Nitrogen contribution of field pea in annual cropping systems.
1. Nitrogen residual effect

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Beckie, H. J. and Brandt, S. A. 1997. **Nitrogen contribution of field pea in annual cropping systems. 1. Nitrogen residual effect.** Can. J. Plant Sci. **77**: 311–322. The nitrogen (N) residual effect of field pea (*Pisum sativum* L.) to a succeeding non-legume crop was determined in a small plot experiment at Scott, Saskatchewan in the moist Dark Brown soil climatic zone, and in a small plot and landscape experiment near Melfort, Saskatchewan in the moist Black soil climatic zone from 1993 to 1995. The N residual effect, defined as the amount of fertilizer N required for a non-legume crop grown on non-legume stubble to produce the same yield as that of the non-legume grown on field pea stubble, averaged 27 and 12 kg N ha^{-1} at Melfort and Scott, respectively, in the small plot experiment, and 28 kg N ha^{-1} in the landscape experiment. Landscape slope position and preseeding tillage did not have a significant or consistent effect on the magnitude of the N residual effect of field pea to the succeeding non-legume crop. The N residual effect, calculated using the difference (economic N rate) method, was presumably due solely to the N benefit, with no non-N benefit contribution. The non-N benefit was effectively marginalized when the crop sequence that included field pea was compared with a reference rotation that included a cereal and an oilseed crop. Based on field pea seed yields and the calculated N residual effect, the N credit (N fertilizer replacement value) of field pea to a succeeding non-legume crop in the moist Black soil climatic zone was 15 kg N ha^{-1} for every 1000 kg of seed. This is slightly higher than the current recommendation of 5 to 10 kg N ha^{-1} 1000 kg^{-1} seed. Results from the small plot experiment at Scott indicate that current N credit recommendations for field pea are appropriate for the moist Dark Brown soil climatic zone.

Key words: *Pisum sativum*, *Triticum aestivum*, *Hordeum vulgare*, *Brassica rapa*, *Linum usitatissimum*, nitrogen residual effect

Beckie, H. J. et Brandt, S. A. 1997. **Apport d'azote par le pois de grande culture à la culture suivante 1. arrière-effet d'azote**. Can. J. Plant Sci. **77**: 311–322. Nous avons mesuré l'arrière-effet de l'azote laissé par une culture de pois sec (*Pisum sativum* L.) sur une culture subséquente non légumineuse. Les emplacements expérimentaux étaient installés à Scott (Saskatchewan) dans la zone pédoclimatique semi-aride des sols bruns foncés en miniparcelles et près de Melfort dans la zone des sols noirs subhumides à la fois en miniparcelles et en parcelles de paysage pleine grandeur. L'effet azotés c.-à-d. la quantité d'engrais N requise par une non-légumineuse pour produire autant après une sole de non-légumineuse qu'après une sole de légumine (pois de grande culture) s'établissait, respectivement, à 27 et à 12 kg N ha^{-1} à Melfort et à Scott en petites parcelles et à 28 kg dans l'expérience paysagère. L'emplacement sur la pente dans le paysage et la préparation du lit de semence n'avaient pas d'effets significatifs ni réguliers sur l'importance de l'arrière-effet N du pois sur les cultures non-légumineuses suivantes. L'arrière- effet N, calculé par la méthode de la différence (taux de fumure N économiquement rentable) était vraisemblablement dû exclusivement à la présence du N résiduel. Les effets secondaires (autres que celui du N résiduel) étaient effectivement négligeables lorsqu'on comparait la séquence culturale comprenant une sole de pois avec la séquence de référence comprenant une céréale et une oléagineuse. D'après le rendement grainier du pois et l'arrière- effet calculé, la valeur de remplacement en fumure N d'une sole de pois sur la non-légumineuse suivante à Melfort était de 15 kg N ha^{-1} par 1 000 kg de poids produits. C'est légèrement plus que les 5 à 10 kg N actuellement recommandés. Les résultats obtenus à Scott dans l'expérience en miniparcelles laissent voir que les recommandations courantes relatives à la valeur de remplacement en fumure N du pois de grande culture sont correctes pour la zone pédoclimatique humide des sols bruns foncés.

