Synchronization of N availability and N uptake by wheat in a Lentil-Wheat Rotation

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Introduction

The inclusion of legumes in crop rotations has been practiced for a long time and the benefits to agriculture have long been known (Pierce and Rice, 1988). Although the primary benefit of legumes in rotation with cereals is due directly to N_2 fixation by the leguminous crop (Janzen and Radder, 1989), crop rotations with legumes may also elicit yield increases via mechanisms other than improved N fertility. More often than not, N from other sources, such as the release of resident microbial biomass-N, mineralization of accumulated organic matter-N (priming effect) and the effect of mineralization-immobilization turnover (MIT) on legume N contribution values (Harris and Hesterman, 1990) add to the increased N availability in a crop rotation with a legume. Several studies have indicated that increased mineralization of indigenous C and N, due to the addition of plant residue, could be considerable (Broadbent and Norman, 1946). Given that legume residues have a lower C:N ratio than cereal residues, N mineralization and enhanced microbial activity may commence much earlier and at a higher rate in a legume-residue soil environment than in a cereal-residue one. This may lead to a differential temporal N availability in the two cropping systems. This differential temporal N availability may explain the usually alluded to concept of better synchronization of N availability and N demand/uptake in a crop succeeding a legume than in one following a cereal crop. Hence, the objective of this study was to determine the degree of synchronization of N availability and N demand/uptake of a wheat *(Triticum sativum* L).crop succeeding lentil (Lens *culinaris* Medikus) compared to one succeeding wheat.

Materials and Methods

The study was conducted at several locations in southern Saskatchewan in the Brown and Dark Brown Soil zones. At Clavet and Zealandia, the study was established on oat and wheat stubble, respectively. At Eston and Conquest, the study was established on fields summerfallowed the previous year (1994).

Establishment year

In the first year of the study (1995), each experiment consisted of two 30 x 6 - 8 m main plots (depending on cooperating farmer's planter width), one each of lentil and wheat, replicated four times. These main plots represented the establishment of the legume-cereal and cereal-cereal crop rotations. Unconfined microplots (1 m x 1 m) were established in each main plot. The wheat microplots were fertilized with 60 kg N ha^{-1} of unlabeled ammonium nitrate and 20 kg N ha^{-1} double labeled $^{15}NH_4{}^{15}NO_3$ at 5.8 atom % ^{15}N. At physiological maturity a few plants were taken from the center of each microplot for N_2 fixation determination and the rest of the microplot was harvested, processed and re-applied in the fall in 1 m^2 microplots at one end of each main plot and used as the source of N from fall-applied, labeled residue. Two microplots were established in each of the lentil main plots. The first was fertilized with 20 kg N ha^{-1} of double-labeled $^{15}NH_4{}^{15}NO_3$ at 10 atom % ^{15}N and used as the source of N from fall-applied, labeled residue. The second lentil microplot was labeled with 5 kg N ha^{-1} of double labeled $^{15}NH_4{}^{15}NO_3$ at 10 atom % ^{15}N and used for the determination of N_2 fixation.

Subsequent crop year

In the second year of the study hard red spring wheat was sown to the entire area at a rate of 80 - **90** kg ha^{-1}. The main plots were subdivided into 6 subplots (5 x 6-8 m). Different amounts of N (0, 30, 60, 90 or 120 kg N ha^{-1}) were randomly applied to the first 5 subplots in the second week after emergence for another aspect of the study that will not be discussed in this paper. The sixth subplot contained the fall-applied-residue microplots. Two weeks after emergence, the fertilizer microplots were established within a meter of the residue microplots and labeled fertilizer ($^{15}NH_4{}^{15}NO_3$ at 1.8 % ^{15}N atom excess) applied at a rate of 50 kg N ha“. The rest of the sixth subplot, including the residue microplot, received the same rate of unlabeled ammonium nitrate. Frequent aboveground biomass samples (from a 0.5 m^2 area) were taken from the sixth subplot for the determination of biomass yield. Aboveground plant tissue and soil samples (O-15 & 15-30 cm soil depth) were taken from the residue and fertilizer microplots at every sampling time throughout the growing season. The plant tissue was dried at 40 °C in a forced air oven and the dry material ground in a cyclone mill and then in a ball-bearing mill. Percentage N and atom % ^{15}N were determined on an ANCA-MS (Europa Scientific, Crewe, UK) with a single inlet and triple collectors. The soil samples were analyzed for 2 M KC1 extractable NH_4-N and NO_3-N and the rest of the filtrate was distilled and the distillate dried down at 50 °C for the determination of atom % ^{15}N. This information was used to determine available soil N, N uptake by the wheat crop, and the proportion of these amounts derived from the residue, soil and fertilizer. At physiological maturity wheat samples were taken from 1 m^2 in each subplot for the determination of grain and straw yield.

