centre at Outlook, Saskatchewan. Two experiments were conducted simultaneously; one under centre pivot irrigation, the other under dryland conditions. Soil characteristics are given in Table 1. With the exception of the water treatment, both experiments were similar in all aspects. Lentil (Laird) and spring wheat (Neepawa) were seeded on May 12 and 13 1987 at recommended rates of 80 and 100 kg/ha for lentil and spring wheat, respectively. Nitrogen was applied at three levels: 10, 50, and 100 kg/ha in the form of NH_4NO_3. ^{15}N-microplots, 1.05 by 2.85 m for each individual harvest plot or 1.05 by 20.0 m for each subplot, were installed in the middle of each subplot. Values for atom % ^{15}N excess of the applied NH_4NO_3 were 4.6337, 0.9267, and 0.4634 for the 10, 50, and 100 kg N/ha, respectively. All plots received P at a rate of 30 kg/ha banded beside the seed row in the form of triple superphosphate. Treatments were laid out in a split-plot design, with main plots arranged in a randomized complete block. Treatments were replicated four times with crop as mainplot treatment and N-level as subplot treatment. Subplot measured 20 by 3.7 m. Irrigated plots were located under a centre pivot system, the non-irrigated plots were just outside the reach of the centre pivot. Lentil was inoculated with Nitragin 'C' using gum arabic as a sticker. Weeds were controlled by Hoegrass and by hand. To promote ripening, lentil was treated with Reglone. Wheat and lentil were harvested at 44 (Feekes 7), 52 (Feekes 9), 63 (Feekes 10), 72 (Feekes 10.1), 88 (Feekes 11.1) and 101 (Feekes 11.3) days after planting (DAP). The harvest area at each sampling was 5.60 m^2. After harvest plants were dried at 60°C until constant weight, weighed and, if necessary, threshed. All yield data reported are based on oven dry weight. Total N, including nitrate and nitrite, was determined by micro-Kjeldahl analysis (Bremner and Mulvaney, 1982). ^{15}N analysis was carried out by conversion of NH_4^+ to N_2 by LiBrOH (Ross and Martin, 1970; Porter and O'Deen, 1977) and the $^{15}N/^{14}N$ ratio determined by a VG Micromass 602E isotope ratio mass spectrometer.

Table 1. Soil characteristics of the irrigated and dryland site at Outlook at time of seeding.

Treatment	Texture	pH	NO_3 0-60 cm	P	K	SO_4-S
				---------- 0-15 cm ----------		
			---------------------- kg/ha ----------------------			
Irrigated	Sandy loam	8.0	66	13.3	493	16.8
Dry	Sandy loam	7.9	60	47.0	777	13.0

Calculations from ^{15}N data were as follows:

$$\% \text{ Ndfa (isotope dilution method)} = \left[1 - \frac{\text{atom } \% \ ^{15}\text{N excess (f)}}{\text{atom } \% \ ^{15}\text{N excess (nf)}}\right] \times 100 \qquad [1]$$

where % Ndfa = percent N derived from the atmosphere
f = N_2-fixing crop
nf = non-N_2-fixing crop

$$N_2 \text{ fixed} = \frac{\% \text{ Ndfa } \times \text{ total N (f)}}{100} \qquad [2]$$

$$\% \text{ Ndff } (\% \text{ N derived from fertilizer}) = \frac{\text{atom } \% \ ^{15}\text{N excess (plant)}}{\text{atom } \% \ ^{15}\text{N excess (fertilizer)}} \times 100 \qquad [3]$$

$$\text{kg Ndff (kg N derived from fertilizer)} = (\% \text{ Ndff x total N}) \qquad [4]$$

$$\% \text{ FUE } (\% \text{ fertilizer use efficiency}) = \frac{\% \text{ Ndff x total N}}{100} \qquad [5]$$

$$\text{Soil N uptake (nf)} = (\text{total N (nf) - kg Ndff (nf)}) \qquad [6]$$

$$\text{Soil N uptake (f)} = (\text{total N (f) - kg Ndff(f) - } N_2 \text{ fixed(f)}) \qquad [7]$$

$$\text{A-value} = \frac{\% \text{ N derived from soil}}{\% \text{ N derived from fertilizer-N}} \times \text{kg N-fertilizer applied} \qquad [8]$$

The ^{15}N natural abundance of the available soil N pool was 0.36925 atom % and this value was used for calculating the atom % ^{15}N excess of both two crops. Spring wheat was used as the non-N_2-fixing reference crop. The analysis of variance of irrigated and dryland treatments were carried out separately. If appropriate, irrigated and dryland crops were compared using the t-test comparison. LSD (<0.05) between means were calculated if F values were significant.