Mots clés: *Pisum sativum* L. *Triticum aestivum*, *Hordeum vulgare*, *Brassica rapa*, *Linum usitatissimum,* arrière-effet N

The major energy cost and one of the main economic costs of continuous cropping systems in western Canada is nitrogen (N) fertilizer (Zentner et al. 1984; Rutherford and Gimby 1987). Inclusion of an annual legume, such as field pea, in a conservation tillage cropping system can reduce input costs, energy requirements and enhance profitability, primarily by eliminating the need for N fertilization of the pulse crop (Coxworth and Wright 1988). Thus, pulses grown in rotation under a conservation tillage system, which can increase the N supplying power of soil over time, have good potential to enhance economic and environmental sustainability of annual crop production systems. Between 1991 and 1994, field pea acreage on the prairies increased by 400% to 0.7 million ha; production reached 1.4 million t. Yields of field pea generally are the same or higher under zero tillage than conventional tillage (Lafond et al. 1992; Borstlap and Entz 1994). Greater plant emergence, seed

Abbreviations: CT, conventional tillage; **DS**, direct seeding; **HI**, harvest index; **L**, lower; **LM**, lower-mid; **N**, nitrogen; **P**, phosphorus; **U**, upper; **UM**, upper-mid weight, water use and nodulation accounted for most of the differences in yield between the two tillage systems. Therefore, the potential for field pea productivity gains on the prairies may be greatest with zero tillage, because of greater water availability for field pea growth and development, and the ability of the crop to thrive under cooler soil temperatures.

The conventional method of determining residual effects of pulses to succeeding crops involves growing a legume and a cereal (reference crop), then growing a cereal on the same land in the second year. Enhanced seed yield of the cereal crop after the grain legume versus that after a cereal frequently is observed. Wright (1990) determined that in a field pea-barley (*Hordeum vulgare* L.)-wheat (*Triticum aestivum* L.) sequence, field pea increased barley yields by 21% and wheat yields by 12% relative to a barley-barley-wheat sequence. Rowland et al. (1994) noted a 41% yield advantage of wheat following field pea compared with wheat following wheat. The authors concluded that it was not profitable to apply N fertilizer to wheat following field pea in 11 of 17 trials. Herridge (1986) noted that cereal yields following grain legumes were 50–80% higher than cereals following cereals. In a small plot and a landscape-scale study, Stevenson and van Kessel (1996b) found a 62% (980 kg ha^{-1}) increase in wheat yield after field pea compared with wheat following wheat. In both rotations, yield was lower in the high-catchment footslopes than the low-catchment footslopes and shoulders. The landform effect on yield in the field pea-wheat rotation was related to greater soil water and N content in the high-catchment footslopes. Increased grassy weed infestation in the high-catchment areas of the wheat-wheat sequence was related to lower yields in that same area. The yield benefit of field pea to wheat was 34% greater in the landscape study compared with the small plot study.

The amount of fertilizer N required for a non-legume crop grown on non-legume stubble to produce the same yield as that of the non-legume grown on legume stubble, is called the ‘N residual effect’ (Mahler and Auld 1989; McEwen et al. 1989). Grain legumes can provide a significant yield benefit to a succeeding cereal crop, equivalent to 50-100 kg N ha^{-1} (Herridge 1986; Wright 1990). The N residual effect of pulses to a succeeding non-legume crop comprises N and non-N benefits. The difference in yield of the cereal following field pea versus that after a previous cereal, may be made up primarily by N fertilizer (Rowland et al. 1994). This is termed the “N benefit” of legumes. This suggests that the yield difference is due mainly to the improved soil N status following the legume (Baldock et al. 1981). However, the yield gap often cannot be closed completely, indicating the involvement of some other factor(s) — the “non-N benefit” (Strong et al. 1986; Wright 1990).

