Landscape-scale Variability of Nitrogen Fixation by Pea and the Availability of its Residue-N for the Succeeding Crop

G. Androsoff and C. van Kessel
Department of Soil Science, University of Saskatchewan, Saskatoon

Abstract

The main objectives of this study were to estimate the variability in N_2 fixation across a large field and to determine whether the availability of legume residue-N to the succeeding crop was controlled by position of incorporation. In 1991, a field was selected near Blaine Lake, Saskatchewan and a 130 x 130 m grid composed of 169 sample sites was laid out. Six landform elements (upper and lower level, divergent and convergent shoulders and footslopes) were identified and the variability of N_2 fixation (^{15}N-isotope dilution) by pea was determined for 60 sites (six landforms x 10 replicates). At each site, the ^{15}N-labeled pea residue was incorporated in a nearby unlabeled area in the spring of 1992.

The percent N derived from N_2 fixation (% Ndfa) by pea had a median of 57%. A difference in % Ndfa between landforms was observed with the highest % Ndfa at the divergent footslopes (69) and the lowest on the convergent shoulders (28). The total N_2 fixed (seed+residue) did not show a landform effect and had a median of 57 kg N ha^{-1}. The total N in pea residue (21-30 kg N ha^{-1}) translated into C:N ratios ranging from 37-56.

In 1992, landform differences for grain yield of spring wheat were present. Grain yield ranged from 1160 kg ha^{-1} on convergent footslopes to 1880 kg ha^{-1} on divergent shoulders. Due to the early frost, the median harvest index was low (0.24). The % Ndfr (N derived from residue) and % RUE (residue use efficiency) in the wheat grain and residue suggested that almost none of the pea residue-N had become available for wheat. The main reasons for the low N availability of the residue were: 1) incorporation of the pea residue at time of seeding (potential net N-mineralization of the residue in the fall and spring was excluded), and 2) the below average temperatures and precipitation in 1992 which would have reduced soil microbial activity and therefore net N-mineralization.

Introduction

Legumes are becoming increasingly important as a component of crop rotation management systems in temperate regions of the world. An increased interest in sustainable agriculture has drawn attention to legumes because N_2 fixation provides an inexpensive form of available N which may also extend benefits to non-legume companion crops and succeeding crops through N-rich plant residues (Herridge, 1982).

Farmers utilizing legumes in crop rotations would like to know how much N_2 is fixed and how much residue-N can be recovered by subsequent crops. It has been suggested that there are no valid estimates of N_2 fixed by legumes in a commercial agriculture setting (Herridge and Bergersen, 1988). Likewise, there is a lack of information on quantities of N contributed from legume residue to subsequent crops (Muller and Sundman, 1988).

The main objectives of this study were: 1) to estimate the variability of N_2 fixation by field pea and 2) to determine the availability of pea residue-N for a subsequent wheat crop. A landscape-scale field experiment was designed to address these objectives within a gently sloping field managed with farm-scale agronomic practices.

Materials and Methods

The field site was located in the Black soil zone near Blaine Lake, Saskatchewan on land with 2-5% slopes. Soil parent materials were deposited as shallow lacustrine plains. Surface soils had a silty loam texture, a slightly alkaline pH, and were non-saline.

In 1991, a 10 m square grid design consisting of 169 sampling points was imposed upon the surface of a representative portion of the landscape. Six landform elements were identified and include: 1) upper-level (UL), 2) divergent shoulder (DSH), 3) convergent shoulder (CSH), 4) divergent footslope (DFS), 5) convergent footslope (CFS), and 6) lower-level (LL). Ten replicates of each landform were randomly selected (60 sites).

