A Landscape-scale Assessment of the Nitrogen and Non-Nitrogen Benefits of Pea in A Crop Rotation

C. Stevenson and C. van Kessel. Dept. of Soil Science, University of Saskatchewan

ABSTRACT

The inclusion of a pulse crop in a rotation could influence the seed yield of a succeeding cereal crop in different slope positions of a field. A landscape-scale study was established in 1993 to examine the N contribution, and the N and non-N rotation benefits, of pea to wheat across a hummocky terrain. Wheat seed yield in the second phase (1994) of the pea-wheat and wheat-wheat rotations was reduced by about 20% in the depressions as compared to the shoulders and footslopes. Soil N availability throughout the growing season was responsible for the landform effect on wheat seed yield in the pea-wheat rotation. The N from pea residue, accumulated by the subsequent wheat crop, met about 5% of its requirements. This response that did not vary across the landscape. Spatial patterns that were detected for N_2 fixation apparently did not relate to the rate of net N mineralization and, in particular, the greater soil N availability in the depressions of the pea-wheat rotation. In the wheat-wheat rotation, grassy weed infestation in the depressions was the most important landscape-scale control on seed yield. The rotation effect of pea on the succeeding wheat crop apparently shifted the landscape-scale control from a non-N to an N related factor.

INTRODUCTION

The most recognized benefit of a pulse crop to a succeeding cereal is the improvement in yield. For example, seed yield of barley ***(Hordeum vulgare*** L.) and wheat ***(Triticum aestivum*** L.) following pea ***(Pisum sativum*** L.) increased by > **20%** compared to the seed yield of a cereal crop following a cereal (Wright, 1990; Evans et al., 1991; Smiley et al., 1994). Factors responsible for the rotation benefit are those affecting soil N availability (N benefit; e.g., N mineralized from legume residue) and those that are non-N related (non-N benefit; e.g., pest problems).

Rotation studies often are conducted on uniform, level fields. However, most fields are characterized by hummocky or undulating features. In landscapes with this form of topography, water redistribution is a fundamental control of nutrient cycling, soil productivity, and crop yield (Pennock et al., 1987). Lower slope positions (e.g., footslopes) typically have the greatest soil water and nutrient content, and generally produce the highest crop yield (Halvorson and Doll, 1991; Fiez et al., 1994; Stevenson et al., 1995). The benefit of pea in a rotation is likely also variable and responsive to topography. Our objective was to assess the landscape-scale variability of N and non-N rotation benefits of pea in a crop rotation.

MATERIAL AND METHODS

A pea-wheat and wheat-wheat rotations were established on two adjacent 100 m by 100 m areas in 1993 at Birch Hills, SK. A 100 sampling point systematic grid with 10 m spacing between each point was superimposed in each rotation. Sampling points were characterized as shoulders, low-catchment footslopes, or high-catchment footslopes (depressions) (Fig. 1). Pea and wheat in 1993, and wheat in 1994, were managed with practices typical of those for the region. In particular, urea, at a rate of 45 kg N ha", was banded across both rotations prior to sowing wheat in 1994.

