Nitrogen and non-nitrogen benefits of lentil in the succeeding wheat crop

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Abstract

Incorporation of legumes in a cropping system has positive agronomic benefits to subsequent crops, particularly cereals. These benefits are associated with improved N availability to the subsequent cereal and/or non-N benefits associated with the preceding legume crop. A study was conducted in southern Saskatchewan, Canada, in the Dark Brown soil zone to determine the N and non-N benefits of lentil (Lens *culinaris* Medikus) in the subsequent wheat *(Triticum sarivum* L.) crop. A systematic grid design was employed and ^{15}N methods were used to determine and separate the two rotation benefits. Grain yield, spring available N, total N yield, A-value and the amount of N derived from the soil were significantly higher on the lentil-wheat rotation than on the wheat-wheat rotation. Leaf disease complex and root rot were lower on the lentil-wheat rotation than on the wheat-wheat rotation. Results indicate that the N-benefit may be higher than the non-N benefit in the Dark Brown soil zone.

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). The beneficial effects of leguminous plants are referred to in early Roman writings more than 2000 years ago (Paul and Clark, 1989). However, during the last two decades, interest in the utilization of legumes in cropping systems has been rekindled by the desire to conserve fossil energy and soil, and to reduce air and water pollution (Walters *et al.*, 1992; Varco et *al.*, 1993). With the current interest in sustainable agricultural systems, the use of legumes in crop rotations to provide N to subsequent crops is increasingly being recognized as an essential component (Pierce and Rice, 1988; Harris and Hesterman, 1990).

The primary benefit of legumes in rotation with cereals is due directly to N_2 fixation by the leguminous crop (Janzen and Radder, 1989). However, crop rotations utilizing legumes may also elicit yield increases via mechanisms other than improved N fertility through N_2 fixation. This realization has lead to the partitioning of these benefits into the N rotation benefit which is that portion attributable to N_2 fixation by the legume (Pierce and Rice, 1988); and the ***non-N rotation benefit,*** a term reserved for that portion of the benefit not attributable to N_2 fixation by the legume (Baldock et *al.*, 1981; Hesterman et *al.*, 1987) and which cannot be compensated for by N fertilizers (Bullock, 1992). Although it is generally agreed that the N rotation benefit plays an important role in crop rotation, Bullock (1992) cautions that this credit may be excessive in some cases due to methodologies employed in partitioning the benefits. Harris and Hesterman (1990) cited several studies which have tried to elucidate the N and non-N rotation effects of legumes on subsequent non-legume crops grown in rotation. However, they noted that information on the actual quantities of N contributed from legume plant material to subsequent crops is lacking. They attributed this failure to the fact that the N credit was based on the fertilizer replacement value (FRV) which is the amount of inorganic N fertilizer required to produce a subsequent non-legume crop yield equivalent to that produced following a legume. However, N and non-N rotation benefits were not adequately separated, and a direct measurement of N contributed from legume plant residue was not obtained.

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), is not measured and its effect is compounded into the N rotation effect. This may lead to overestimation of the benefits due to N_2 fixation. 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). However, other studies have shown that this priming effect may be minor compared to the overall rates and could be either positive or negative (Jansson and Persson, 1982). Hence, in our paper we take a more conservative definition of what constitutes N benefit. The N benefit will be that portion of yield increase that can be accounted for by the addition of fertilizer N and hence, equated to the fertilizer replacement value to the subsequent crop. On the other hand, the non-N benefit is that portion of the yield increase that can not be compensated for by the addition of fertilizer N.

The objective of the present study is to quantify the rotation benefit of a lentil crop to the succeeding wheat crop in a lentil-wheat rotation in the Dark Brown soil zone and to separate these benefits into the N and non-N components.

Materials and Methods

A Systematic Grid Design (SGD) study was conducted at Dinsmore in the Dark Brown soil zone. The soils at the site are classified as Elstow-Weybum loam - clay loam. A 2-year fallow-wheat system had been followed at the site for many years. The field was summerfallowed the previous year - 1993.