The study area was seeded to field pea (*Pisum sativum* L.) in the spring of 1991. At each of the 60 sites, N fertilizer (10 kg ha^{-1} of 10 atom % ^{15}N excess) was applied to $1m^2$ plots after seeding to estimate N_2 fixation by pea (^{15}N enrichment isotope dilution). Volunteer mustard (*Brassica juncea* L.) grown with the pea crop was used as the reference crop. Separate $1m^2$ plots were established at each of the 60 sites to measure yield. At physiological maturity, pea plants from the yield plots were harvested, dried, threshed, and weighed. The ^{15}N-labeled peas and reference plants from ^{15}N enrichment plots were harvested, dried, and manually separated into grain and residue components. Peas from the ^{15}N enriched plots were analyzed for total N by micro-Kjeldahl methods (Bremner and Mulvaney, 1982), total C (C-N analyzer at 1000°C), and atom % ^{15}N (Bremer and Van Kessel, 1990). The ^{15}N-labeled residue material was ground (<2 mm) in a Wiley mill.

In early June 1992, the field was seeded to spring wheat (*Triticum aestivum* L.). Open-end cylindrical microplots (25.0 cm diameter by 33.0 cm length) were then hydraulically pressed into the soil in an unlabeled area close to each of the original 60 sites. The ^{15}N-labeled pea residue was incorporated at a rate equivalent to 1991 residue yields to estimate the amount of pea residue-N available to the 1992 wheat crop. As in 1991, separate $1m^2$ yield plots were established at each of the 60 sites. At physiological maturity, wheat plots were harvested and analyzed as described above for pea.

A meteorological station was installed in the center of the grid to measure average daily air temperature (thermistors) and daily precipitation (tipping bucket rain gauge).

The data were summarized utilizing non-parametric statistics because as with most landscape-scale studies, population parameters are unknown and non-normal distributions exist for some variables. Assumptions inherent to the use of parametric statistics include normality, randomness, equal variance, and independence of observations. If either of the first three assumptions is invalid, any inferences or conclusions drawn from such tests are based only on approximate evidence (Siegel and Castellan, 1988). Many soil properties and landscape analysis data sets have unknown parameters and do not have a normal distribution (McIntyre and Tanner, 1959; Pennock et al., 1992).

Skewness provides information on the nature of the population distribution. Generally, if skewness is less than ± 1.0, a normal distribution is present. The interquartile range (75th minus the 25th percentile) indicates the spread of values about the median. An index of variation (interquartile range/median x 100) is included as a measure of the relative amount of variation for populations with different medians.

Data was collected based on a landform element sampling design. The Kruskal-Wallis one way analysis of variance by ranks is a test designed to determine whether differences exist between the median values of groups (Siegel and Castellan, 1988). The significance level suggested for landscape studies is $\alpha=0.20$ (Van Kessel et al., 1993). If a significant difference was observed, a multiple comparison method was used to determine which groups were different. The multiple comparison is an approximate test and may not detect differences if the p value is close to α. If $p>0.20$, the variable was considered to be randomly distributed. Variables were separated on the basis of landform pattern and would not be responding to the same underlying controls if placed in different categories.

Once variables were grouped with respect to landform effect, a Spearman rank-order correlation could be computed to measure association between variables. The Spearman correlation is based on the ranking of data in ordered series (Siegel and Castellan, 1988).

Results

The total precipitation at the study site was 50.9 cm in 1991 and 24.8 cm in 1992. In 1991 most of the precipitation occurred in June while almost all precipitation in 1992 was recorded during the last three weeks in July. During 1991 minimum mean daily air temperatures were between 12-14°C (6 days) while maximum values between 17-21°C were recorded on 31 days. In 1992 the mean daily air temperatures dropped to 5-10°C for several days in June and reached a maximum of 17-19°C only eight times (Figure 1).

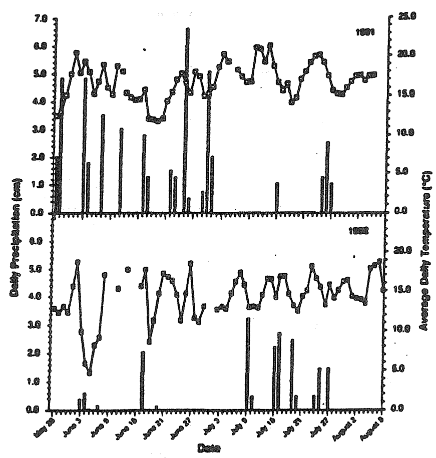

Fig. 1. Daily precipitation (vertical bars) and mean daily temperature for 1991 and 1992.