Statistical analysis

Data from the four locations were combined and analyzed using repeated measures analysis according to Rowell and Walters (1986). Polynomial regression lines that best described trend were fitted to data for better interpretation of the main effects and interactions of rotation and time.

Results and discussion

The wet spring of 1996 delayed seeding following spring soil sampling. Frequent soil and aboveground plant material sampling began three weeks after seeding. Significant differences in soil moisture content were observed among the four locations throughout the growing season (Table 1). Clavet and Conquest with light loam and gravely sandy loam textures, respectively, had the lowest total soil moisture regimes. The heavy clay soil at Eston maintained a high total soil moisture regime while the silty clay loam soil at Zealandia had an intermediate total soil moisture regime. When averaged across locations, total soil moisture regimes between the two rotations were not different during the first and the last two sampling dates. However, the total soil moisture regime on the wheat-wheat (W-W) rotation was significantly higher than that on the lentil-wheat (L-W) rotation from the third to the sixth sampling date (July 7 to August 7).

Table 1: Gravimetric soil moisture content (%) in the lentil-wheat and wheat-wheat rotation among locations during the 1996 growing season

Location	Rotation	DAYS AFTER SEEDING 0	20	40	JO	60	70	80	100
CLAVET									
	L - W	27.1	20.8	15.0	12.2	9.4	7.4	6.6	10.8
	W - W	25.6	19.7	15.2	13.4	10.0	7.8	5.9	11.7
CONQUEST									
	L - W	20.1	13.3	10.8	12.9	9.3	5.9	4.5	11.0
	W - W	19.7	13.5	11.1	14.0	9.3	5.9	4.6	10.9
ESTON									
	L - W	47.7	41.1	34.9	40.9	39.1	30.3	27.4	37.9
	W - W	49.5	41.8	38.4	43.4	40.4	32.9	28.4	38.4
ZEALANDIA									
	L - W	33.7	24.4	21.6	20.8	23.0	16.5	12.3	14.6
	W - W	36.2	27.0	24.6	25.6	26.9	21.2	15.6	18.1
MEANS									
	L - W	32.2 ns	24.9 ns	20.6 •	21.7 •*	20.2 •	15.0 **	12.7 ns	18.6 ns
	W - W	32.7	25.5	22.3	24.1	21.6	16.9	13.6	19.8
	SE[¶]			0.8	0.6	0.6	05	0.5	0.8

¶SE for rotations averaged over locations.

• ,** and ns Significant rotation effect at P ≤ 0.05 and 0.01. and non-significant. respectively.

Averaged over all four locations, available soil N and combined plant and soil N were significantly higher on the L-W rotation than on the W-W rotation throughout the season (Figures 1 and 2). Significant linear, quadratic and cubic trends in available soil N were observed in both rotations over time. Trend comparison revealed no difference in the time at which maximum available soil N was attained. This could be as a result of fertilizer application at three weeks after seeding which imposed an external effect on the trend. However, despite the application of the same rate of fertilizer, the maximum available soil N attained was significantly higher on the L-W than on the W-W rotation. This is indicative of a higher N supplying power of the soil as a result of inclusion of lentil in the cropping system compared with that following a cereal crop.