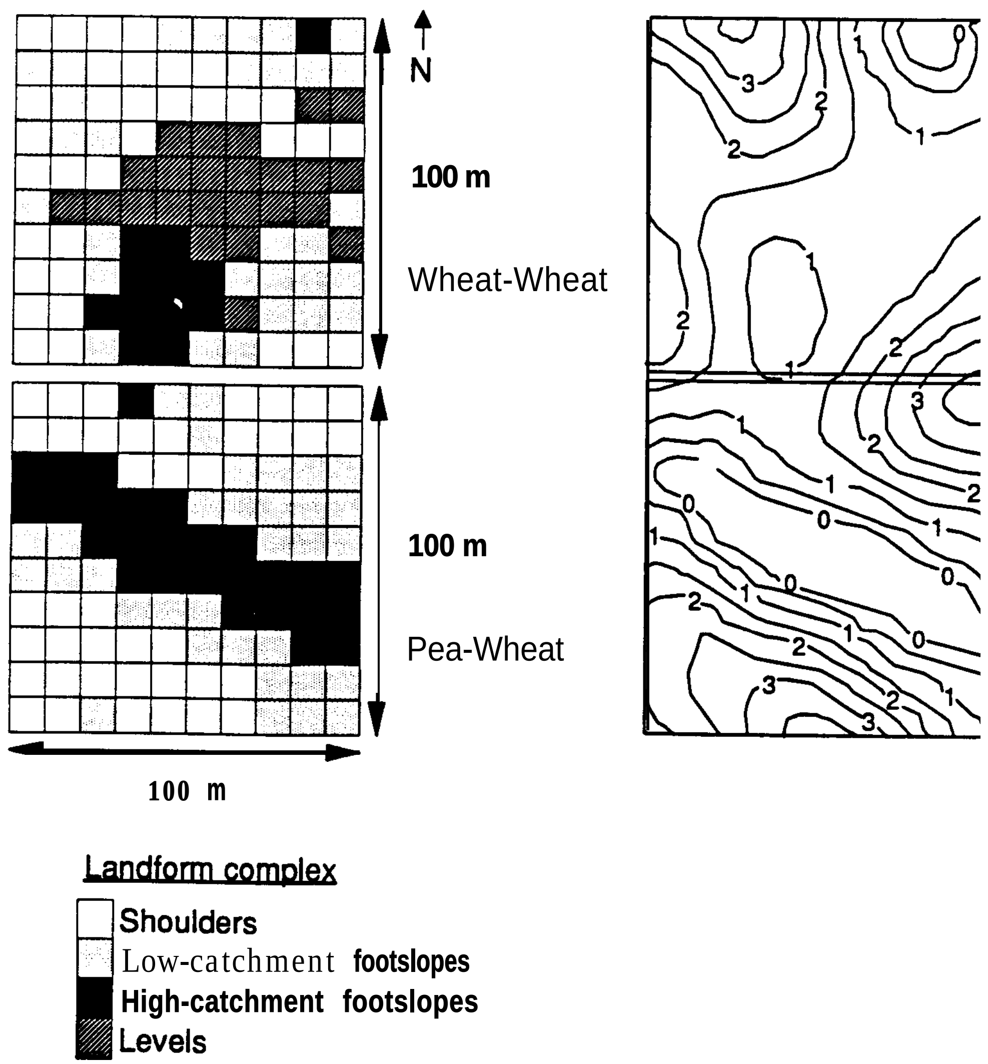

Fig. 1. A. Spatial pattern of landform complexes (shoulders are not shaded; low-catchment footslopes are dotted; high-catchment footslopes are filled) at the Birch Hills site. B. Contour of the landscape within each crop rotation. Elevations were assigned relative to the lowest point in the sampling grid which was assigned an elevation of 0.0 m.

In 1993, the A-value method was used to determine N_2 fixation by pea (Rennie and Rennie, 1983). Nitrogen-15 labelled pea residue was used to determine the recovery of N from pea residue in 1994. The percent N content and yields of pea in 1993 and wheat in 1994 were measured. In 1994, wheat residue was used to assess the A-value (an indicator of soil N supplying power) (Senartne and Hardarson, 1988). Leaf disease severity (tan spot: *Pyrenophoru tritici-repentis* [Died.]Drechs., and septoria leaf blotch: *Septoria avenue* Frank f. sp. *triticea*, Johns., *Septoria tritici* Rob. in Desm., and *Septoria nodorum* [Berk.]Berk.) was assessed at anthesis, in both rotations in 1994. Lesions on the flag and upper leaves were rated using a 0 to 11 scale. At harvest (25 Aug.), quackgrass (*Agropyron repens* L.) and wild oat (*Avena fatua* L.) infestations were assessed at all 100 sampling points in both rotations. A visual rating method (0 = none, 1= moderate, and 2 = severe yield losses) was used to assess weed infestations.

RESULTS

The percentage N that pea derived from N_2 fixation was 19% higher in the shoulders and footslopes than in the depressions (Table 1). An opposite landform effect was observed for the residue yield of pea. As a result, 13 less kg N ha^{-1} were fixed by pea growing in the shoulders as compared to footslopes and depressions. If the N contribution of legume residue to the subsequent crop is related to N_2 fixation, we would expect it to be greatest in the lower slope positions.

Table 1. Averages for pea residue N_2 fixation and yield among three landform complexes at, Birch Hills, Saskatchewan.

Landform complexes	*n*	N_2 fixation		Yield
		%	kg ha^{-1}	kg ha^{-1}
Shoulders	40	84	64	3929
Footslopes	33	80	75	4427
Depressions	27	63	79	5459
SD		16	33	1621

Six percent of the N (7 of the 130 kg ha^{-1}) accumulated by wheat in the pea-wheat rotation was derived from pea residue. This proportion did not vary among landform complexes (Table 2). Also, the recovery of pea residue N in the subsequent wheat crop was small relative to the amount that was returned to the soil, and insensitive to the effect of landform complex (Table 2). As a result, the 63% increase in N return from pea residue in the footslopes and depressions in 1993, and the 38% greater demand for N by the succeeding wheat crop in the depressions were not related to the N recovery from pea residue. Others have found that most of the N from pulse crop residues is incorporated into the soil organic matter in a more recalcitrant form, thus being relatively unavailable to succeeding crop (Bremer and Van Kessel, 1992; Jensen, 1994). Six of the 7 kg N ha" derived from pea residue was directly attributable to the N_2-fixing activity of pea. However, the additional N contribution of N_2 fixation in the footslopes and depressions did not correspond to the actual N contribution from pea residue in following year.

