LANDSCAPE-SCALE VARIABILITY OF NITROGEN FIXATION AND N BALANCE OF LENTIL

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Abstract

A study was conducted near Dinsmore, SK in the Dark Brown Soil zone to determine the landscape-scale variability of N2 fixation and N balance of a lentil crop. Stable ^{15}N isotope dilution method was used to determine N2 fixation. A digital elevation model was used to establish the landform element complexes available at the site. Results showed that N2 fixation varies with geomorphological variations in the landscape. Both yield and N fixation were highest in the footslopes and lowest on the shoulders and upper level positions. A negative N balance was observed, with the deficit being lowest on the footslopes and highest on the upper level positions.

Introduction

Crop rotations and the use of legumes have existed for a long time and the benefits to agriculture have long been known (Pierce and Rice, 1988). But, for decades the importance of legumes in agriculture declined due to the availability of inexpensive inorganic nitrogen fertilizers and the expansion of monocultural cereal production. 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 water and air pollution (Walter *et al*, 1992; Varco *et al.*, 1993).

In the Canadian prairies the use of legumes has increased over the last fifteen years due to the desire by producers to diversify and reduce the fertilizer-N input in the wake of low producer prices for cereals (Campbel *et al.*, 1992). Among the leguminous crops which have increased in production are field pea (*Pisum sativum* L.) and lentil (*Lens culinaris* Medikus). The introduction of these legumes into the cropping system and the availability of adapted cultivars have provided an alternative to the traditional summerfallow practice (Wright, 1990; Campbel *et al.*, 1992). Lentil is used either as a seed or a green manure crop. The former constitutes about 98% of the lentil grown in the relatively dry southern Saskatchewan. It is generally agreed that incorporation of lentil in the cropping system, either as a seed crop or as a green manure crop, benefits succeeding crops such as wheat (*Triticum sativum* L.). This benefit is attributed to the ability of the legume to fix N in a symbiotic association with *Rhizobium* (Janzen and Radder, 1989). However, it has also been observed that some grain legumes may in fact take more N than they fix, thus resulting in a negative net N balance (Eaglesham *et al.*, 1982; Kucey, 1989). This may be due to the low aboveground residue, resulting in more N being taken from the soil through the grain than returned through the residue. Furthermore, the net N balance would vary in accordance with yield and N2 fixation variations across the landscape.

The amount of N_2 fixed by a legume will depend on the legume species, dry matter yield, soil inorganic N, and prevailing environmental conditions (Power, 1990; Evan *et al*, 1991). Plants preferentially assimilate inorganic soil N, probably due to its low energy cost. Thus, legumes do not fix significant amounts of N2 in the presence of high levels of available soil N or if they are stressed by environmental conditions. Legumes can obtain all their N from N2 fixation, but they typically obtain 30- 80% from this source (Bremer, 1991)

Materials and Methods

The study was conducted at Dinsmore, SK, in the Dark Brown Soil zone. The soils at the site are classified as Eston-Weyburn loam clay loam. The field was summerfallowed the previous year.

In the spring of 1994, a 100 x 100 m grid was 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. Soil samples were taken at each grid point for subsequent moisture content and mineral N analyses. A 50 g sample of the wet soil was collected in a bottle and 100 ml of 2M KC1 added and shaken. The mixture was further shaken in the laboratory, extracted and analyzed for mineral N using a Technicon AutoAnaliser II Single-Channel Calorimeter.

The field was cultivated and rolled prior to seeding lentil (var. Laird) in the third week of May, 1994. At each grid point a 1 x 1 m micro-plot was manually seeded to wheat in rows within the same week. Wheat was used as a reference crop in the subsequent determination of N2 fixation by lentil. Both wheat and lentil emerged at about the same time. Two weeks after emergence, lentil micro-plots were also staked within one meter of the wheat micro-plot, and on the other side of the grid point. The wheat micro-plots were labeled with 10 kg N ha^{-1} using single labeled $NH_4{}^{15}NO_3$ at 5 atom % ^{15}N. The lentil micro-plots were labeled with 20 kg N ha^{-1} double labeled $^{15}NH_4{}^{15}NO_3$ at 10 atom % ^{15}N. A meteorological station was set up to monitor daily temperature and precipitation.