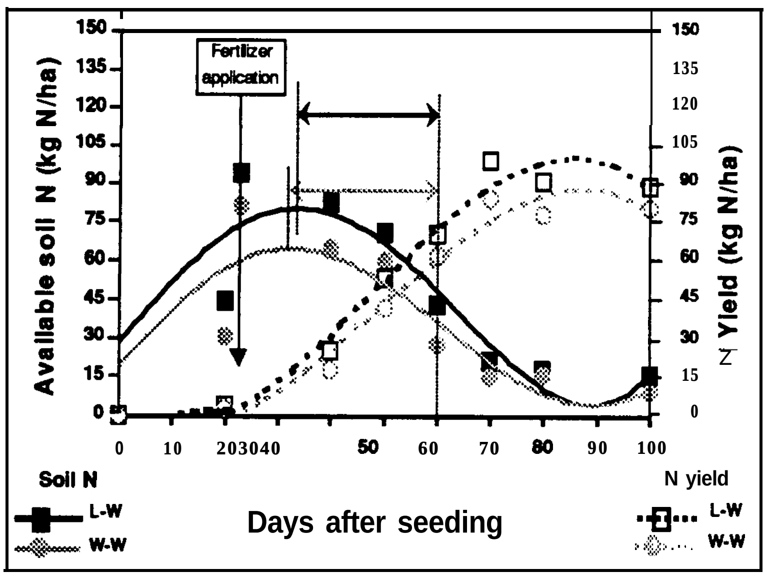

Figure 1: Available soil N and cumulative N uptake (N yield) of the second wheat crop during the growing season in a lentil-~ and wheat-wheat rotations, 1996.

Cumulative N uptake was higher on the L-W rotation than the W-W rotation at all times. On both rotations linear, quadratic and cubic trends were observed in cumulative N uptake.

Examination of the trends showed no significant difference in the period at which maximum rate of uptake was attained. A similar observation was made when uptake rate was calculated on the basis of daily N uptake (Figure 2).

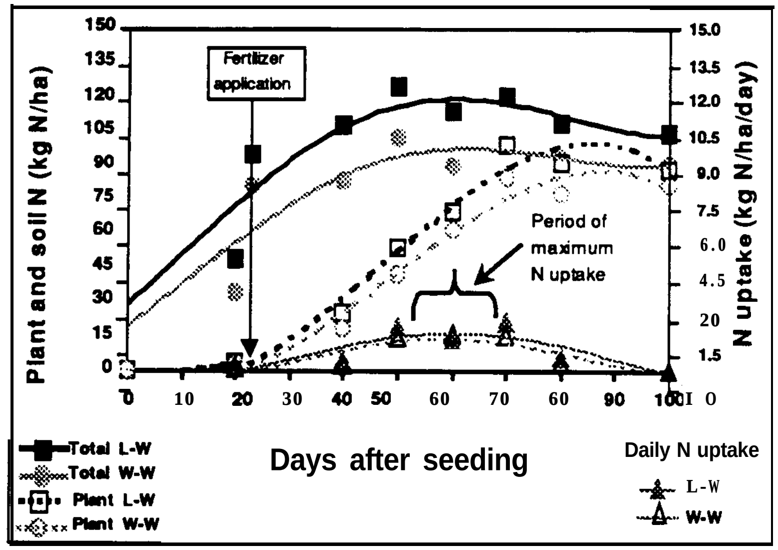

Figure 2: Total N (plant N and soil mineral **N)** and cumulative N uptake **(N** yield) of the second wheat crop during the growing season in a lentil-~ and **wheat-wheat** rotations, 1996.

The decline in available soil N from the fourth week onward (Figure 1) was due to increasing N uptake by the crop. Combining available soil N and crop N yield (Figure 2) showed that available soil N continued to increase for another four weeks. Trend comparison revealed no difference in the time at which maximum combined available N was attained. Furthermore, this time period coincided with the time period of maximum N uptake rate. This shows that the available N (all sources) was synchronized with N uptake of the subsequent crop in both rotations.

At the time of seeding, N derived from the residue (Ndfr) in the soil was significantly higher in the **L-W** than in the **W-W** rotation (Figure 3). A linear trend was observed in the decline in soil Ndfr in both rotations. Trend analysis showed that soil Ndfr on both rotations reached its peak during the first week after seeding and then decreased throughout the season.

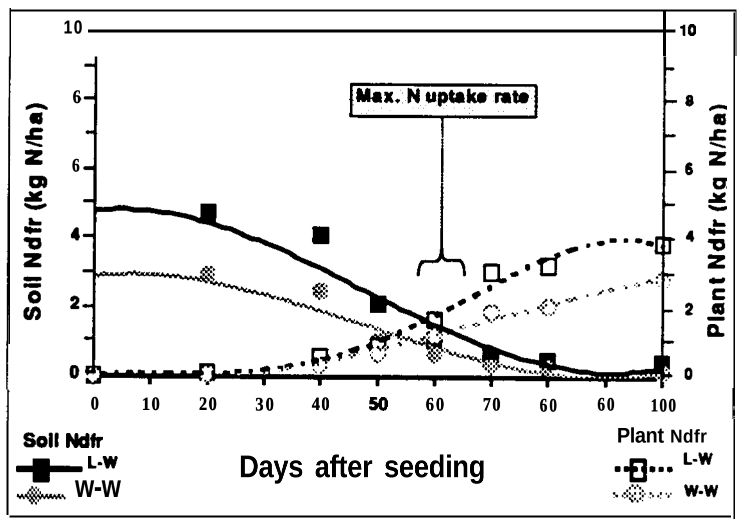

Figure 3: Soil **Ndfr** and Ndfr in the wheat crop (plant **Ndfr)** in the lentil-wheat and wheat-wheat rotations, 1996.