RESULTS AND DISCUSSION

Dry Weight and Total Grain

Nitrogen application increased the average dry weight of irrigated wheat by 30% (Table 2) but was non-significant (P <0.05 level) at final harvest. Similar increases in grain yield of irrigated wheat due to N fertilization have been reported earlier where 84 kg N/ha increased grain yield to 2577 kg/ha (Henry and McGill, 1975). The increase in dry weight for dryland wheat due to N application was largely non-significant. Dry weights of irrigated wheat were always significantly higher (around 100%) than those of dryland wheat. Grain weight of irrigated wheat was increased by N application but the effect was only significantly at 88 DAP. All irrigated and dryland wheat, irrespective of N treatments, showed lower dry weight at 101 DAP than at 88 DAP. For all dryland wheat treatments and irrigated wheat receiving 100 kg N/ha, grain weight of wheat decreased between 88 DAP and final harvest. While the decrease in dry weight can be explained by leaf losses, the decrease in grain weight remains unclear.

Dry weight and grain yield of irrigated and dryland lentil did not increase due to N application (Table 2). Lentil was inoculated and the rhizobium-legume symbiosis was efficient enough to provide the host plant with sufficient N. A possible starter N effect, 10 kg N/ha at time of seeding, had no beneficial effect on dry weight or grain yield. Similar effect of starter N on lentil has been observed previously (Bremer et al., 1989). In contrast with wheat, dry weight and grain yield of lentil increased between 88 DAP and final harvest. While irrigated crop harvests significantly increased dry matter production of lentil by an average of 70%, grain yield of irrigated lentil was significantly lower at 88 DAP and not significant different at 101 DAP as compared with dry land lentil. Lentil requires a stress period before pod fill will occur (A. Slinkard, personnel communication) and without the stress period, the plant will remain in the vegetative growth stage in dryland lentil, the stress was induced by a lack of moisture. Irrigated lentil received water until the end of July and were not stressed for the remainder of the growing season.

Total N

Fertilizer N application significantly increased total N uptake in irrigated wheat during early plant growth and during the last three weeks of the growing period (Table 3). This was in contrast with dryland wheat where N application had no apparent effect on total N accumulation at the early growth stages and at the final harvest. Similar results were obtained by Henry and McGill (1975) where a N-fertilizer application of 84 kg/ha showed no significant total N increase for dryland wheat but an increase of 36% by irrigated wheat. No effect of N application on N uptake was found for irrigated and dryland lentil and lentil did not respond to N application. A total N yield of 157.4 and 89.4 kg/ha was found for irrigated and dryland lentil, respectively. Total N yield of irrigated Laird lentil of 178 and 190 kg/ha have been reported (Rennie and Dubetz, 1986). Wheat accumulated most of its N during the first 52 DAP. This is in contrast with spring wheat planted in Georgia, USA

Table 2. Total yield of irrigated and dryland wheat and lentil.

	N rate kg/ha	Dry weight (kg/ha)						Grain (kg/ha)		
		Days after planting								
		44	52	63	72	88	101	72	88	101
Irrigated										
Wheat	10	898	1777	3207	4305	4791	4411	749	2108	2241
	50	1109	1958	3577	5099	6005	5257	811	2606	2665
	100	1223	2260	3974	5787	6382	5283	920	2808	2539
Lentil	10	417	939	1973	3407	5793	6565	27	1251	1753
	50	458	1011	2194	3654	5491	6709	15	955	1208
	100	441	1005	2284	3975	6109	6822	12	1356	1665
LSD (<0.05)	N	88	NS	224	710	394	NS	NS	143	NS
Dryland										
Wheat	10	661	1134	1882	2444	2937	2130	753	1569	1105
	50	772	1321	1928	2623	2766	2363	779	1530	1250
	100	417	1458	2062	2693	3052	2484	948	1614	1361
Lentil	10	251	512	1213	2155	4021	4284	67	1194	1495
	50	319	648	1213	2096	3366	4502	119	771	1157
	100	263	632	1206	2336	3453	4238	96	981	1509
LSD (<0.05)	N	NS	142	NS	NS	NS	NS	60	NS	146
LSD (<0.05)	I-D/W†	160	391	397	606	697	579	NS	321	327
	I-D/L‡	30	137	294	539	471	488	19	192	NS

†Wheat (Irrigated vs. Dry)
‡Lentil (Irrigated vs. Dry)

where significant N accumulation occurred after the first leaves senesced and continued until the end of the growing season (Harper et al., 1987). Climatically differences between the two sites might account for this difference. Lentil accumulated significantly less N than wheat during the first 52 DAP. At final harvest, however, lentil had accumulated more than twice the amount of N than wheat, irrespective of moisture treatment.

Irrigated wheat and lentil accumulated significantly more total N during all harvest periods than dryland wheat and lentil (Table 3). Moisture had been a limiting growth factor for both crops, especially during the first weeks after seeding when rainfall was negligible.

The highest daily N uptake per day for irrigated wheat receiving 100 kg N/ha was 1.86 kg/ha, day and occurred between 44 and 52 DAP (Fig. 1). For lentil this value was 6.80 kg/ha, day and occurred between 63 and 72 DAP. For the dryland treatment these

Table 3. Total N of irrigated and dryland wheat and lentil.