At physiological maturity, the crop was harvested. A 1 m^2 area away from the micro-plots was harvested at ground level from each grid for grain and straw yield determinations. Four to five plants were harvested from the center of each micro-plot by cutting them at ground level. The plants were dried at 40 ^oC and the grain and straw separated by hand and ground in a cyclone mill. The straw was further ground in the ball mill. Percent N and atom % ^{15}N were determined on an ANCA-MS (Europa Scientific, Crewe, UK) equipment with a single inlet and triple collectors. Due to the differences in N rate and enrichment used during the labeling of lentil and wheat micro-plots, the A-value method, as described by Boddey and Urquiaga (1992), was used to determine N2 fixation. This procedure was used to determine percent N derived from fertilizer (% Ndff), percent N derived from the soil (% Ndfs) and percent N derived from the atmosphere (% Ndfa). In combination with the yield data, the results were used to determine total N derived from the atmosphere.

Statistical Analysis

Parametric statistics were used to analyze the results. The Kolmogorov - Sminorv Z statistic test was conducted and showed that although some skewness occurred in the data, it was still normally distributed. 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, independence and equal variance are not seriously violated. However, non-normality was significant for mineral N, as expected, at the landscape-scale .Kruskal-Wallis U test for one way analysis of variance was used for this parameter to compare the medians of the response variables associated with each landform complex. The results were similar to those obtained when this non-normality was ignored and parametric statistics used. For the sake of uniformity, parametric statistics were used on all variables. A confidence level of 0.20 was used because of the high inherent variability expected in **the** landscape-based study (Pennock et al., 1994); otherwise, the chances of committing Type II error are high.

Results

Four landform complexes were identified at the site (Fig. 1) with 30% on lower level, 24% on shoulder, 21% on upper level and 15% on footslope complexes. The area is generally gently sloping with about 50% level. Moisture content in the spring was significantly higher on the footslopes and lower levels than on the upper levels and the shoulders (Table 1). The differences were more pronounced in the top O-30 cm of soil. Hence, a lower level-footslope-centered spatial pattern was observed for total moisture content in the 0 - 60 cm profile (Fig. 2a). In the O-30 cm soil profile, no significant differences in spring available N was observed among th landform complexes (Table 1). However, it was noted that shoulders had more available N than upper levels. Differences in available mineral N in the spring were not significant among shoulder, footslope and lower level landform complexes in the 30-60 cm soil depth, and the combined O-60 cm soil profile. However, available mineral N in the spring was significantly lower on the upper level than on the lower level and shoulder. Unlike soil moisture content, available mineral N in the spring (O-60 cm) did not show landform complex pattern, but was randomly distribution (Fig. 2b).

Figure 1: Landform complexes at th eDinsmore site.

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Grain yield and straw yield were significantly higher on the footslopes than on the other three landform complexes, which were not different from each other (Table 2). Total yield ranged from 2022 kg ha- on the footslopes to 1779 kg ha- on the upper levels, while straw yield ranged from 3 112 kg ha- on the footslopes to 2736 kg/ha on the shoulders and upper levels. Percent nitrogen derived from the atmospher (% Ndfa) in both the grain and the straw was highest on the footslopes and significantly higher than on the shoulders. However, in quantitative terms nitrogen derived from the atmosphere was significantly higher on the footslopes than on the other three landform complexes. Percent Ndfa in the grain ranged from 40.4% on the footslopes to 27.8% on the shoulders. The trend was similar for % Ndfa in the straw, ranging from 41.1% on the footslopes to 29.4% on the shoulders (Table 2). Overall, more N was fixed in the footslopes and this was also reflected in the amount of N in the grain.

Table 1: Spring moisture and available N distribution among landform complexes

Landform	Moisture content (%)			Mineral N (kg ha-l)		
complex	O-3Ocm	30-6Ocm	O-6Ocm	O-3Ocm	30-6Ocm	O-60cm
Shoulder	17.6 b*	15.7 c	16.6 b	20.3	11.8 ab	32.1 a
Footslope	19.2 a	17.3 ab	18.2 a	19.8	11.4 ab	31.2 ab
Lower level	19.4 a	17.8 a	18.6 a	18.7	13.5 a	32.2 a
Upper level	16.9 b	16.5 bc	16.7 b	17.0	9.9 b	26.9 b

* Variables followed by the same letter in the same column are not significantly different from each other at 0.20 level of significance.