The % Ndfa (^{15}N enrichment isotope dilution) data indicate that the median rate of N_2 fixed by pea was 57% which translated into 57 kg ha^{-1} of Ndfa in total above-ground plant parts. Both % Ndfa and total Ndfa displayed high variability (index of variation) (Table 1). The % Ndfa was highest in DFS positions and lowest in CSH landforms (Table 2) while total Ndfa was randomly distributed (Table 1).

Table 1. Descriptive statistics for field pea for the 1991 growing season.

	Units	N (#)	Median	Inter-quartile range	Index of variation (%)	Skewness	Landform effect$^{\Delta}$
Grain yield	kg ha^{-1}	60	2745	890	32	-0.4	no
Residue yield	kg ha^{-1}	60	3010	1050	35	0.3	yes**
Residue N	kg ha^{-1}	58	26	11	42	0.2	yes*
Residue C:N	---	58	45	18	40	0.4	yes**
% Ndfa	%	53	57	35	61	-0.6	yes*
Total Ndfa	kg ha^{-1}	52	57	41	72	-0.1	no

Δ Determined with Kruskal-Wallis one way analysis of variance.
*,** Significant at $p<0.20$ and $p<0.05$ respectively.

The median grain yield of pea was 2745 kg ha^{-1} and randomly distributed (Table 1). Median residue yield was 3010 kg ha^{-1} and displayed a strong landform effect (Table 1) with yields in CSH positions being greater than UL and DFS (Table 2). The total amount of N in pea residue was 26 kg ha^{-1} with a slight landform effect while the median C:N ratio in pea residue was 45:1 with a strong landform pattern present (Table 1). Residue-N was greatest in CSH positions and lowest in UL while differences between individual landforms was not detected for residue C:N (Table 2).

Table 2. Median values in relation to landscape position for % Ndfa by pea and yield, N content, and C:N of pea residue in 1991.

Landform	% Ndfa	Residue yield ($kg\ ha^{-1}$)	Residue N ($kg\ ha^{-1}$)	Residue C:N$^{\Delta}$
Upper-level	63^{ab*}	2630^{a*}	21^{a*}	53
Divergent shoulder	49^{ab}	2995^{ab}	26^{ab}	50
Convergent shoulder	28^{a}	3690^{b}	30^{b}	56
Divergent footslope	69^{b}	2590^{a}	27^{ab}	37
Convergent footslope	60^{ab}	2710^{ab}	26^{ab}	41
Lower-level	54^{ab}	3090^{ab}	28^{ab}	41

* Medians within columns followed by same letter are not significantly different ($p<0.20$).

$^{\Delta}$ No differences detected between landforms with multiple comparisons test.

The relatively low median yield of wheat (1470 $kg\ ha^{-1}$) in comparison to residue yield (5015 $kg\ ha^{-1}$) is reflected in the low harvest index (0.24). All three of these variables displayed a landform pattern (Table 3). Grain yield was greater in shoulder positions (DSH and CSH) than in footslopes (DFS and CFS). Conversely, residue yield was highest in the CFS and lowest in DSH landforms. The harvest index was highest in the two shoulder positions and lowest in the CFS positions (Table 4).

The calculation of % Ndfr, total Ndfr, and % RUE is based upon the following equation: % Ndfr=(atom % ^{15}N excess in wheat/atom % ^{15}N excess in pea residue) x 100. All measurements derived from this equation are highly skewed and highly variable (index of variation) (Table 3). The median % Ndfr in grain (0.31%) and residue (0.07%) translate into a value of 0.13 $kg\ ha^{-1}$ for total Ndfr in the above-ground plant parts of wheat. The efficiency of pea residue as an N source (RUE) is 0.49% (Table 3). The only measure of pea residue N availability for wheat to display a landform pattern was total Ndfr in which CFS positions were greater than UL positions (Table 4).

Table 3. Descriptive statistics for spring wheat for the 1992 growing season.