	N rate kg/ha	Total kg N/ha Days after planting 44	52	63	72	88	101
		Irrigated					
Wheat	10	27.0	41.9	48.1	45.8	57.0	69.5
	50	35.2	47.2	60.9	66.4	82.4	79.2
	100	41.3	63.4	69.1	77.6	88.6	89.6
Lentil	10	15.4	22.3	49.4	83.7	140.1	149.4
	50	17.2	27.5	46.5	91.6	141.5	154.4
	100	16.7	28.7	50.8	111.9	151.8	157.4
LSD (<0.05)	Crop	5.5	8.3	NS	17.1	12.7	19.8
	N	3.7	NS	NS	16.4	12.2	10.7
		Dryland					
Wheat	10	23.4	26.0	28.6	35.8	50.3	37.0
	50	27.0	30.4	43.0	40.0	48.2	42.7
	100	15.4	36.7	40.8	46.6	54.3	48.7
Lentil	10	9.4	14.9	33.4	51.9	85.4	90.3
	50	11.8	15.2	32.0	55.5	77.7	92.4
	100	10.5	17.4	30.8	62.1	73.6	89.4
LSD (<0.05)	Crop	12.7	NS	NS	NS	30.2	10.5
	N	NS	NS	11.5	6.7	NS	NS
LSD (<0.05)	I-D/W†	6.2	11.5	11.5	12.7	12.5	10.5
	I-D/L‡	2.3	4.5	7.3	10.2	10.1	10.5

†Wheat (Irrigated vs. Dry)
‡Lentil (Irrigated vs. Dry)

values were 1.20 and 3.48 kg/ha, day for wheat and lentil, respectively, and occurred between 44 and 52 DAP for wheat and between 63 and 72 DAP for lentil (Fig. 2). Similar results were found for the other two N treatments. Irrigated crops can be fertilized during the growing season and the fertilizer is applied though the water supply. Data from this study suggest the following: (1) wheat shows the highest need for N within 52 DAP, or (2) a higher N requirement was present after 52 DAP but no increased N uptake occurred because not enough N was available. It the former is correct, the second N application should occur before 52 DAP when the apparent need for N is the highest. It is unclear yet if this results in higher yields. If the latter is correct, an additional N application should result in higher wheat yield.