Figure 2: Quartile maps for (A) gravimetric moisture content and (B) total mineral N taken in the spring of 1994.

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In terms of the N contribution to the soil (net N balance), lentil removed more N from the system than it actually contributed, thus leaving a negative net N balance (Table 3). However, relatively less N was lost from the system in the footslopes where N2 fixation was highest, and more N was lost from the system on the shoulders where N_2 fixation was the lowest. These differences in net N balance were not statistically significant.

All N variables (grain % Ndfa, straw % Ndfa, grain Ndfa, straw Ndfa and total Ndfa) were highly significantly correlated with grain and straw yield (Table 4). Straw yield was significantly correlated with spring moisture content, available mineral N and grain yield. However, grain yield was not correlated with spring moisture content and available total mineral N. All plant N variables (except straw % Ndfa) were significantly correlated with spring total available mineral N. Only grain and straw Ndfa were significantly correlated with total moisture content measured in the spring. Although some significant correlations were observed between plant N variables and total moisture content and available mineral N measured in the spring, these correlations were of low magnitude. Grain and straw % N derived from the soil (%Ndfs) were negatively correlated with total mineral N, grain yield and straw yield.

Table 2: Yield and N derived from the atmosphere on the shoulders, footslopes, and upper and lower levels

Landform complex	Yield		N derived from the atmosphere			
	Grain	Straw	Grain	Straw	Grain	Straw
	(kg ha $^{-1}$)		(%)		(kg ha $^{-1}$)	
Shoulders	1792 b*	2736 b	27.8 b	29.4 b	19.9 b	7.6 b
Footslopes	2022 a	3112 a	40.4 a	41.1 a	33.4 a	13.9 a
Lower levels	1823 b	2761 b	32.8 ab	34.4 ab	23.6 b	9.9 b
Upper levels	1779 b	2736 b	33.8 ab	35.6 ab	22.3 b	9.1 b

* Variables followed by the same letter in the same column are not significantly different from each other at 0.20 level of significance.

Table 3: Net nitrogen balance of lentil at different Landscape complexes

Landform Complex	Total N Fixed	Grain N	Net N Balance
	--------- ($kg\ ha^{-1}$) ----------		
Shoulders	27 b	68 b	- 41
Footslopes	47 a	79 a	- 32
Lower Levels	33 b	70 ab	- 37
Upper Levels	31 b	65 b	- 34

* Variables followed by the same letter in the same column are not significantly different from each other at 0.20 level of significance.

Discussion

Gram and straw yield and nitrogen derived from the atmosphere were consistently higher on the footslopes compared with those on the other landform complexes. Although the site does not have the very steep slopes needed to accentuate topographic differences in N_2 fixation and yield (Mahler et *al.*, 1979), the influence of water redistribution associated with slope morphology (Pennock and Acton, 1989; Pennock et *al.*, 1994) was large enough to cause significant variations among different landform complexes. Water redistribution is the single most important factor causing variation in soil properties and crop responses at the landscape-scale (Pennock et *al.*, 1987). Water will move both on the surface and through the soil and converge in the convergent areas of the landscape. This moving water carries soluble nutrients along with it, resulting in a lower mineral N content at the upper level compared to the other landform complexes. In the relatively dry parts of Saskatchewan even small amounts of water redistribution can make a big difference on crop response and performance. The higher yield and N2 fixation observed on the footslopes is in agreement with findings of Wendroth *et al.* (1992) who noted the N_2 fixation of alfalfa ***(Medicago sativa*** L.) varied with landscape formation. However, in the wetter Black Soil zone of Saskatchewan, Androsof *et al.* (1994) found that although, topography influenced soil water and soil N, it was not a dominant factor in controlling N_2 fixation by pea.