Unlike combined available N, combined Ndfr (soil and plant) declined during the entire growing season (Figure 4). This shows that by seeding time a high proportion of the readily mineralizable residue N in the previous crop was available for crop uptake as well as other avenues of mineral N loss. Therefore, this source of N is poor synchronized with crop demand and uptake. The general decrease in combined Ndfr shows that the soil Ndfr observed in the spring prior to seeding could not be completely accounted for in the soil (maximum root zone) and crop. The difference is the amount of N lost through leaching and immobilization and/or denitrification. The extent of the depression reflects the comparative potential loss in Ndfr between the two rotations. The trend of total N derived from the soil (Ndfs, in soil and crop) was the major source of available N for most of the season when Ndfr and N derived from the fertilizer were declining. The peaks of total Ndfs in both L-W and W-W rotations coincided with the period of maximum N uptake by the crop. The decline in Ndfs was similar to that of soil available N (Figure 1), indicating the dominant contribution of Ndfs to the system

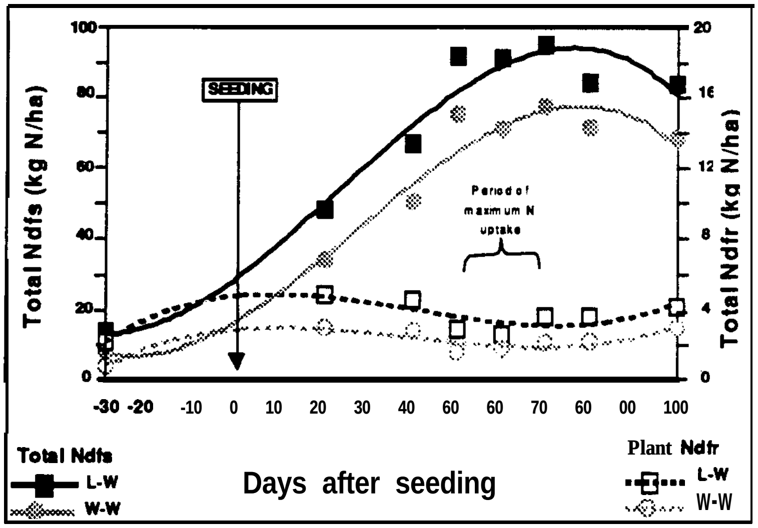

Figure 4: Total Ndfs and total Ndrf in the wheat crop during the growing season in a lentil-~ and a **wheat-wheat** rotations, **1996.**

One site (Zealandia) was lost before final harvest. At harvest time, grain and straw yield, total N uptake in both the grain and straw, **Ndfr,** Ndfs, N recovery and protein content were higher in the L-W rotation than in the **W-W** rotation (Table 2). Comparison of the effect of rotation on these variables within location showed significant differences among locations. At Clavet and Eston, the trend was the same showing higher values of measured plant variables on the L-W rotation. However, significant differences were observed only at Eston. At Conquest higher values of measured plant variables were observed in the **W-W** rotation than the **L-W** rotation, with significant differences observed for TAB N yield, N recovery and protein.

Table 2: Grain and total aboveground biomass (TAB) yield, N yield, Ndfs, Ndfr, N recovery and protein content in the wheat crop in a lentil-wheat and wheat-wheat rotation at three locations, 1996

Location	Rotation	YIELD grain	YIELD TAB	N Yield grain	N Yield TAB	TAB Ndfr	TAB Ndfs	N Recovery	Protein content
		kg ha^{-1}		kg ha^{-1}		kg ha^{-1}		%	%
Clavet	I-W	1490 ns	3750 ns	40.0 ns	51.3 ns	1.4 ns	27.8 ns	13.3 ns	15.4 ns
	w-w	1358	3338	35.2	45.3	1.2	23.0	11.7	14.7
Conquest	I-w	2898 ns	6968 ns	68.0 ns	86.0 *	2.3 ns	55.5 ns	20.4 *	13.5 *
	w-w	2580	6593	77.7	103.9	3.4	66.0	28.4	17.4
Eston	I-W	4035 *	9760 **	103.0**	128.1 **	7.8 **	87.6 ns	22.5 ns	14.7 *
	w-w	3050	7590	68.6	92.5	3.9	65.6	17.1	12.9
	SE[1]	152	446	5.4	7.9	0.7	12.0	3.3	0.7
mean	I-w	2808 **	6826 **	70.3 *	88.5 ns	2.9 *	57.0 ns	18.7 ns	14.5 ns
	w-w	2329	5840	60.5	80.6	0.3	51.6	19.1	15.0
	SE	76	223	2.7	4.0		6.0	1.6	0.3