In the spring of 1994, a 100 x 200 m area was separated into two 100 x 100 m areas, each with 100 10 x 10 m grid cells. These two areas were surveyed using a theodolite total station for subsequent digital elevation model and landform element derivation. This information was used to classify the landscape into the landform elements and complexes as described by Pennock et al. (1987, 1994). Four landform complexes were classified as shown in Figure 1. Lentil was seeded to one area and wheat to the other. In the lentil area 1 x 1 m microplots of lentil and wheat were established in each grid cell and fertilized with an ^{15}N double labelled $^{15}NH_4{}^{15}NO_3$ for the subsequent determination of N_2 fixation by lentil (^{15}N isotope dilution method). The labelled lentil residue was retained after harvest and applied back into the field in the fall for the determination of lentil residue N. At each 10 m grid point 1 x 1 m microplot was established on the eastern side of the center of the grid cell at least 1 m away from the previous microplot and the respective residue applied. The labelled residue was lightly incorporated in the top 2-4 cm to avoid drift and loss of material over the winter and in the spring.

In the spring of 1995 one pass with a small spiked cultivator was made to break the crust with little disturbance to the standing straw and residue microplots. In both the lentil and the wheat areas soil samples were taken from each of the 100 grid cells at three depths (O-15, 15-30 and 30-60 cm), for the determination of spring soil moisture and available mineral N. Urea at 49 kg N ha-1 was banded a day before wheat (cv. Leader) was seeded on 10 May 1995. Monoammonium super-phosphate (11-55-O) at 33.6 kg ha-t was applied with the seed. A 2 m strip was left unfertilized on the western side of the center of the grid cells opposite from the lentil residue microplots. Two weeks after seeding a 1 x 1 m microplot was established in each grid cell in the unfertilized portion and single labeled $NH_4{}^{15}NO_3$ at 5 atom % ^{15}N was applied at 5 g/m^2. Unlabelled ammonium nitrate fertilizer was added to give a total of 14.7 g/m^2 (Equivalent to 48.5 kg N ha^{-1}). Weeds were controlled as required.

Common root rot incidence was rated from randomly selected grid cells to represent the landform complexes and the leaf disease complex was rated for each grid cell in both grids at anthesis (Bailey et *al*. 1992). At physiological maturity samples from each labelled fertilizer microplot and the residue microplots were taken for %N and ^{15}N determination. The ^{15}N numbers were used to determine the percentage of N derived from lentil residue and that from fertilizer. Wheat samples were taken from 1 m^2 in each grid cell for the determination of grain and straw yield.

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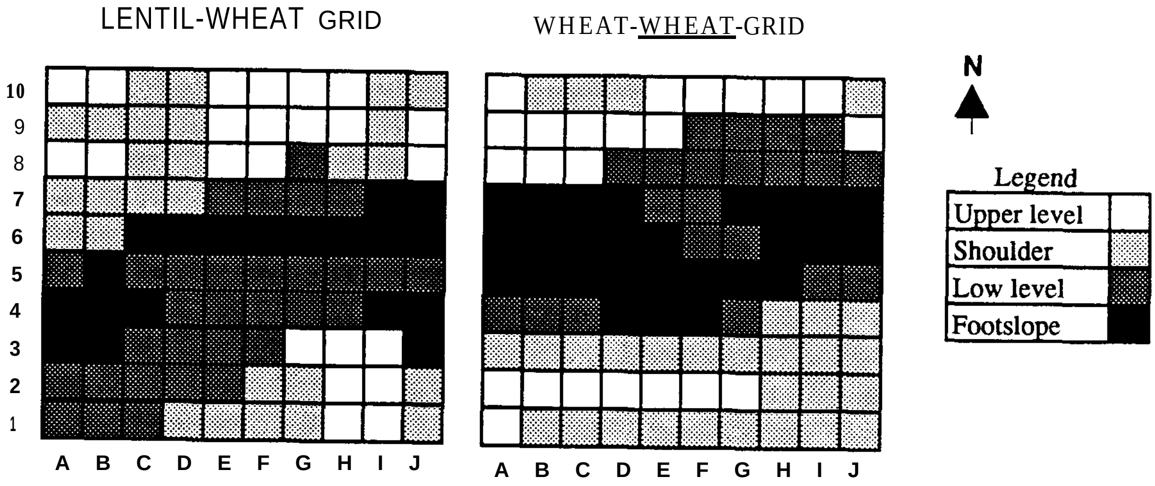