Table 4: Pearson correlation coefficients for total moisture content (TMC) O-60 cm; total mineral N (TMN) 0-60 cm; grain yield (GYLD), straw yield (SYLD) and plant N variables

	TMC	TMN	GYLD	SYLD
	(0-60 cm)	(0-60 cm)		
	(%)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)
Total mineral N (0-60 cm)	0.12			
Grain yield ($kg\ ha^{-1}$)	0.14	0.13		
Straw yield ($kg\ ha^{-1}$)	0.24*	0.29***	0.78***	
Grain % Ndfs	-0.11	-0.18*	-0.32***	-0.38***
Straw % Ndfs	-0.08	-0.04	-0.26**	
-0.30***				
Grain % Ndfa	0.13	0.22*	0.32***	0.39***
Straw % Ndfa	0.09	0.09	0.27**	0.33***
Grain Ndfa ($kg\ ha^{-1}$)	0.16*	0.27**	0.54***	0.54***
Straw Ndfa ($kg\ ha^{-1}$)	0.19*	0.21*	0.38***	0.47***
Total Ndfa ($kg\ ha^{-1}$)	0.17	0.26**	0.50***	0.53***

*, ** and *** Indicate Pearson's Correlation Coefficients (r) which are significant at 0.2, 0.05 and 0.01 levels of significance, respectively.

Dinitrogen fixation was positively correlated with available soil N (O-60 cm) measured in the spring. It has been reported that available soil N will reduce N2 fixation as the crop will preferentially use available soil N rather than spend energy in fixing atmospheric N 2 (Bremer 1991). Although, the mineral N content in the spring was lower in the upper slope than in the other landform complexes, the actual amounts may not have been high enough to impede N2 fixation. In fact, the relatively higher N levels on these landform complexes may have acted as a booster for the crop, thus enabling the crop to better establish itself in the early stages of growth before it started to fix its own N (Jensen, 1986; Sprent and Minchin, 1983). This positive effect of available N can be seen in the positive correlation of total mineral N measured in the spring with straw yield and its negative correlation with % Ndfs. It appears that the available N promoted early biomass production in the early stages which set appropriate conditions for increased N 2 fixation resulting in higher % Ndfa and lower % Ndfs.

Lentil removed more N from the soil than it fixed, thus creating a negative N balance. Chalk et *al.* (1993) noted that a grain legume will only add to the soil N pool if % Ndfa is greater than the N harvest index, otherwise, a negative N balance is obtained. This negative N balance has been observed by several researchers. Bremer (199 1) noted that N benefits in the first year of the crop rotation are minimal when the lentil crop is harvested for grain. Bezdicek et *al.* (1978) showed that harvesting legumes for seed usually creates a negative soil N budget. Eaglesham e t al. (1982) found that most cowpea genotypes and all soybean genotypes which they tested removed more N from the soil than they left behind in the residue. Hence, the use of a legume crop in a rotation may not always result in increased availability of soil N to a succeeding crop. However, even in such situations, there are benefits accrued from the use of the legume crops. These benefits may be due to the fact that the legume crop may not require as much supplemental N (Kucey et al., 1989) or due to the N sparing effect (Chalk et al. (1993), as the legume crop fixes part of its N requirement.

In terms of spatial variability, this negative N balance should be reduced on those landform complexes where N2 fixation was highest. It should be borne in mind that this negative N balance was observed only when the aboveground material was considered. It is likely that the negative N balance would have been less had the N that remained in the soil been included. However, some studies have shown that root N contribution may be less than 10% of the total amount of N in the grain (Senaratne and Hardarson, 1988).

Conclusions

This study has shown that in the Brown Soil zone of Saskatchewan N2 fixation varies with geomorphological variations in the landscape. Both yield and N2 fixation were highest in the footslopes and lowest on the shoulders and upper level positions. The general trend, with regards to N balance, is that lentil can remove more N from the soil than it will fix in a single season, thus creating a negative balance. However, the deficit also varied across the landscape and was lowest on the footslopes and highest on the upper level positions.

The implications of the findings in this study point to the importance of considering landscape variability as an important factor when making recommendations for agronomic practices. Farmers may have to adjust N fertilizer rates upward in those areas of the landscape where N2 fixation is the lowest before they plant the succeeding cereal crop. The negative N balance also indicates that the lentil may also require some fertilizer N; otherwise both the lentil and the succeeding cereal crop may exhibit N deficiency, resulting in lower yields of both crops.