	Units	N (#)	Median	Inter-quartile range	Index of variation (%)	Skewness	Landform effect$^{\Delta\Delta}$
Grain yield	$kg\ ha^{-1}$	60	1470	520	35	-0.4	yes**
Residue yield	$kg\ ha^{-1}$	60	5015	1720	34	1.0	yes*
Harvest index	---	60	0.24	0.10	42	-0.5	yes**
% Ndfr-grain	%	60	0.31	0.54	174	2.0	no
% Ndfr-residue	%	59	0.07	0.51	729	2.7	no
Total Ndfr$^{\Delta}$	$kg\ ha^{-1}$	57	0.13	0.23	177	1.5	yes*
RUE$^{\Delta}$	%	57	0.49	0.70	143	2.8	no

$^{\Delta}$ Measurement includes both grain and residue.

$^{\Delta\Delta}$ Determined with Kruskal-Wallis one way analysis of variance.

*,** Significant at $p<0.20$ and $p<0.05$ respectively.

Table 4. Median values in relation to landscape position for total Ndfr (N derived from residue) and grain yield, residue yield, and harvest index of wheat in 1992.

Landform	Total Ndfr ($kg\ ha^{-1}$)	Grain yield ($kg\ ha^{-1}$)	Residue yield ($kg\ ha^{-1}$)	Harvest index
Upper-level	0.07^{a*}	1465^{ab*}	4785^{ab*}	0.25^{abc*}
Divergent shoulder	0.13^{ab}	1880^{b}	4000^{a}	0.30^{c}
Convergent shoulder	0.20^{ab}	1800^{b}	5000^{ab}	0.27^{bc}
Divergent footslope	0.13^{ab}	1240^{a}	4925^{ab}	0.22^{ab}
Convergent footslope	0.28^{b}	1160^{a}	5815^{b}	0.15^{a}
Lower-level	0.18^{ab}	1405^{ab}	4930^{ab}	0.22^{abc}

* Medians within columns followed by same letter are not significantly different ($p<0.20$).

Discussion

The climatic conditions in both years were not typical of long term weather data. Temperatures in 1991 were average to above-average and precipitation during the growing season was twice the long-term average. Temperatures in 1992 were cooler than normal and precipitation in spring was below normal (Saskatchewan Agriculture and Food, 1989; Saskatchewan Research Council, 1991 and 1992).

The median % Ndfa for pea (57) falls in the mid-range of rates reported from small-plot dryland studies in Saskatchewan but was highly variable between landforms (69 at DFS and 28 at CSH). The median is lower than 74-87% Ndfa in the Gray soil zone (Cowell et al., 1989), similar to the 52-56% average across five soil zones (Bremer et al., 1988), but higher than 27-38% in the Black soil zone (Cowell et al., 1989). Small research plots represent potential N_2 fixation under optimal conditions (LaRue and Patterson, 1981).

The yield of pea was high with residue comprising over half of the biomass. The median grain yield of pea (2745 $kg\ ha^{-1}$) was nearly twice the 1971-89 provincial average of 1610 $kg\ ha^{-1}$ (Saskatchewan Agriculture and Food, 1989) with high/low yields randomly distributed across topographic positions. Podfill occurred when high air temperatures and low precipitation (Figure 1) may have reduced differences in grain yield.

The grain yield of wheat (1470 $kg\ ha^{-1}$) was well below the 1980-89 crop district average of 1905 $kg\ ha^{-1}$ (Saskatchewan Agriculture and Food, 1989). Grain yield and harvest index were affected by growing conditions and early frost. Harvest index and grain yield were poor in low-lying footslopes where frost would have had a stronger effect.

Although a median rate of 26 $kg\ ha^{-1}$ of pea residue-N was incorporated almost none became available to wheat in 1992. Less than 0.5% of the N in wheat was mineralized from pea residue and the % RUE was nearly zero. A similar study in the Dark Brown soil zone of Saskatchewan reported 7% Ndfr by wheat from lentil residue (Bremer and Van Kessel, 1992). The effect of preceding legume crop residue on subsequent cereal crops may be reduced when lower yielding conditions (e.g., 1992) occur for the succeeding crop (Wright , 1990). It should be noted that we did not measure N accumulated from below-ground pea material. Losses of N compounds from legume roots are a source of N for a succeeding crop (Sawatzky and Soper, 1991). Since pea residue N availability was so low, correlation analysis with Ndfr was not biologically significant and is not shown.