Non-N or secondary benefits, i.e., rotational effects, are concluded when N response curves for the second-year cereal crop in cereal-cereal and pulse-cereal sequences do not converge, even at relatively high fertilizer N rates (Baldock et al. 1981). Greater uptake of soil N by crops that succeed pulses may be attributed to: the effect of legumes in breaking cereal disease and pest cycles (McEwen et al. 1989; Stevenson and van Kessel 1996a); higher residual soil water after pulse crops (Elliott et al. 1987); enhanced nutrient cycling due to faster breakdown of legume crop residues in the soil to release nutrients other than N; better and deeper root growth as a result of improved soil properties (Toogood and Lynch 1959), such as soil tilth (Moldenhauer et al. 1983); or reduction of phytotoxic and allelopathic problems associated with cereal crop residues and release of growth-promoting substances from decomposing legume residues (Ries et al. 1977). Rice (1983) showed that roots of field pea exude substances that apparently stimulate both photosynthesis and absorption of nutrients by cereal plants. Overall however, decreased incidence and severity of weeds and diseases by including pulses in rotation may constitute the primary non-N benefit (McEwen et al. 1989; Stevenson and van Kessel 1996a,b). However, there is evidence that inclusion of other broadleaf crops, such as oilseeds, in the rotation produces comparable non-N benefits to succeeding cereal crops (Campbell et al. 1990).

Previous studies have documented a relatively large N residual effect, but small direct N benefit of pulse crops to a succeeding cereal crop. The comparison of the pulse-cereal rotation to a reference cereal monoculture sequence, which usually resulted in a large non-N benefit of the pulse, and the traditional method of calculating the N residual effect, which was inaccurate when the non-N benefit was large (Lory et al. 1995), contributed to overestimation of the N residual effect. In the study reported herein, a reference rotation consisting of a non-legume broadleaf crop and a cereal crop is compared with a rotation that includes field pea, to determine if the rotations produce similar non-N benefits relative to a cereal or an oilseed crop sequence. In addition, the N residual effect is calculated using the difference (economic N rate) method that presumably excludes any non-N benefit. Because topography may influence crop productivity and the N contribution of legumes in the cropping system, the N residual effect of field pea also was quantified across the landscape. Therefore, the prime objective of this study was to determine the N residual effect of field pea to a succeeding cereal or oilseed crop in a Dark Brown (small plot experiment) and a Black (small plot and landscape experiments) Chernozemic soil, and additionally, the effect of slope position and tillage regime on the N residual effect in a Black Chernozemic soil (landscape experiment).

MATERIALS AND METHODS

Small Plot Experiment

The study was conducted at the Agriculture and Agri-Food Canada Research Farms at Scott (52.4°N, 108.8°W) and Melfort (52.8°N, 104.6°W), Saskatchewan from 1993 to 1995. The climatic conditions range from semiarid at Scott to subhumid at Melfort. The soils at each site are described in Table 1.

The 2-yr experiment, which was established in 1993 and re-established in 1994 at both sites, was arranged in a split-split-plot design with three replications. Main plot treatments in year 1 were crop type: cereal, oilseed and pulse. The cereal crop was spring wheat (cvs. Katepwa and Makwa

Table 1. Description of the plow layer (0–0.15 m) of the soils in the small plot experiment at Melfort and Scott, Saskatchewan

	Melfort[z]	Scott[z]
Organic carbon (mg g^{-1})	55	25
Sand (mg g^{-1})	160	270
Clay (mg g^{-1})	440	310
CEC (cmol kg^{-1})[y]	43	25
FC [-0.033 MPa] (m m^{-1})[y]	0.48	0.38
PWP [-1.5 MPa] (m m^{-1})[y]	0.27	0.19
pH[x]	6.0	7.4
Bulk density (Mg m^{-3})	1.2	1.3

[z]The soil at Melfort is a Melfort silty clay (Orthic Black Chernozem); the soil at Scott is an Elstow clay loam (Orthic Dark Brown Chernozem).
[y]CEC, cation exchange capacity; FC, field capacity; PWP, permanent wilting point.
[x]1:2 soil to water mixture.