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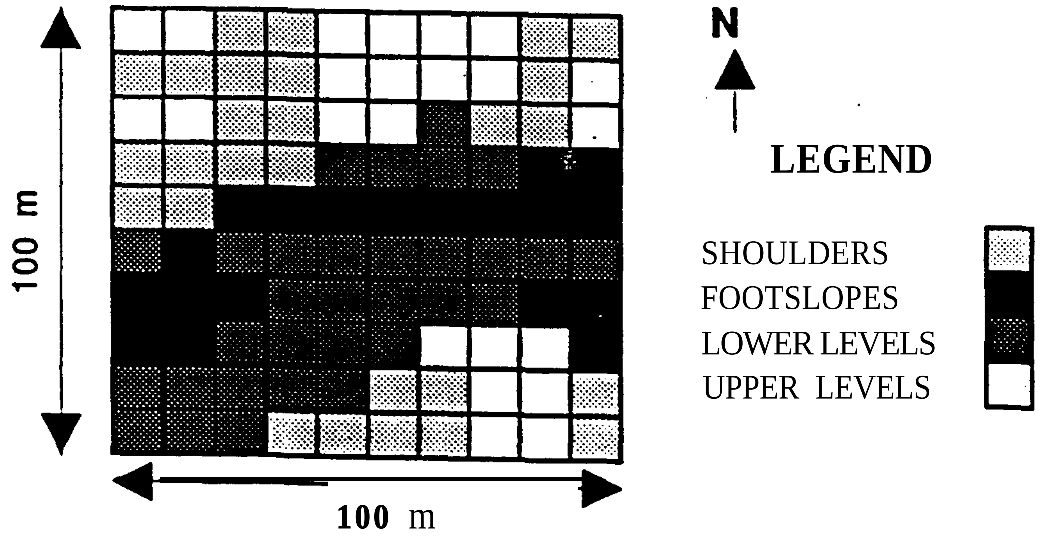
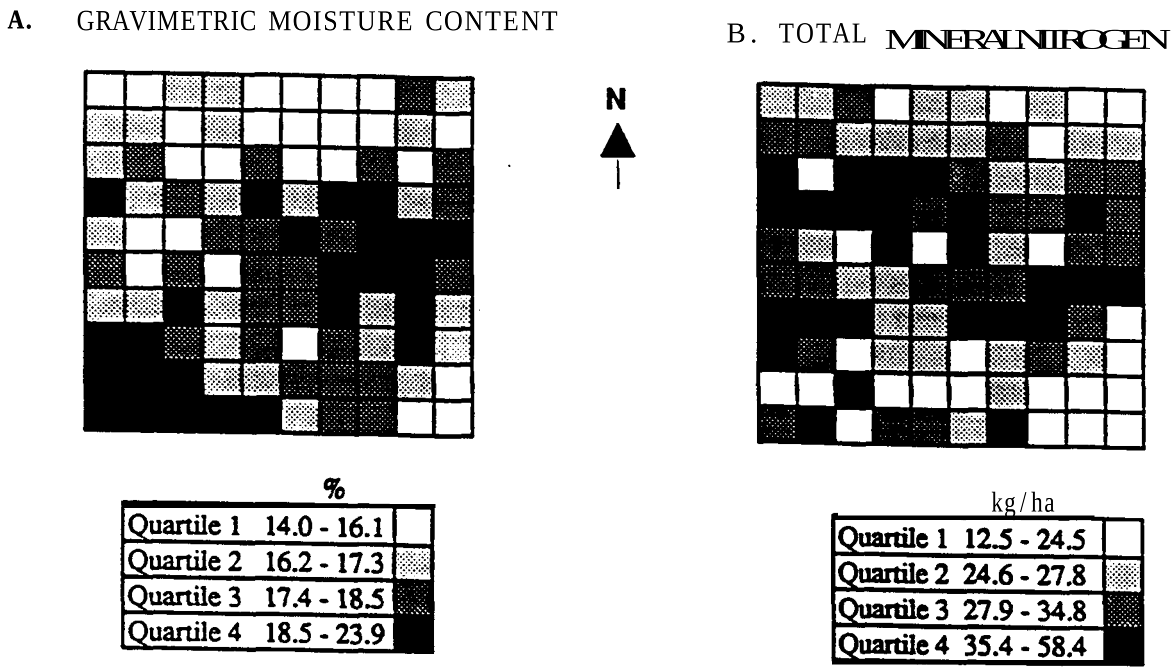


Figure 1: Landform complexes at the Dinsmore site.



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