Legend	
Upper level	☐
Shoulder	░
Low level	▓
Footslope	■

LENTIL-WHEAT GRID

	A	B	C	D	E	F	G	H	I	J
10	☐	☐	░	░	☐	☐	☐	☐	░	░
9	░	░	░	░	☐	☐	☐	☐	░	☐
8	☐	☐	░	░	☐	☐	▓	░	░	☐
7	░	░	░	░	▓	▓	▓	▓	■	■
6	░	░	■	■	■	■	■	■	■	■
5	▓	■	▓	▓	▓	▓	▓	▓	▓	▓
4	■	■	■	▓	▓	▓	▓	▓	■	■
3	■	■	▓	▓	▓	▓	☐	☐	☐	■
2	▓	▓	▓	▓	▓	░	░	☐	☐	░
1	▓	▓	▓	░	░	░	░	☐	☐	░

WHEAT-WHEAT-GRID

	A	B	C	D	E	F	G	H	I	J
10	☐	░	░	░	☐	☐	☐	☐	☐	░
9	☐	☐	☐	☐	☐	▓	▓	▓	▓	☐
8	☐	☐	☐	▓	▓	▓	▓	▓	▓	▓
7	■	■	■	■	▓	▓	■	■	■	■
6	■	■	■	■	■	▓	▓	■	■	■
5	■	■	■	■	■	■	■	■	▓	▓
4	▓	▓	▓	■	■	■	▓	░	░	░
3	░	░	░	░	░	░	░	░	░	░
2	☐	☐	☐	☐	☐	☐	☐	░	░	░
1	☐	░	░	░	░	░	░	░	░	░

Figure 1: Schematic diagram of the lentil-wheat and wheat-wheat rotation grids showing grid cells and positions of landform complexes.

Descriptive statistics showed that the data had no serious departure from normality. Hence, the use of non-parametric statistics common in landscape-scale analyses, was not necessary. Parametric statistics are more powerful than non-parametric procedures when the fundamental assumptions of normality, randomness, and independence are not seriously violated. Hence, for each grid a one-way analysis of variance with landform complex as the independent factor was performed for all the variables. To see the effect of crop rotation a combined general linear model analysis of variance was performed with crop rotation and landform elements as the two independent variables. The A-value was the major determinant of the N benefit. Among the measured variables spring soil moisture content and leaf and root diseases were considered part of the non-N rotation benefit. A covariance analysis was done to separate and help determine the contribution of N and non-N rotation benefits.