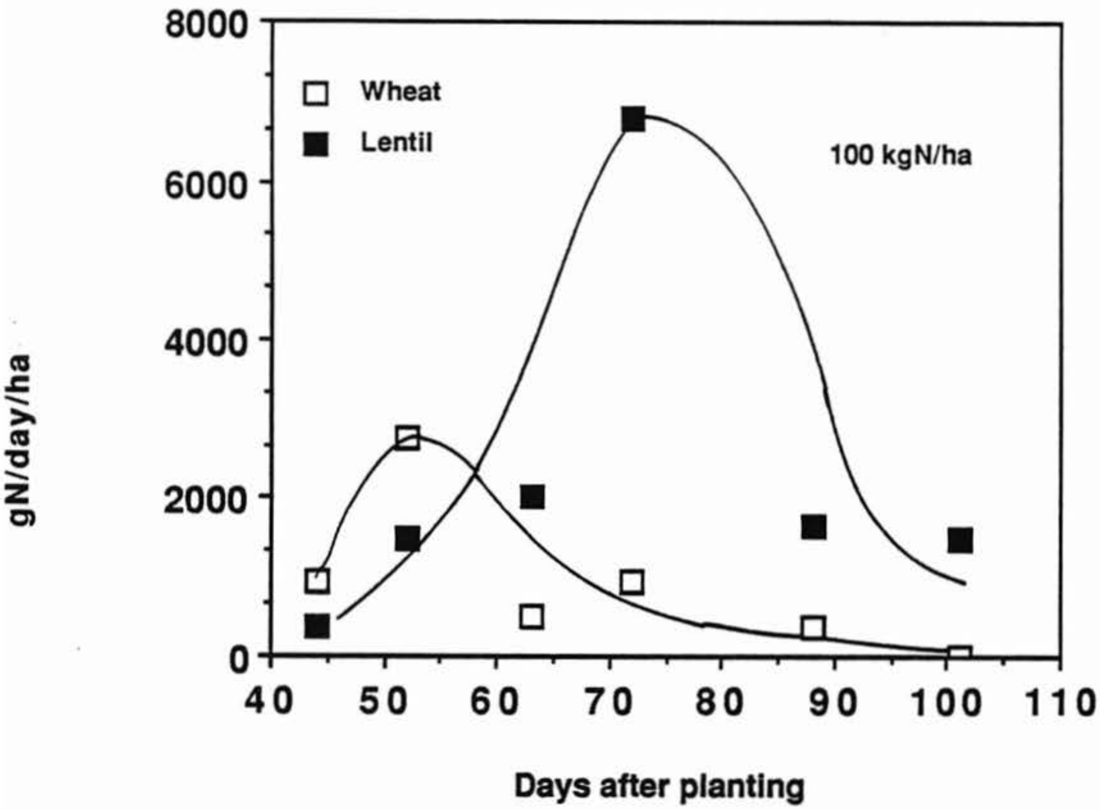

Fig. 1: N-uptake per day of irrigated wheat and lentil

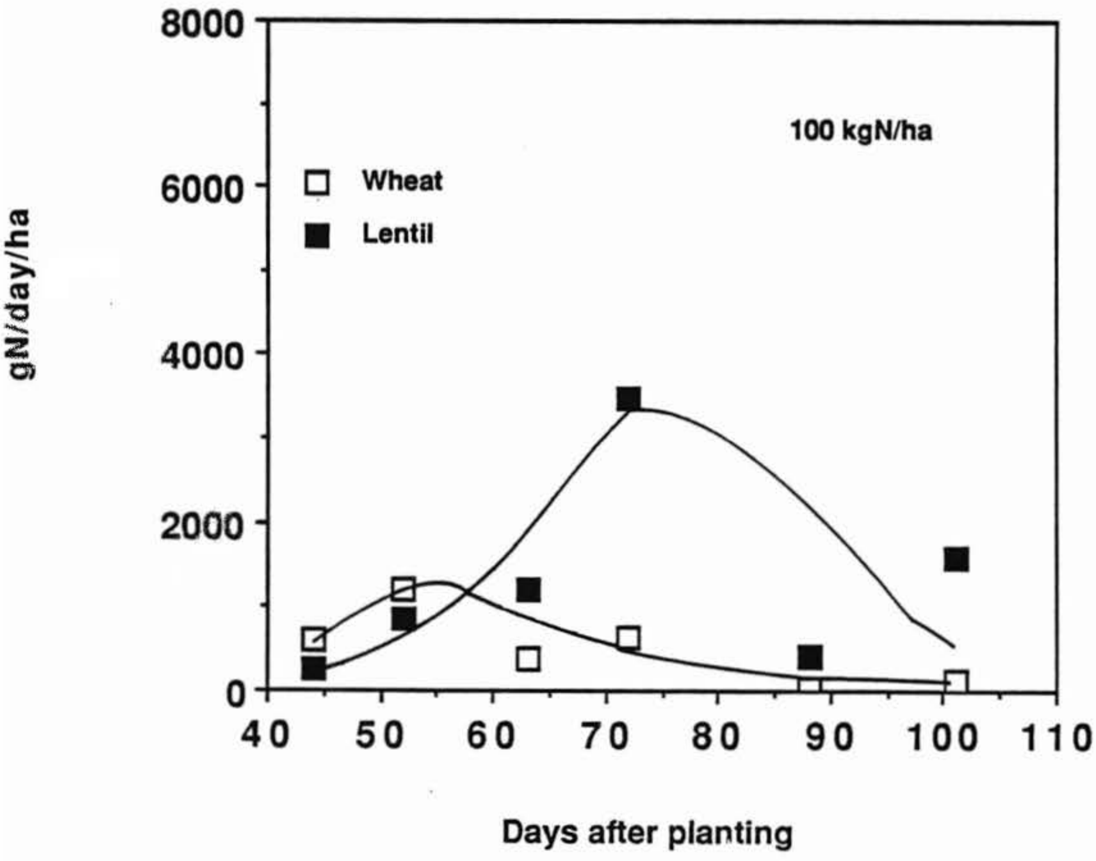

Fig. 2: N-uptake per day of dryland wheat and lentil

During the period when wheat had its highest N uptake, i.e. 1.86 and 1.2 kg N/day/ha for irrigated and dryland wheat, lentil accumulated N only 40% of that amount. This indicates that N was available for plant uptake but there was no apparent demand for N by irrigated and dryland lentil. Results from this study indicate that the practice of suppling small amounts of N to lentil at time of seeding to alleviate possible N stress is dubious. The demand for N by lentil is rather low during the first 60 DAP and the available soil N at time of seeding and the amount of N being mineralized during the first two months after seeding should be sufficient to meet the N requirements by lentil grown under Saskatchewan conditions.

The large difference in the time course of N uptake between the two crops is of significance for the N fertilization management of irrigated wheat and lentil. It is apparent that N fertilization of irrigated wheat should all take place within 2 months of planting. N fertilization requirements for lentil should be kept to a minimum or eliminated completely.

Percent N Derived from Fertilizer

The amount of N applied had a significant effect on the percent of N derived from fertilizer-N. While irrigated wheat that received 10 kg N/ha derived around 6% of its N from the fertilizer, dryland wheat that received 10 kg N/ha accumulated a slightly lower percentage of its N from the applied fertilizer (Table 4). Irrigated lentil showed similar values at early stage of the growing season but the percentage decreased, due to N_2-fixation, to 0.8 at final harvest. With the exception of 63 DAP no significant differences between dryland wheat and lentil were found for the percentage of N derived from fertilizer regardless of the amount of N applied. Irrigated and dryland that received 100 kg N/ha accumulated around 40% of its N from fertilizer. Similar results were found for dryland lentil but not for irrigated lentil where the percentage of N derived from fertilizer decreased significantly to 12.4% at final harvest caused by N_2-fixation. Intermediate values were found for crops that received 50 kg N/ha. Throughout the growing season, irrigated and dryland wheat derived similar percentage of their total N from fertilizer, regardless of the amount of N applied. During early growth stages, irrigated and dryland lentil derived similar percentages of its N from fertilizer. However at the end of the growing season dryland lentil derived a significantly higher percentage of their N from fertilizer as compared with irrigated lentil. This indicates that irrigated lentil had higher N_2-fixation activity than dryland lentil and that dryland lentil was less stressed for N than irrigated lentil.