Table 2. Description of the plow layer (0–0.15 m) of the Black Chernozemic soil at the upper (U) and lower (L) slope positions of the landscape sites located near Melfort, Saskatchewan

	Site 1		Site 2	
	U slope	L slope	U slope	L slope
Organic carbon (mg g^{-1})	29	47	34	55
Sand (mg g^{-1})	160	40	176	206
Clay (mg g^{-1})	460	520	394	434
FC [-0.033 MPa] (m m^{-1})	0.34	0.41	0.37	0.41
PWP [-1.5 MPa] (m m^{-1})	0.21	0.24	0.20	0.26
pH	7.2	6.6	7.0	6.7
Bulk density (Mg m^{-3})	1.2	1.2	1.2	1.2

at Melfort and Scott, respectively), the oilseed crop was polish canola (*Brassica rapa* L. ‘AC Parkland’) and the pulse crop was field pea (cvs. Express and Radley at Melfort and Scott, respectively). The crops were direct seeded into barley stubble using a hoe drill with 20-cm row spacing. Wheat was seeded at a rate of 100 kg ha^{-1}, canola at 7 kg ha^{-1} and field pea at 240 (Express) and 170 kg ha^{-1} (Radley). For the cereal and oilseed crops, fertilizer N was applied as urea at recommended rates based on soil tests. The fertilizer was mid-row banded at a depth of 7.5 to 10 cm. Field pea seed was inoculated with a commercial *Rhizobium* inoculant (liquid formulation) immediately prior to planting. Fertilizer phosphorus (P) was applied as monoammonium phosphate (12–51–0) with wheat and canola seed and as superphosphate (0–45–0) with field pea seed, at a rate of 9.6 kg P ha^{-1}.

Sub-plot treatments (8 m × 15 m) in year 2 were a cereal and an oilseed crop. The cereal crop was barley (cvs. AC Oxbow at Melfort and Brier at Scott) and the oilseed crop was flax (*Linum usitatissimum* L. ‘Norlin’ at Melfort and ‘Vimy’ at Scott). Similar to year 1, crops were direct seeded into stubble between 9 and 24 May at depths of 2.5 to 5 cm, depending on soil conditions at each site-year. Barley and flax were seeded at a rate of 90 and 45 kg ha^{-1}, respectively. Fertilizer P was applied with the seed at rates of between 7.4 and 12.2 kg P ha^{-1}, depending on crop type and soil test results.

Sub-sub-plot treatments (2 m × 15 m) in year 2 were N fertilizer rates. Urea was mid-row banded at rates such that available soil N, measured the previous fall, plus fertilizer N equalled 75, 100 and 125% of total crop N requirements, based on provincial fertilizer recommendations. An unfertilized check plot was included. In years 1 and 2, weeds were controlled by glyphosate, which was applied 3 d prior to seeding, and by postemergence herbicides, which were applied in-crop. Seed was harvested at the recommended moisture content from a 10-m^2 area using a plot combine that had a 1.25-m cutting width and was equipped with a distance meter, and the samples were weighed.

Landscape Experiment

Two landscape sites were located near Melfort, Saskatchewan. The landscape site established in 1993 (“site 1”) was located at 52.8°N, 104.6°W, whereas the second landscape site established in 1994 (“site 2”) was located at 53.0°N, 104.5°W. Both sites had similar topographic and soil properties and covered an area of approximately 3 ha each. Orthic Black Chernozemic soils (Melfort clay) occurred across the landscape at both sites. A detailed description of the soils at the sites, at the upper (U) and lower (L) slope positions, are given in Table 2.