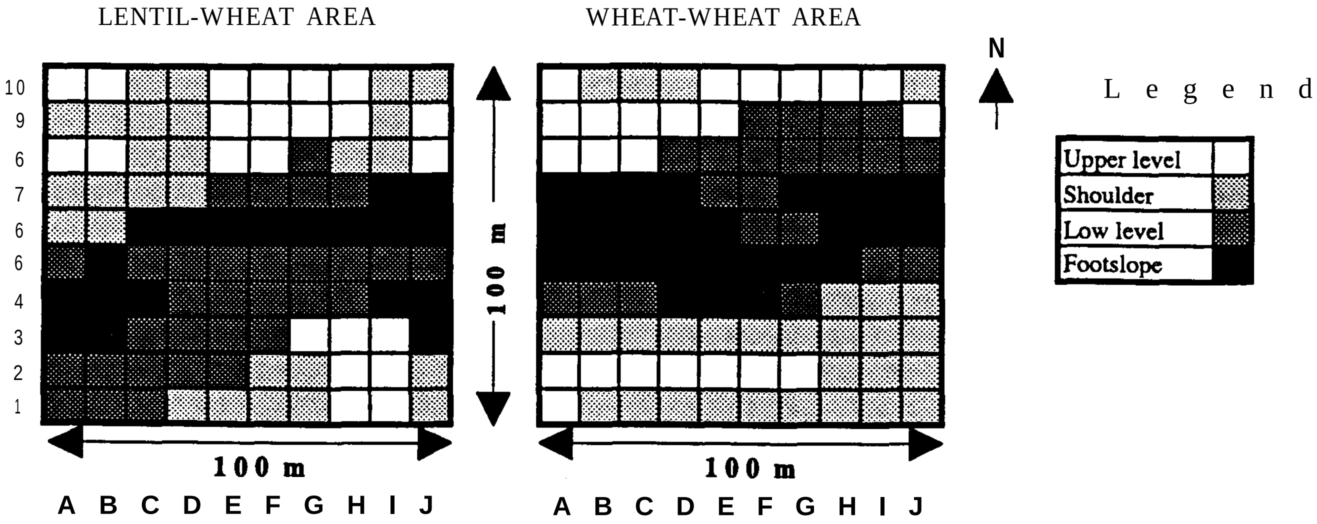

Figure 1: Schematic diagram of the lentil-wheat and wheat-wheat rotation grids showing grid cells and positions of the landform complexes.

Results

Four different landform complexes were identified in both lentil-wheat and wheat-wheat rotations (Fig. 1). Landform complex distribution in the lentil-wheat rotation was 23% upper level, 27% shoulder, 19% footslope and 31% lower level while in the wheat-wheat rotation it was 23% upper level, 29% shoulder, 27% footslope and 21% lower level. Moisture content in the spring of 1995 was not significantly different among the landform complexes in the lentil-wheat rotation in the O-15 cm (Table 1). However, the upper level had significantly low water content than the lower level and footslope in the 15-30 cm soil depth. No significant differences among landform complexes were observed in the 30-60 cm soil depth in the lentil-wheat rotation. In the wheat-wheat rotation, the footslope and the lower level had significantly higher moisture content than the upper level and shoulders in all the three soil depths. On the average, the wheat-wheat rotation had significantly higher spring moisture content than the lentil-wheat rotation.

Available mineral N on the upper level in the top 30 cm was significantly lower than on the other landform complexes (Table 2). In the 30-60 cm soil depth differences among the landform complexes were not significant in the lentil-wheat rotation. However, the upper level showed a significantly lower mineral N content than the shoulder and the lower level. The footslope had an intermediate mineral N content compared to the two extremes. In the wheat-wheat rotation, the footslope and the lower level had significantly higher mineral N content than the upper level and the shoulders in the O-15 and 15-30 cm soil profiles. In the 30-60 cm soil profiles, the lower level had significantly higher mineral N content than the other landform complexes. The shoulders had the lowest mineral N content, though not significantly different from that on the upper level.

Table 1: Spring moisture distribution among landform complexes in the lentil-wheat and wheat-wheat rotations

Landform complex	SOIL DEPTH O-15 cm	15-30 cm	30-60 cm	O-60 cm
	%			
Lentil-Wheat				
Upper level	23.3	19.8 c*	17.8	20.3
Shoulder	23.8	20.4 bc	16.2	20.3
Footslope	25.4	22.3 a	18.2	22.0
Lower level	24.2	21.6 ab	17.1	21.0
Average**	24.1	21.0	17.8	20.9
LSD (0.05)	ns	1.5	ns	ns
Wheat-Wheat				
Upper level	23.9 b	22.8 b	18.9 ab	21.9 b
Shoulder	23.7 b	22.5 b	18.0 b	21.4 b
Footslope	27.9 a	25.4 a	20.2 a	24.5 a
Lower level	27.2 a	24.9 a	19.3 a	23.8 a
Average	25.6	23.8	19.1	22.8
LSD (0.05)	1.6	1.7	1.3	1.3

* Variables followed by the same letter in the same column within a rotation are not significantly different from each other at 0.05 level of significance.