Fertilizer Use Efficiency

Percent fertilizer use efficiency (% FUE) of irrigated wheat was the lowest at 44 DAP but increased only slightly after 52 DAP (Table 5). Dryland wheat that received 50 and 100 kg N/ha obtained maximum % FUE at 63 and 72 DAP, respectively. The % FUE follows the total N uptake and fertilizer N uptake pattern and occurred predominantly within two months after planting. With the exception of lentil that received 50 and 100 kg N/ha and harvested at 72 DAP, irrigated lentil showed lower % FUE than irrigated wheat. The large increase in % FUE of lentil at 72 DAP and the subsequently decrease in % FUE at 88 and 101 DAP is unclear but may be due to experimental error. Conclusions drawn from the % FUE of lentil at 72 DAP are therefore questionable. One possible explanation of the lower % FUE of irrigated lentil as compared with that of the irrigated wheat can be found in the N-uptake curve of the two crops. Wheat took up most of its N during early growth before leaching occurred. This is in contrast with lentil which accumulated most of its N later in the growing season and by which time leaching may had occurred and

Table 4. Percent N derived from fertilizer in irrigated and dryland wheat and lentil.

	N rate kg/ha	Percent N derived from fertilizer					
		Days after planting					
		44	52	63	72	88	101
		Irrigated					
Wheat	10	6.7	7.4	6.5	5.4	8.5	4.7
	50	18.9	21.9	19.9	21.0	20.8	17.6
	100	29.6	43.6	36.2	36.8	44.1	40.7
Lentil	10	5.5	5.4	2.5	1.2	0.8	0.8
	50	17.0	23.5	20.0	13.6	4.9	4.4
	100	25.6	35.5	34.7	31.0	14.1	12.4
LSD (<0.05)	Crop	NS	NS	NS	NS	4.2	3.4
	N	6.4	6.0	7.4	5.6	5.4	3.7
		Dryland					
Wheat	10	5.8	4.1	5.0	4.7	4.9	4.0
	50	21.0	23.0	26.4	27.0	21.9	26.2
	100	35.4	38.9	37.8	41.7	34.3	46.4
Lentil	10	5.4	4.9	4.9	3.5	2.4	2.3
	50	24.0	22.8	18.2	16.8	13.2	14.0
	100	35.9	28.2	32.5	30.9	26.7	41.2
LSD (<0.05)	Crop	NS[§]	NS	3.6	NS	NS	NS
	N	5.7	6.0	4.6	6.3	9.2	6.9
LSD (<0.05)	I-D/W[†]	NS	NS	NS	NS	NS	NS
	I-D/L[‡]	NS	NS	NS	NS	NS	10.3

[†]Wheat (Irrigated vs. Dry)
[‡]Lentil (Irrigated vs. Dry)
[§]NS - Not Significant

fertilizer-N became less available for plant uptake. Measurements taken to determine water use by lentil indicate that most of the water uptake by irrigated lentil occurred from the top 45 cm of soil. It is therefore unlikely that irrigated lentil had an extensive root system below 45 cm.

Dryland lentil showed lower % FUE at early growth stages as compared with dryland wheat but accumulated significantly more fertilizer-N at final harvest (Table 5). Lentil is an indeterminate species and regrowth occurs if the conditions are favorable. The 1987 growing season was characterized by a dry spring with normal or above normal

Table 5. Percent fertilizer use efficiency in irrigated and dryland wheat and lentil.

	N rate kg/ha	% FUE					
		Days after planting					
		44	52	63	72	88	101
			Irrigated				
Wheat	10	16.6	27.2	28.1	24.7	48.4	32.1
	50	12.9	20.9	22.8	25.7	34.4	28.1
	100	11.8	27.9	25.6	28.3	38.5	36.4
Lentil	10	8.4	11.9	12.3	10.2	11.0	12.1
	50	5.9	12.9	18.4	25.6	13.7	13.5
	100	4.3	10.2	17.6	34.7	21.9	19.4
LSD (<0.05)	Crop	7.3	15.0	NS[§]	NS	7.6	10.5
	N	2.9	4.0	NS	8.7	NS	NS
			Dryland				
Wheat	10	13.7	10.1	14.0	16.6	23.7	14.5
	50	10.8	13.7	21.8	21.1	21.3	21.7
	100	9.5	13.9	15.0	19.1	18.2	22.2
Lentil	10	5.4	7.2	17.2	18.8	20.7	21.1
	50	5.4	7.0	12.0	19.2	21.2	26.1
	100	3.9	4.9	10.2	19.8	19.8	36.4
LSD (<0.05)	Crop	NS	3.6	NS	NS	NS	2.4
	N	NS	NS	NS	NS	NS	9
LSD (<0.05)	I-D/W[†]	NS	6.1	7.0	6.0	7.8	7.1
	I-D/L[‡]	NS	2.4	NS	NS	NS	5.9

[†]Wheat (Irrigated vs. Dry)
[‡]Lentil (Irrigated vs. Dry)
[§]NS - Not Significant

precipitation in July and August (Innovative Acres Report, 1988). At the time rainfall occurred wheat was already in the boot stage and no additional growth occurred. Lentil showed regrowth and accumulated additional N from the soil/fertilizer-N pool or through N_2-fixation. The % FUE increased after 62 DAP and became significantly higher than the %FUE of dryland wheat. In contrast with fertilizer-N of irrigated lentil, no fertilizer-N was leached below the rooting zone under dryland conditions. With the exception of the final harvest, the amount of N applied had largely no effect on the % FUE of dryland crops. At the final harvest, lentil that received 100 kg N/ha showed the highest % FUE of all dryland treatments.