The experiment was arranged in a split-split-block design with three replications. Each replicate and plot covered the full length of the slope with the strip-plot (block) factor, i.e., slope position, running perpendicular to the slope. The sites were surveyed for elevation. Based on the resulting elevation contour map, the landscape was divided into 4 slope positions: (1) U; (2) upper-mid (UM); (3) lower-mid (LM); and (4) L (Fig. 1). The simple landscape had down-slope variation in elevation, but little across-slope variation. The topographic relief ranged from 8 to 10 m; the slope at both sites was approximately 5%, with site 1 having a south aspect and site 2 a west aspect. Main plot (16-m wide) treatments were two tillage regimes: 1) conventional tillage (CT) and 2) direct seeding (DS) into untilled stubble. Field pea and flax (sub-plot treatments) were grown in year 1 on canola (site 1) and flax stubble (site 2). Sub-sub plot (2-m wide) treatments in the wheat crop in year 2 were four N fertilizer rates.

YEAR 1. Norlin flax was seeded at a rate of 56 kg ha^{-1} and Express field pea at 240 kg ha^{-1} at site 1 on 21 May 1993 and at site 2 on 6 May 1994. The crops were seeded using a hoe drill with 20-cm row spacing in 1993, whereas in 1994 the crops were seeded using an air drill with 23-cm row spacing. Field pea was inoculated immediately prior to seeding. In flax plots, fertilizer N was banded at 7.5-cm depth prior to seeding in 1993 and was sidebanded in 1994. Fertilizer N was applied at the recommended rate of 78 kg N ha^{-1} at site 1 in 1993 and 90 kg N ha^{-1} at site 2 in 1994. Fertilizer P was applied as superphosphate with the seed of field pea and as ammonium phosphate with flax seed, at the recommended rate of 7.4 kg P ha^{-1}. Since soil S levels were sufficiently high at both sites (≥50 kg ha^{-1} from 0 to 0.6-m depth), no fertilizer S was applied. CT plots were tilled once in the spring and once in the fall using a field cultivator with mounted harrows. Three days prior to seeding, the DS plots were sprayed with glyphosate herbicide as a burnoff treat-