Table 2. Averages for the N yield pea residue returned to soil in 1993, and the recovery of N from pea residue and N accumulation in the subsequent wheat crop in 1994 among three landform complexes at Birch Hills, Saskatchewan.

			Wheat N		
Landform complexes	*n*	Pea residue N	Recovery‡	Ndfr†	Total accumulation
		kg ha“	%	kg ha^{-1}	
Shoulders	40	47	14	6	107
Footslopes	33	68	12	8	116
Depressions	27	85	11	8	154
SD		33	3	4	41

†N derived from pea residue.
‡ The recovery of N from pea residue.

In the pea-wheat rotation, wheat seed yield in the depressions was 18% lower than in footslopes and shoulders (Table 3). Similarly, a 19% reduction in seed yield occurred in the depressions of the wheat-wheat rotation. The controls responsible for these landform effects differed between rotations. In the pea-wheat rotation, soil N supplying power (the A-value) was 36% higher in the depressions as compared to the other slope positions. Greater soil N supply in the depressions caused wheat to lodge, reducing the harvest index of wheat in these same areas of the pea-wheat rotation. In the wheat-wheat rotation, the overall yield was 56% lower than in the pea-wheat rotation. This yield reduction was due to 53% greater leaf disease severity in the wheat-wheat (9.2± 1.1) as compared to the pea-wheat (6.0±1.2) rotation, and the competitive effect of grassy weeds in the wheat-wheat rotation (Table 3). Therefore, wheat following wheat did not respond as much to the greater soil N supplying power (the A-value) in the footslopes and depressions as in the pea-wheat rotation. Because leaf diseases did not vary among landform complexes, the 0.8 unit increase in grassy weed infestation in the depressions was responsible for the landform effect on seed yield in the wheat-wheat rotation.

Table 3. Averages for the A-value of residue, seed yield, and harvest index of the subsequent wheat crop, and grassy weed infestation among three landform complexes and between two rotations at Birch Hills, Saskatchewan.

Rotation / landform complex	*n*	A-value	Seed yield	Harvest index	Grassy weeds
		kg ha^{-1}	kg ha^{-1}		O-2 scale
Pea-wheat					
Shoulders	40	379	2874	0.36	0
Footslopes	33	473	2657	0.32	0
Depressions	27	580	2256	0.24	0
SD		198	659	0.06	—
Wheat-wheat					
Shoulders	32	230	1685	0.29	0.6
Footslopes	32	385	1758	0.24	0.6
Depressions	12	504	1387	0.19	1.4
SD		203	548	0.06	0.7

The expected N contribution associated with the greater N_2 fixation by pea and return of N from pea residue in the footslopes and depressions did not translate to an increase in the N derived from pea residue of a subsequent wheat crop growing in those same slope positions (Tables 1 and 2). This meant that the greater soil N supplying power in the footslopes and depressions occurred through greater net mineralization of indigenous soil N, and to a certain extent unaccounted N from pea roots (Table 3). This meant that the N benefit from pea residue was not responsible for the landscape-scale control of yield in the succeeding wheat crop. Apparently, pest problems that were eliminated by including pea prior to wheat in a crop rotation made wheat more responsive to differences in soil N availability among landform complexes. The non-N related factor responsible for the yield reduction in the wheat-wheat rotation also was related to the lower seed yields in the depressions of the same rotation. Future investigations should confirm whether the effect of crop rotation on the landscape-scale controls of crop yield in producers fields varies with different cropping histories and growing conditions (Fiez et al., 1994)

Researchers and producers have become interested in the variable rate applications of N fertilizer across different management units (e.g., landform complexes) in a field; site-specific or precision farming. Our results suggest that a wheat crop following pea would require lower N fertilizer rates in the depressions to reduce the negative effect of excessive soil N supply. In the wheat-wheat rotation, the N fertilizer strategy may have considered greater N fertilizer rates in the depressions to reduce the competitive effects of grassy weeds. However, lower N fertilizer rates in the depressions also may alleviate a potentially greater competitive advantage of grassy weeds. Future variable-rate studies will have to address the complexity of decisions when N and non-N related factors affect the demand for N in different management units in a field.

ACKNOWLEDGEMENTS

Funding was provided by the Agriculture Development Fund of Saskatchewan, the Saskatchewan Pulse Crop Development Board, the Natural Sciences and Engineering Research Council of Canada and the Canadian Wheat Board.

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