Irrigated wheat showed higher %FUE than dryland wheat during all sampling periods except the first. Irrigated wheat, in particular wheat that received 10 kg N/ha, was more stressed for N as dryland wheat and the irrigated wheat crop became a bigger sink for fertilizer N. This is in contrast with lentil where irrigated lentil showed higher or similar %FUE during the first 88 DAP but had significantly lower %FUE at final harvest as compared with dryland lentil. The only plausible explanation may be that fertilizer-N had leached below the rooting zone where it became unavailable for uptake by irrigated lentil.

Values for % FUE of wheat at final harvest have been reported and range from 29.8% for wheat that received 50 kg N of $^{15}NH_4NO_3$ to 40.9% for wheat receiving 50 kg N/ha of $NH_4{}^{15}NO_3$ (Recous et al., 1988). Those figures agree with the irrigated wheat from this study. To our knowledge, % FUE of irrgated and dryland lentil have not been reported.

Total Soil N Uptake

Total soil N uptake followed the same pattern as total-N and fertilizer-N uptake. Significant soil-N uptake of irrigated wheat occurred within 63 DAP. Wheat that received only 10 kg N/ha showed significantly higher soil-N uptake than wheat that received 100 kg N/ha and at higher N applications fertilizer-N was substituted for soil-N (Tables 4 and 6). Similar results were obtained for dryland wheat. With the exception of irrigated wheat harvested at 101 DAP, fertilizer-N had no effect on soil-N uptake for dryland and irrigated wheat. This indicates that all available soil-N was used for plant uptake and that higher N applications did not cause a priming effect whereby additional soil N through N application became available for plant uptake. N-fertilizer applications were solely responsible for increased N uptake.

Soil-N uptake by dryland wheat was significantly lower as than that of irrigated wheat (Table 6). This is another indication that dryland wheat was less stressed for N than it was for moisture.

Irrigated lentil accumulated significantly less soil N as irrigated wheat, with the exception of lentil harvested at 72 DAP. As with the result for %FUE of lentil harvested at 72 DAP (Table 4), this sudden increase and subsequently decrease in soil-N uptake is difficult to explain in terms of plant growth. A possible explanation of the reduced soil-N uptake by irrigated lentil as compared to that of wheat is: (1) wheat rooted deeper than lentil and available soil N at the lower depth was not available for lentil, and (2) it was more energy efficient for irrigated lentil to fix N than to derive its N from the available soil N pool. Dryland lentil accumulated similar amounts of soil N than dryland wheat and N application had no effect on soil N uptake.

Dryland lentil accumulated significantly less soil N than irrigated lentil during the first 52 DAP but significantly more during the last two harvest periods. As with the fertilizer-N uptake and the lower soil N accumulation as compared with that of irrigated wheat, it appears that soil N under irrigated lentil was less available for uptake at the end of the growing season.

A-values of wheat in this study were not dependent of the amount of N applied, as has been argued recently (Smith et al., 1989) and no differences were found between the two moisture treatments and time of sampling (Table 7). This would indicate that the A-value approach for estimating N_2-fixation by lentil using a reference crop which had received a higher N application than the N_2-fixing crop would have been valuable.

Table 6. N derived from soil in irrigated and dryland wheat and lentil.

	N rate kg/ha	kg N soil/ha Days after planting 44	52	63	72	88	101
		Irrigated					
Wheat	10	25.3	39.2	45.3	43.3	52.1	66.3
	50	28.7	36.7	49.5	53.5	65.2	65.1
	100	29.5	35.6	43.5	49.3	50.2	53.2
Lentil	10	11.6	14.9	17.6	13.5	11.3	24.3
	50	10.8	19.7	32.6	48.4	26.7	42.6
	100	10.3	13.1	28.0	60.2	28.1	33.4
LSD (<0.05)	Crop	6.6	6.3	4.0	NS	17.5	24.1
	N	NS§	NS	NS	14.8	NS	8.4
		Dryland					
Wheat	10	22.1	25.0	27.2	34.1	48.0	35.6
	50	21.6	23.5	32.1	29.4	37.6	31.8
	100	11.6	22.8	25.8	27.5	36.1	26.5
Lentil	10	7.8	13.4	26.2	36.8	39.0	47.7
	50	7.6	10.4	16.3	26.2	39.9	38.9
	100	6.3	7.5	16.2	28.1	37.2	43.6
LSD (<0.05)	Crop	NS	NS	NS	NS	NS	NS
	N	NS	NS	NS	NS	NS	NS
LSD (<0.05)	I-D/W†	5.7	8.3	9.4	9.4	9.9	10.2
	I-D/L‡	3.2	4.0	NS	NS	13.1	9.1