** Average moisture content for all depths was significantly lower in Lentil-Wheat than in Wheat-Wheat rotation at 0.05 level of significance.

Landform complex showed no significant effect on grain, straw or N yield in the lentil-wheat rotation (Table 3). However, grain %N was significantly different on the lower level and footslope than on the upper level. No significant differences in grain N content was observed between the footslope and the shoulder. On the wheat-wheat rotation, significantly higher grain and straw yields were obtained on the footslope than on the upper level. Grain yield on the upper level was not significantly lower than that on the shoulder and lower level, while straw yield was not significantly different on the lower level and shoulder or on the shoulder and the upper level. Grain N content was significantly higher on the lower level than on the other three landform complexes. Comparing the two rotations, grain, straw and grain N content were significantly higher on the lentil-wheat rotation than on the wheat-wheat rotation.

The N supplying power of the soil as measured by the A-value (Table 3) was significantly higher on the footslope than on the other landform complexes in the lentil-wheat rotation. In the wheat-wheat rotation the lower level and the footslope had significantly higher A-values than the other two, of which the shoulder A-value was significantly higher than that on the upper level. Over all, the lentil-wheat rotation A-value was more than double that of the wheat-wheat rotation. Leaf disease complex was significantly lower on the upper level than on the other landform complexes, while no significant differences in leaf disease severity were observed among the other landform complexes. On the wheat-wheat rotation, the lower level had a significantly higher leaf disease severity than the other three landform complexes, among which no significant differences in leaf disease severity were observed. Root rot was significantly higher in the wheat-wheat rotation than in the lentil-wheat rotation. However, no significant root rot incidence was observed among landofrm complexes within each rotation.

Total N yield and total N derived from the soil were significantly higher in the lentil-wheat rotation than in the wheat-wheat rotation (Table 4). Total N derived from residue of the previous year (Ndfr) was measured only on the lentil-wheat rotation. Only 2.3 kg N ha-1 was recovered in the subsequent wheat crop. Although this amount was only 3% of the total N yield in the subsequent wheat crop, it represented 14.6% of the 15.8 kg N ha-1 supplied by the lentil residue. No significant total Ndfr nor residue N recovery were observed among landform complexes.

Table 2: Spring available mineral N distribution among landform complexes in the lentil-wheat and wheat-wheat rotations

Landform complex	SOIL DEPTH			
	O-15 cm	15-30 cm	30-60 cm	O-60 cm
	(kg ha^{-1})			
Lentil-Wheat				
Upper level	12.4 b*	9.9 b	6.6	28.9 b
Shoulder	16.1 a	14.1 a	8.7	38.9 a
Footslope	17.5 a	13.9 ab	8.4	39.8 a
Lower level	19.3 a	15.4 a	8:0	42.7 a
Average**	16.5	13.5	7.9	37.9
LSD (0.05)	3.5	4.2	ns	8.8
Wheat-Wheat				
Upper level	7.0 b	8.4 b	6.1 bc	21.4 b
Shoulder	8.6 b	8.4 b	4.8 c	21.9 b
Footslope	11.9 a	12.8 a	6.6 b	31.2 a
Lower level	11.2 a	14.0 a	8.5 a	33.7 a
Average	9.7	10.8	6.4	26.8
LSD (0.05)	2.0	2.0	1.6	4.6

* Variables followed by the same letter in the same column within a rotation are not significantly different from each other at 0.05 level of significance.