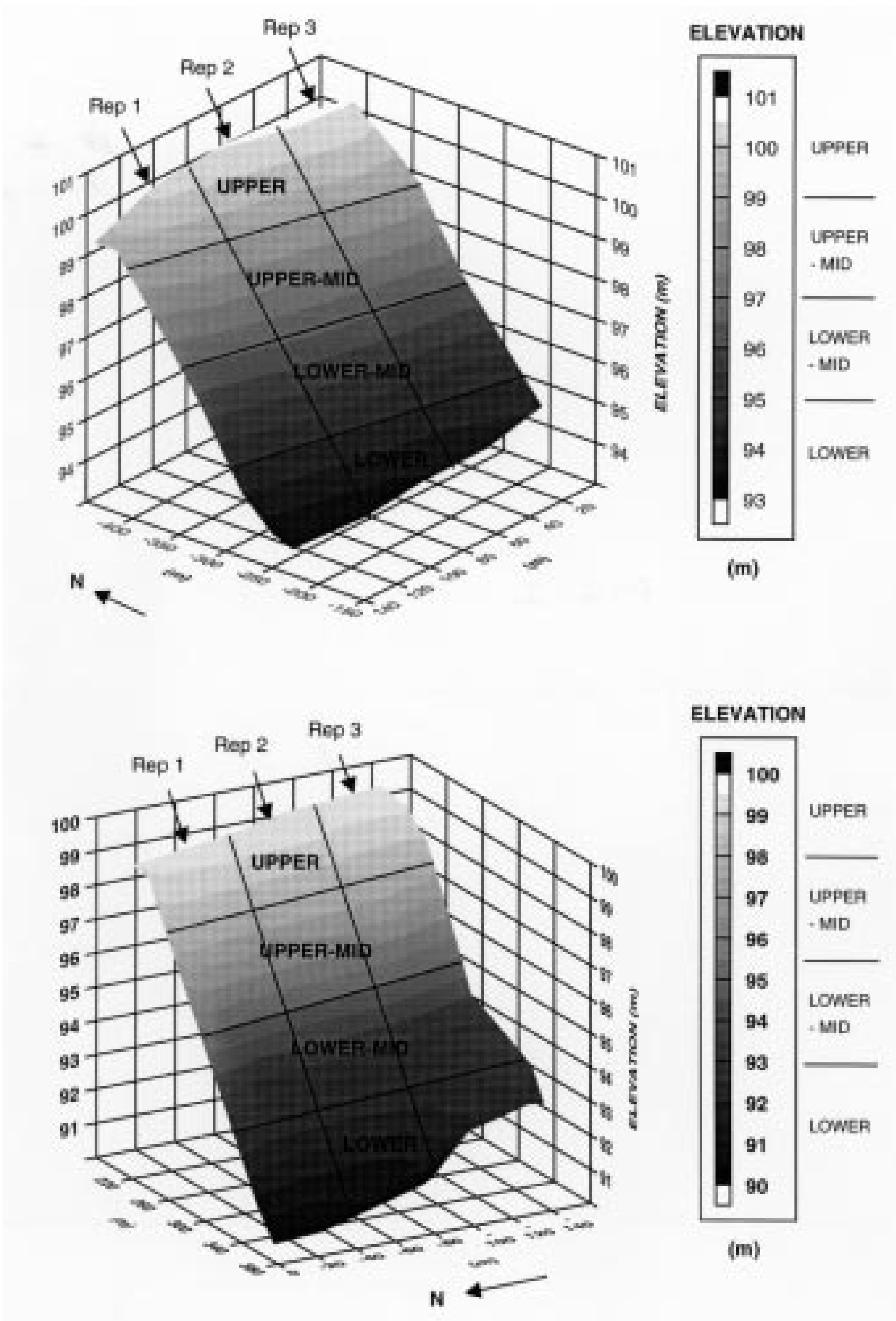

Fig. 1. Three-dimensional elevation contour map of landscape site 1 (top) and site 2 (bottom), located near Melfort, Saskatchewan.

ment. A tank mixture of sethoxydim and MCPA (sodium salt formulation) was used for in-crop weed control for field pea and flax.

At crop maturity, seed yield was determined by harvesting three 10-m^2 areas from each plot within slope position, using a small plot combine. Total aboveground biomass was hand-harvested from four 1-m^2 areas per plot within slope position and dried. The remaining area was swathed and combined using field-scale equipment. Seed and biomass samples were weighed.

YEAR 2. Katepwa wheat was seeded at a rate of 100 kg ha^{-1} at site 1 on 27 May 1994 and at site 2 on 23 May 1995. The crop was seeded using a hoe drill with 20-cm row spacing. Urea-N was mid-row banded at rates of 0, 50, 100 and 150 kg N ha^{-1}. Fertilizer P was applied as superphosphate with the seed at the recommended rate of 9.6 kg P ha^{-1} in 1994 and 14.8 kg P ha^{-1} in 1995. CT plots were tilled in the spring prior to seeding using a field cultivator with mounted harrows. Three days before seeding, the DS plots were sprayed with glyphosate herbicide as a burnoff treatment. Fenoxaprop-p-ethyl and bromoxynil/MCPA (1:1) were used for in-crop weed control. Seed yield was determined by harvesting two 10-m^2 areas from each plot within slope posi-

Table 3. May to August precipitation and mean temperatures at the Agriculture and Agri-Food Canada Research Farms at Melfort and Scott, Saskatchewan from 1993 to 1995

	Melfort				Scott			
	Precipitation		Mean temperature		Precipitation		Mean temperature	
	Amount (mm)	%[z]	Avg daily (C)	%	Amount (mm)	%	Avg daily (C)	%
1993								
May	13	31	11.0	104	22	62	11.2	105
June	119	192	13.2	85	100	149	12.7	84
July	158	237	15.2	86	82	125	14.3	83
August	46	87	15.4	94	39	89	14.9	91
Total	336	151			243	115		
Avg.			13.7	91			13.3	89
1994								
May	55	133	10.8	102	54	152	10.9	102
June	60	97	15.7	102	55	82	15.0	99
July	76	114	16.9	96	60	92	17.1	99
August	45	85	15.8	96	72	165	16.0	98
Total	236	106			241	114		
Avg.			14.8	99			14.8	99
1995								
May	6	14	10.3	97	30	84	10.2	95
June	55	89	18.1	117	38	56	16.4	108
July	29	44	16.7	95	39	59	16.8	98
August	135	254	16.0	98	89	204	14.8	90
Total	225	101			196	96		
Avg.			15.3	102			14.6	98