†Wheat (Irrigated vs. Dry)
‡Lentil (Irrigated vs. Dry)
§NS - Not Significant

N_2-fixation

For the first 72 DAP irrigated and dryland lentil derived similar percentages of their N from N_2-fixation (Table 8). After 72 DAP significantly higher percentages of N in irrigated lentil was derived from N_2-fixation as compared with dryland lentil. N application reduced N_2-fixation activity but the inhibitory effect was more pronounced for irrigated lentil than for dryland lentil. Regardless of N or irrigation treatment the percentage of N derived from N_2-fixation increased during the growing season. Lentil require low amounts

Table 7. A-value of irrigated and dryland wheat (Outlook, 1987).

Treatment	N rate kg/ha	A-value (kg/ha)						Mean
		Days after planting						
		44	52	63	72	88	101	
Irrigated	10	192	160	198	196	108	227	180
	50	237	221	263	222	195	236	229
	100	291	136	192	177	136	151	180
Dryland	10	199	261	226	246	254	243	238
	50	230	171	143	150	196	181	179
	100	195	171	176	154	232	128	176
Mean		224	187	200	191	187	194	197

of N during early stages of growth and most of the N could be supplied through the available soil-N pool. Once the lentil N requirements exceeded the availability of soil N, N_2-fixation increased and at the final harvest low N supplied lentil derived more than 80% of its N from N_2-fixation.

The percentage of N_2-fixed of dryland and irrigated lentil have been reported. Bremer et al. (1988) reported an average value of 52% for dryland lentil. Rennie and Dubetz (1986) reported that 86.3% of the N in lentil grown under irrigation was derived from N_2-fixation.

Amounts of N_2-fixed of irrigated and dryland lentil was low during the first two months after planting but increased to 123.8 kg N/ha for irrigated lentil at final harvest. With the exception of the first 52 DAP, significant more N was fixed by irrigated lentil as compared with dryland lentil under low N application had accumulated 123.8 kg N/ha through N_2-fixation at final harvest and dryland lentil under the same N regime 40.6 kg/ha. At 63 and 72 DAP higher N applications reduced the total amount of N fixed but thereafter N application had no effect on N_2-fixation. At that stage the inhibitory effect of fertilizer-N on N_2-fixation had disappeared. This in contrast with dryland lentil where the inhibitory effect of fertilizer N on N_2-fixation was still present at final harvest. The major proportion of the higher total N accumulation of lentil as compared with that of wheat is derived from N_2-fixation.

Table 8. N derived from N-fixation in irrigated and dryland lentil.

	N rate kg/ha	Days after planting					
		44	52	63	72	88	101
		% Ndfa					
Irrigated	10	19.0	27.2	61.6	82.7	91.1	82.9
	50	20.5	5.2	9.3	34.7	76.1	67.6
	100	13.6	18.6	10.4	15.2	67.8	66.2
Dryland	10	15.9	6.5	20.4	27.4	52.1	45.0
	50	11.2	8.8	32.0	37.3	37.1	44.5
	100	5.6	28.4	15.6	25.3	23.2	9.5
LSD (<0.05)	D-I§	NS#	NS	NS	NS	17.4	13.4
	N (IRR)	NS	15.8	13.8	24.4	NS	12.2
	N (DRY)	NS	NS	NS	NS	11.8	15
		kg N fixed/ha					
Irrigated	10	2.9	6.1	30.5	69.2	127.7	123.8
	50	3.4	1.4	4.8	30.3	107.9	105.0
	100	2.1	5.4	5.2	17.0	101.8	104.6
Dryland	10	1.1	0.7	5.5	13.2	44.3	40.6
	50	1.5	1.4	9.7	19.1	27.2	40.4
	100	0.4	5.0	4.4	14.2	16.6	9.4
LSD (<0.05)	D-I	NS	NS	11.0	19.0	17.5	16.7
	N (IRR)	NS	NS	6.0	23.7	NS	NS
	N (DRY)	NS	NS	NS	NS	16.2	13.8

§Dry vs. Irrigated
#NS - Not Significant

CONCLUSIONS

Irrigation significantly increased dry matter of lentil and wheat. Grain yield at final harvest of irrigated wheat was twice that of dryland wheat. Lentil grain yield, however, was not increased by irrigation. The required stress period for irrigated lentil did not occur and lentil remained in the vegetative growth stage. While irrigated wheat responded to N application, although not always significantly. However, lentil showed no yield response to N.

Irrigation significantly increased total N accumulation in lentil and wheat. Total N in irrigated wheat at final harvest depended on the N applied but total N in irrigated and dryland lentil was independent on N application. Irrigated and dryland lentil accumulated significantly less N at the early growth stage than irrigated or dryland wheat but significantly more after 72 DAP.

The highest daily N uptake of irrigated and dryland wheat was 1.86 and 1.20 kg/ha day for irrigated and dryland wheat, respectively and occurred between 44 and 52 DAP. For irrigated and dryland lentil these values were 6.80 and 3.48 kg N/ha/day and occurred between 63 and 72 DAP.