** Average available mineral N for all depths was significantly higher in Lentil-Wheat than in Wheat-Wheat rotation at 0.05 level of significance.

Table 5 gives the analysis of covariance showing selected covariates that contributed to either the N or the non-N rotation benefits and which individually showed a significant effect on grain yield within or between rotations. The % contribution to variation given in Table 5 indicates the % contribution to variation of the particular covariate among the selected covariates or its contribution to the total variation (accounted and unaccounted for), respectively. The A-value was the main variable contributing to the N-benefit, while all other variables in the covariance analysis contributed to the non-N benefits of rotation.

In the lentil-wheat rotation the A-value was the main variable responsible for grain yield variation among landform complexes. It accounted for 53.1% of the two covariates selected and 23.8% of the total variation. Leaf disease complex accounted for 46.9% and 21%, respectively. In the wheat-wheat rotation the A-value was the least important variable responsible for grain yield variation among landform complexes. It accounted for 16.1% of the covariates selected and 6.9% of the total variation. Spring moisture content in the O-60 cm soil depth was the most important variable, accounting for 58.3% of the covariates selected and 24.9% of the total variation. The

A-value accounted for 54.2% of the selected covariates and 26.1% of the total variation with regards to rotation. Leaf disease complex was intermediate, accounting for 25.6% and 10.9%, respectively. Leaf disease complex was next, accounting for 42.6% and 20.6% respectively. Spring moisture content was the least important variable responsible for grain yield variation between the two rotations, accounting for 3.3% of the covariates selected and 1.6 % of the total variation. Over all, the selected covariates explained a large portion of the variation observed either within or between rotations. In the lentil-wheat rotation the selected covariates explained 44.8% of the variation due to landform complex, while in the wheat-wheat rotation the selected variables explained 42.3%.

Table 3: Response of selected soil and plant variables as affected by crop rotation and landform complex

Landform complex	Yield		Grain N		Grain	Diseases+	
	Grain	Straw			A-value	Leaf	Root
	—— (kg ha-l) - - -		%	kg ha^{-1}	kg N ha^{-1}	0-11	0-4
Lentil-Wheat							
Upper level	1888	2413	2.92 c*	55.2	73 b	4.9 b	0.8
Shoulder	1786	2247	3.03 bc	54.1	67 b	6.4 a	0.7
Footslope	1967	2730	3.11 ab	61.4	100 a	5.7 a	0.8
Lower level	1732	2348	3.17 a	54.9	71 b	6.2 a	0.8
Average**	1827	2408	3.06	56.0	73	**5.9**	**0.8**
LSD (0.05)	ns	ns	0.10	ns	19	**0.8**	**ns**
Wheat-Wheat							
Upper level	1286 b	1727 c	2.63 b	33.6 c	31 b	7.7 b	1.7
Shoulder	1385 ab	1769 bc	2.63 b	36.0 ab	20 c	7.5 b	1.7
Footslope	1620 a	2403 a	2.58 b	41.5 ab	42 a	7.8 b	1.3
Lower level	1481 ab	2265 ab	2.90 a	42.8 a	48 a	8.4 a	1.2
Average	1446	2035	2.67	38.4	34	**7.8**	1.5
LSD (0.05)	305	500	0.17	5.8	9	**0.5**	ns

*Variables followed by the same letter in the same column within a rotation are not significantly different from each other at 0.05 level of significance.

** Average value for all variables was significantly different in Lentil-Wheat than in Wheat-Wheat rotation at 0.05 level of significance.

*Diseases were scored on a 0- 11 scale for leaf disease complex and O-4 scale for root rot.