[z]Percent of 30-yr mean from 1961 to 1990 (Source: Environment Canada Climate Center, Winnipeg, MB).

tion using a small plot combine. Total aboveground biomass was hand-harvested from two 1-m^2 areas per plot within slope position.

Data Analyses

Analysis of variance was performed using the General Linear Model procedure of the Statistical Analysis System package (SAS Institute Inc., Cary, NC). Fisher's (protected) least significant difference (LSD) test was used to compare treatment means in year 1 of the landscape experiment. The data were tested for homogeneity of variances to determine if a transformation was required. For the landscape experiment, a probability level (alpha) of 0.10 was used, which is within the range (0.10 to 0.20) typically used for landscape studies because variances are relatively high and uncontrollable; a more rigorous level would greatly increase the probability of failing to detect treatment differences when, in fact, they did occur (Walley et al. 1996). Fertilizer response curves in year 2 were fitted to the data using curvilinear regression procedures (Freund and Littell 1986). Responses were best described by the quadratic model. Regression analysis was performed on treatment means averaged over replications as recommended by Gomez and Gomez (1984). Regression equations were statistically compared when required, by using the parameter estimates as described by Ratkowsky (1983).

The N residual effect was calculated using the difference method, defined as the difference between the economic fertilizer N rate of the non-legume crop after field pea compared with that of the non-legume after a previous non-legume crop (Lory et al. 1995). Economic N rate was defined as the rate at which the marginal fertilizer cost equalled the marginal return from increased grain yield. In the economic analyses, the price of wheat and barley were set at \$238 and \$190 t^{-1}, respectively (1995–1996 adjusted initial prices) and flax was \$314 t^{-1} (1995–1996 average price). The cost for urea fertilizer was set at \$815 t^{-1}N.

RESULTS AND DISCUSSION

Weather Conditions

Growing season precipitation at Melfort was above the long-term average in 1993, and was average in 1994 and 1995 (Table 3). However, dry soil water conditions occurred during the early part of the 1995 growing season. At Scott, growing season precipitation was slightly above average in 1993 and 1994, and was average in 1995. Monthly mean temperatures for the 1993 growing season generally were below normal, whereas temperatures in 1994 and 1995 were near normal.

Small Plot Experiment

Previous crop affected seed yield response of barley and flax to N fertilization (Fig. 2 and Table 4). Barley yields generally were lowest on cereal (wheat) stubble and flax yields were lowest on oilseed (canola) stubble, whereas both crops yielded best on pulse stubble. The effect of previous crop on crop yield, which has previously been reported (Wright 1990), was significant for both barley and flax for each site-year. The greater convergence of the response curves of barley on canola stubble and barley on field pea stubble compared with the curves of barley on wheat stubble and barley on field pea stubble (Fig. 2), indicates a larger