Percent N derived from fertilizer in the crop was largely dependent or the amount of N applied and independent of moisture treatment. After 88 and 101 DAP irrigated lentil the percentage of N derived from fertilizer N dropped and was attributed to increased N_2-fixation.

% FUE was largely independent of the amount of N applied. At final harvest, irrigated lentil had recovered significantly less fertilizer-N than irrigated wheat or dryland lentil. Irrigated wheat showed higher % FUE than dryland wheat.

Irrigated lentil accumulated significantly less soil N than irrigated wheat and was largely independent of the amount of N applied. Dryland wheat and lentil accumulated similar amounts of soil N, independent of N applied. Irrigated wheat showed higher soil N uptake than dryland wheat. For lentil, soil N uptake of irrigated lentil was higher during the early growth stages than that of dryland lentil but soil N uptake became significantly less at final harvest.

Until 72 DAP the percent N derived from N_2-fixation was similar for dryland and irrigated lentil but after 72 DAP the irrigated lentil showed significantly higher N_2-fixation activity than dryland lentil. N application reduced N_2-fixation activity and the inhibitory effect was still present at final harvest. Irrigated lentil that received 10 kg N/ha derived up to 91% of its total N from N_2-fixation. The highest amount of total N_2 fixed was found in irrigated lentil and reached 123 kg N/ha for lentil that received 10 kg N/ha as fertilizer. Total N_2-fixed was low during the first 63 DAP but increased substantially towards the end of the growing season.

ACKNOWLEDGEMENTS

The technical assistance of many summer student is greatly appreciated. We thank Lynn Gray, George Swerhone, and Garth Parry for the ^{15}N-analysis and Elaine Farkas for typing the manuscript. Financial support was provided by the Innovatice Acres/Agricultural Development Fund, Saskatchewan.

LITERATURE CITED

Allen, O.N., and E.K. Allen. 1981. The Leguminosae, A source Book of Charactersitics, Uses, and Nodulation. The University of Wisconsin Press. p. 812.

Aulakh, M.S., and D.A. Rennie. 1986. Nitrogen transformations with special reference to gaseous N losses from zero-tilled soils of Saskatchewan, Canada. Soil and Tillage Res. 7:157-171.

Breitenbeck, G.A., A.M. Blackmer, and J.M. Bremner. 1980. Effects of different nitrogen fertilizers on emission of nitrous oxide from soil. Geophys. Res. Lett. 7: 85-88.

Bremer, E., R.J. Rennie, and D.A. Rennie. 1988. Dinitrogen fixation of lentil, field pea and fababean under dryland conditions. Can. J. Soil Sci. 68: 553-562.

Bremer, E, C. van Kessel, and R.E. Karamanos. 1989. Nitrogen, phosphorus and rhizobial strain responses by lentil. Can. J. Plant Sci. (*in press*)

Bremner, J.M., and C.S. Mulvaney. 1982. Nitrogen-Total. *In* Page, A.L., R.H.Miller and D.R. Keeney (eds). Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, 2nd edition. Am. Soc. Agron., Inc. Madison, WI. pp. 595-624.

Harper, L.A., R.R.Sharpe, G.W. Langdale, and J.E. Giddens. 1987. Nitrogen cycling in a wheat crop: soil, plant, and aerial nitrogen transport. Agron. J. 79: 965-973.

Henry, J.L., and K.S. McGill. 1975. Soil-Plant-Nutrient Research Report. Dept. of Soil Science, Univ. of Saskatchewan, Saskatoon.

Mosier, A.R., G.L. Hutchinson, B.R. Sabey, and J. Baxter. 1982. Nitrous oxide emissions from barley plots treated with ammonium nitrate or sewage sludge. J. Environ. Qual. 11: 78-81.

Porter, L.K., and W.A. O'Deen. 1977. Apparatus for preparing nitrogen from ammonium chloride for nitrogen-15 determinations. Anal. Chem. 45: 514-516.

Recous, S., J.M. Machet, and B. Mary. 1988. The fate of labelled ^{15}N urea and ammonium nitraste applied to winter wheat crop. II. Plant uptake and N efficiency. Plant Soil 112: 215-224.

Rennie, R.J., and S. Dubetz. 1986. Nitrogen-15-determined nitrogen fixation in field-grown chickpea, lentil, fababean, and field pea. Agron. J. 78: 23654-660.

Ross, P.J., and A.E. Martin. 1970. A rapid procedure for preparing gas samples for N-15 determinations. Analyst 95: 817-822.

Ryden, J.C., L.J.Lund, and D.D. Focht. 1979. Direct measurements of denitrification loss from soils: II Development and application of field methods. Soil Sci. Soc. Am. J. 43: 110-118.

Smika, D.E., D.F. Heermann, H.R. Duke, and A.R. Batchelder. 1977. Nitrate-N percolaton through irrigated sandy soil as affected by water management. Agron. J. 69: 623-626.

Smith, C.J., D.M. Whitfield, and O.A. Gyles. 1989. Estimation of available N status of soil by wheat and barley: A-values. Soil Biol. Biochem. 21: 169-172.