Table 4: Response of selected plant variables in wheat as affected by crop rotation

Rotation	N yield	Total Ndfs		Total Ndfr		Residue N recovery
	kg ha^{-1}	%	kg ha-l	%	kg ha^{-1}	%
Lentil-Wheat	75.2 a	54.7 a	41.1 a	3.0	2.3	14.6
Wheat-Wheat	49.4 b	37.2 b	18.4 b	ND	ND	ND
LSD (0.05)	**..8.7**	**5.7**	**7.0**	NA	NA	NA

* Variables followed by the same letter in the same column within a rotation are not significantly different from each other at 0.05 level of significance.

Ndfs = N derived from the soil; Ndfr = N derived from the residue; ND = Not determined; NA = Not applicable.

Table 5: Covariance analysis of the A-value and selected variables with landform effect for grain yield

Source of variation	df	Sum of squares	P	% Contribution to variation* Covariates	Total
Lentil-Wheat					
Total	**99**	**21461459**			**100.0**
Covariates	**2**	**9621720**	**0.00**	**100.0**	**44.8**
A-value	1	5113913	0.000	53.1	23.8
Leaf diseases	1	4507807	0.000	46.9	21.0
Wheat-Wheat					
Total	**99**	**20037979**		-	**100.0**
Covariates	**3**	**857 1770**	**0.00**	**100.0**	**42.8**
GMC♦	1	4997216	0.000	58.3	24.9
Leaf diseases	1	2193905	0.000	25.6	10.9
A-value	1	1380649	0.001	16.1	6.9
Rotation					
Total	99	48757488	-		100.0
Covariates	3	23535669	0.00	100.0	48.3
A-value	1	12746847	0.000	54.2	26.1
Leaf diseases	1	10020224	0.000	42.6	20.6
GMC♦	1	768597	0.015	3.3	1.6

* Proportion of the total sum of squares and the total of the covariates, respectively, attributable to a given covariate.

● GMC = Gravimetric moisture content (O-60 cm) measured in the spring.

Discussion

These results show that crop rotation has a significant effect on both soil moisture content and available mineral N in the spring prior to seeding a subsequent crop resulting in a significant effect on both grain and total aboveground biomass yield. The difference in moisture content could be a result of the low residue cover from the previous lentil crop as compared to that of the previous wheat crop. Such a lower residue cover would result in a lower snow trap, earlier soil warming and subsequent soil water evaporation and snow-melt runoff. Furthermore, lentil, a later maturing crop, may have extracted more water from the soil in the previous year compared to the wheat crop. Despite a poorer soil moisture conservation of the lentil-wheat rotation compared to the wheat-wheat rotation, the increased N supplying power of the lentil-wheat rotation overwhelmed the benefits of conserved moisture. However, the benefits of conserved moisture were more significant across the landscape within the wheat-wheat rotation.

The A-value adequately measures the N-benefit of the cropping system as it integrates the system's soil N supplying power to the subsequent crop. The 41% higher spring available mineral N on the lentil-wheat rotation compared with the wheat-wheat rotation (Table 2.) explains a large portion of the 52% higher grain N yield on the lentil-wheat rotation than on the wheat-wheat rotation (Table 3). The remainder of the greater grain N yield can be attributed to a high N supplying power of the soil under lentil-wheat rotation over the rest of the growing 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 26% grain yield advantage.

In comparing the N and non-N benefits of a legume crop to a succeeding non-legume crop, it is important that factors contributing to either are clearly identified. In our study we chose to recognize N-benefit as that portion of yield increase that can be accounted for by the addition of fertilizer N and hence, equated to the fertilizer replacement value to the subsequent crop. On the other hand, the non-N benefit is that portion of the yield increase that can not be compensated for by the addition of fertilizer N. The fertilizer replacement value-based definition includes both the direct N contribution of the legume crop through N_2 fixation and the indirect N contribution through other processes that make N more available. Our results show that the direct N contribution as measured by the amount of N derived from the lentil residue (Ndfr = 3.0%) is small and its effect on grain yield insignificant. However, this amount (2.3 kg N ha-l) represents 14.6% of lentil residue N recovery in the subsequent wheat crop, a value higher than the 5.5% observed by Bremer and van Kessel (1992). However, it falls within the 9-27% N recovery of wheat from lentil and flat pea (Lathyrus *tingitunus* L.) green manure obtained by Janzen et al. (1990).