[1] SE for testing **rotations** within location, with 9 df for MSE.
*, ** and ns Significant rotation effect at P ≤ 0.05 and 0.01, and non-significant, respectively.

Spring mineral N in the **L-W** rotation blocks at Conquest was lower than in the W-W rotation (Table l), probably because the first year wheat crop was given more N than the lentil crop (at all locations). Given the poor moisture situation and the sandy texture of the soil at Conquest, this N may not have been efficiently used by the wheat crop and, thus, remained in the system Furthermore, poor N_2 fixation forced the lentil crop to obtain most of its N from the small amount of applied fertilizer and from organic N mineralization, resulting in a higher N deficit. Soil moisture levels between the two rotations show that moisture loss (via evaporation/ evapotranspiration) may be higher in lentil stubble than in wheat stubble. The non-significant effect of water content between the two rotations at the beginning and end of the season reflects the wet spring and fall of 1996. For almost all measured variables, the effect of location was significant. This could be attributed to the significant soil textural differences among the locations. Soil texture has a significant effect on N availability through its influence on the soil physical environment by modifying soil water availability (not content ***per se),*** gas diffusion and soil microbial activity (Hassink et al., 1993; Scott et ***al.,*** 1996).

The difference in N availability between the **L-W** and W-W rotations at the beginning of the season prior to fertilizer application reflect both the direct and indirect increase of N availability in the wheat crop succeeding lentil. Although the quantities of both lentil and wheat residue-derived N were low, the differences in availability and uptake were highly significant. The readily decomposable lentil residue, rich in N, enhanced mineralization of resident soil organic N resulting in more available N derived from the soil in the **L-W** rotation than in the **W-W** rotation. Furthermore, lentil residue may have a higher mineralization-immobilization turnover (MIT), resulting not only in an initially higher N availability in the spring but throughout the season. In a study that utilized different types of legumes, Badaruddin and Meyer (1994) in North Dakota, USA, showed that inclusion of grain legumes in crop sequences increased spring soil NO_3-N, grain yield, and total N accumulation. Our data show similar results. Whereas they observed a 28% grain yield advantage over two locations and two seasons in the lentil-wheat rotation, we observed a 25% grain yield advantage. In a related study at a landscape-scale, Mooleki et al., (1996) observed similar results with a 26% yield advantage. Evans et ***al.*** (1991) attributed increased wheat grain yield after legumes to increased available soil N and decreased cereal diseases.

Since the legume crop can meet most of its N requirement through symbiotic N_2 fixation, it removes less inorganic soil N compared to a cereal crop. The fixed N_2 represents spared N that becomes available to the subsequent crop. Thus, a grain legume may actually decrease the size of the soil N pool (negative N balance), but at the same time confer a N-benefit to a succeeding cereal due to the N-sparing effect (Chalk et al. 1993). Other N sources include release of resident microbial biomass-N, mineralization of accumulated organic matter-N (priming effect) and the effect of mineralization-immobilization turnover (MIT) on legume N contribution values (Harris and Hesterman, 1990; Vanotti and Bundy, 1995). In a later study, Harris et ***al.*** (1994), showed that a larger soil microbial biomass existed in a cropping system that incorporated a legume crop than in a fertilizer-based system This large soil microbial biomass was responsible for the greater soil N supplying power of the legume-based system In a long term study in the Brown soil zone of southern Saskatchewan, Campbell et ***al.*** (1992) found that lentil straw may supply 50% more N to the soil organic matter pool than well fertilized wheat stubble. With time, this N slowly builds up and eventually enhances net N mineralization.

Results of this study show that the inclusion of a legume in the rotation increases the availability of both the residue and soil N from early spring throughout the growing season, resulting in higher grain yield and higher protein. However, this trend may not always be the case.