High C:N ratios and drying of plant material may have affected availability of pea residue-N. Legume residue with a C:N of 30:1 has been reported to be a critical level for N immobilization (Fox et al., 1990). Drying of pea tissue at 50-60°C for laboratory analysis may have slowed decomposition to a small degree (Muller and Sundman, 1988).

There were conditions unique to this experiment that help to explain our results since similar C:N ratios and oven-drying of material are common concerns to such studies.

Limitations due to farm-scale field operations prevented pea residue from being incorporated until late spring. Potential net N-mineralization in the fall and early spring was thus not accounted for. Secondly, low temperatures and lack of precipitation created sub-optimal conditions for soil microbial activity and therefore net N-mineralization.

Acknowledgements

Financial support was provided by the Saskatchewan ADF.

References

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., and C. van Kessel. 1990. Appraisal of the nitrogen-15 natural abundance method for quantifying dinitrogen fixation. Soil Sci. Soc. Am. J. 54:404-411.

Bremer, E., and C. van Kessel. 1992. Plant-available nitrogen from lentil and wheat residues during a subsequent growing season. Soil Sci. Soc. Am. J. 56:1155-1160.

Bremner, J.M., and C.S. Mulvaney. 1982. Nitrogen-total. p. 595-624. *In* A.L. Page et al. (ed.) Methods of Soil Analysis. Part 2-Chemical and Microbiological properties. American Society of Agronomy, Madison, Wisconsin USA.

Cowell, L.E., E. Bremer, and C. van Kessel. 1989. Yield and N_2 fixation of pea and lentil as affected by intercropping and N application. Can. J. Soil Sci. 69:243-251.

Fox, R.H., R.J.K. Meyers, and I. Vallis. 1990. The nitrogen mineralization rate of legume residues in soil as influenced by their polyphenol, lignin, and nitrogen contents. Plant and Soil 129:251-259.

Herridge, D.F. 1982. Assessment of nitrogen fixation. p. 123-136. *In* J.M. Vincent (ed.) Nitrogen Fixation in Legumes. Academic Press, Toronto.

Herridge, D.F., and F.J. Bergersen. 1988. Symbiotic nitrogen fixation. p. 46-65. *In* J.R. Wilson (ed.) Advances in Nitrogen Cycling in Agricultural Ecosystems. C.A.B. International, Wallingford, UK.

LaRue, T.A., and T.G. Patterson. 1981. How much nitrogen do legumes fix? Adv. Agron. 34:15-38.

McIntyre, D.S., and C.B. Tanner. 1959. Anormally distributed soil physical measurements and nonparametric statistics. Soil Sci. 88:133-137.

Muller, M.E., and V. Sundman. 1988. The fate of nitrogen (^{15}N) released from different plant materials during decomposition under field conditions. Plant and Soil 105:133-139.

Pennock, D.J., C. van Kessel, R.E. Farrell, and R.A. Sutherland. 1992. Landscape scale variations in denitrification. Soil Sci. Soc. Am. J. 56:770-776.

Saskatchewan Agriculture and Food. 1990. Agricultural Statistics-1989. Saskatchewan Agriculture and Food, Regina, Saskatchewan.

Saskatchewan Research Council. 1991. Saskatoon climate reference station-monthly weather summaries.

Saskatchewan Research Council. 1992. Saskatoon climate reference station-monthly weather summaries.

Sawatzky, N., and R.J. Soper. 1991. A quantitative measurement of the nitrogen loss from the root system of field peas (*Pisum arvense* L.) grown in the soil. Soil Biol. Biochem. 23:255-259.

Siegel, S., and N.J. Castellan Jr. 1988. Nonparametric Statistics for the Behavioral Sciences. McGraw-Hill Book Company, Toronto.

Van Kessel, C., D.J. Pennock, and R.E. Farrell. 1993. Seasonal variations in denitrification and N_2O evolution at the landscape-scale. Soil Sci. Soc. Am. J. (in press).

Wright, A.T. 1990. Quality effects of pulses on subsequent cereal crops in the northern prairies. Can. J. Plant Sci. 70:1013-1021.