Dinitrogen fixation does not only contribute to the N benefit through legume residue N recovered in the succeeding non-legume crop but also through spared N. In southern Alberta, Kucey (1989) observed that field pea *(Pisum sativum)* fixed 57% of its N requirement and concluded that use of legumes in crop rotation may not result in increased N availability to a succeeding crop, but that the benefit arises from the fact that the legume crop may not require as much supplemental N. However, from the succeeding crop's "point of view", this 57% Ndfa for the previous pea crop, represents spared soil N that could be made available to it. Since the legume crop meets all or part of its N requirement through symbiotic N_2 fixation, it may remove less inorganic soil N compared to a cereal crop. In the first year of our study, the lentil in the lentil-wheat rotation fixed 34.7 kg N ha-1 on the average across the landscape. This figure represented a 35.6% soil N sparing of its total requirement of 97.4 kg N ha-l. Hence, a grain legume may actually decrease the size of the soil N pool, but at the same time confer an N-benefit to a succeeding cereal due to the N sparing effect (Chalk *et al.* 1993). Other 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 incorporating a legume crop than in 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 the net N mineralization.

The N benefits, as reflected by the measured variables which accounted for 48.3% of the grain yield variation between the rotations, were higher but equally as important as the non-N benefit. This is in conformity with our expectation that in the Dark Brown soil zone, given a near normal moisture regime, N will be an important limiting factor. As shown in the results, leaf diseases also posed an important limiting factor, second only to N availability. Evans *et al.* (1991) attributed increased wheat grain yield after legumes to increased available soil N and decreased cereal diseases. Reduction of disease incidence is one of the non-N benefits attributed to crop rotation. Pedersen and Hughes (1992) found that crop rotation was effective in reducing the severity of disease epidemics caused by the complex of septoria diseases of spring wheat in the Parkland region of Saskatchewan. Under unfavourable conditions for disease development, they found that one year of rotation was enough to control the diseases. Otherwise, a two-year rotation was required. The control of cereal root-rot by crop rotation has a significant bearing on the performance of subsequent crops. This ensures that the root system is sufficiently healthy to explore the soil for nutrients and thus attain healthy growth and good yields. Cook (1992) indicated that no single factor will do more for N-use efficiency in wheat production than having a healthy root system that would take advantage of the N applied for the crop.

Weed competition is another non-N benefit of incorporating legumes in cropping systems (Bullock, 1992), but was not observed at this site. This could be attributed to the long term fallow-wheat rotation at this site. Such a rotation helps prevent the build up of weeds, especially grassy weeds which are problematic in continuous wheat systems.

As N becomes less limiting to yield, non-N rotation benefits become more important (Russelle *et al.* 1987). Stevenson (1996 - personal communication) observed that the importance of N availability following a legume in a rotation may be reduced significantly, if other factors such as diseases and weeds manifest themselves. It may also be true to say that in a situation where the soil N fertility is inherently high (such as in the Black soil zone) non-N benefits may be more important than N benefits. Conversely, where the soil N fertility is inherently low (such as in the Brown soil zone) N benefits may be more important than non-N benefits. Campbell *et al.* (1992) in a long-term study indicated that grain lentil did not increase grain yield of the succeeding wheat crop beyond that expected from N_2 fixation (i.e. there was no non-N rotational effect). Given the drier conditions of the Brown soil zone there may be no differential moisture regimes between the two rotations and disease pressure may be suppressed. Between the two extreme soil zones falls the Dark Brown soil zone where our study was conducted. The importance of N and non-N rotation benefits in this area seem to be intermediate, i.e., both are equally important.

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