Under conditions that may cause poor lentil growth and/or N_2 fixation, as at Clavet and Conquest in 1995, the results may not be as dramatic or may actually show poor N availability and uptake as seen at Conquest. Hence, for a lentil crop to contribute positively to N availability and uptake in the following year, it must have a good stand and experience no adverse environmental and agronomic conditions.

This study has shown strong synchronization between the period of peak N availability and period of maximum N demand by the subsequent crop. This fact is not apparent when N availability is based only on extractable N in the soil as the crop takes up most of it. With regards to Ndfr, residue N availability of the immediate previous crop to the subsequent crop is poorly synchronized with the period of high N demand by the subsequent crop. However, synchronization of N availability and N demand does not differ for the L-W and W-W rotations. The higher amount of N available in the L-W rotation compared to the W-W rotation ensures that the early N requirements of the crop are met and helps establish a better crop with a stronger vigor to exploit more resources from the soil as well as added fertilizer N. Under semi-arid conditions, the early higher N availability contributes to the N benefits of the subsequent crop, as much of the mineral N remains available to the crop. However, under humid conditions this may not be the case as the N may be lost before the crop fully utilizes it.

References

Badaruddin, M. and Meyer, D.W. 1994. Gram legume effects on soil nitrogen, gram yield, and nitrogen nutrition of wheat. Crop Sci. 34: 1304-1309.

Broadbent, FE. and Norman, A.G. 1946. Some factors affecting the availability of the organic nitrogen in soil - a preliminary report. Soil Sci. Soc. Am. Proc. 11:264-267.

Campbell, CA., Zentner, RP., Selles, F., Biederbeck, V.O. and Leyshon, A.J. 1992. Comparative effects of grain lentil-wheat and monoculture wheat on crop rotation, N economy and N fertility in the Brown Chemozem. Can. J. Plant Sci. 72:1091-1107.

Chalk, P.M., Smith, C.J., Hamilton, S.D. and Hopmans, P. 1993. Characterization of the N benefit of a grain legume *(Lupines* ***angustifolius*** L) to a cereal (***Hordeum vulgare*** L.) by an in ***situ*** ^{15}**N** isotope dilution technique. Biol. **Fert.** Soils **15:39-44.**

Evans, J., Fettell, **N.A,** Coventry, **D.R., O'Connor, G.E.,** Walsgott, D.N., Mahoney, J. and Armstrong, **E.L.** 1991. Wheat response after temperate legumes in south-eastern Australia. **Aust.** J. Agric. **Res. 42:3** 143.

Harris, G.H. and Hesterman, O.B. 1990. Quantifying the N contribution from alfalfa to soil and two succeeding crops using Nitrogen-15 Agron. J. **82:129-134.**

Harris, **G.H.,** Hesterman, O.B. Paul, **E.A.,** Peters, S.E. and Janke RR 1994. Fate of legume and fertilizer Nitrogen-15 in a long-term cropping systems experiment Agron. J. 86:910-915.

Hassink, J., Bouwman, L.A., Zwart K.B. and Brussard, L. 1993. Relationships between habitable pore space, soil biota and mineralization rates in grassland soils. Soil Biol. Biochem. 25:47-55.

Janzen, HH and Radder, G.D. 1989. Nitrogen mineralization in a green manure-amended soil as influenced by cropping history and subsequent crop. PI. Soil **120:125-131.**

Mooleki, S.P., Slinkard, A.E. and van Kessel, C. 1996. Nitrogen and non-nitrogen benefits of lentil in the succeeding wheat crop. Soils & Crops Workshop '96. University of Saskatchewan, SK, Canada. pp. 292-302.

Pierce, F.J. and Rice, C.W. 1988. Crop rotation and its impact on efficiency of water and nitrogen use. In W.L. **Hargrove, ed. Cropping strategies for efficient use of water and nitrogen. ASACSSA-SSSA Special Publ. no. 5 1, Madison, WI. pp. 2142.**

Rowell, J.G. and Walters, D.E. 1976. Analyzing data with repeated observations on each experimental unit. J. Agric. Sci. (Camb.) 87:423-432.

Scott, N.A., Cole, C.V., Elliott, E.T. and Huffman, S.A. 1996. Soil textural control on decomposition and soil organic matter dynamics. Soil Sci. Soc. Am. J. **60:1102-1** 109.

Vanotti, M.B. and Bundy, L.G. 1995. Soybean effects on soil nitrogen availability in crop rotation. **Agron. J. 87:676-680.**