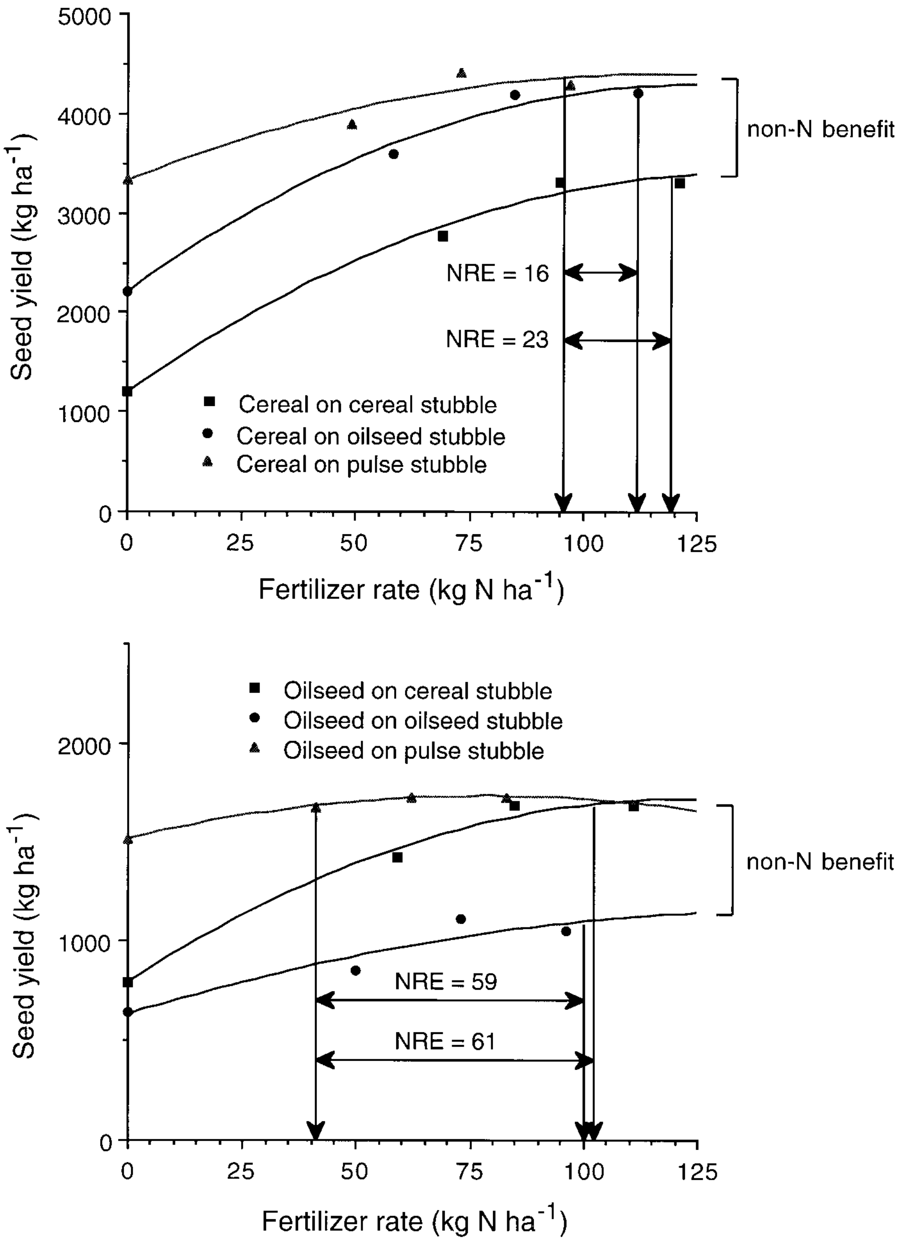

Fig. 2. Seed yield response of barley (top) and flax (bottom), grown on wheat, canola and field pea stubble, to N fertilization in the small plot experiment at Melfort, Saskatchewan in 1994, with depiction of N residual effect (NRE) calculated from economic N rates and non-N benefit. See Table 4 for parameter estimates of the equations for the regression curves for this site-year and the others.

non-N benefit of field pea to the succeeding barley crop when compared with the mono-cereal reference sequence than the oilseed-cereal reference sequence. The response curve of flax on wheat stubble converged with the curve of flax on pulse stubble as N fertilizer rates increased, whereas the curves of flax on canola stubble and flax on pulse stubble did not. The stubble × fertilizer interaction was significant only for flax yields at Melfort in 1994 and 1995; for other site-years, no differences were detected in the yield response of barley or flax to N fertilization when grown on different stubble. Neither the stubble × fertilizer × year interaction nor the stubble × fertilizer × site interaction was significant.

The economic N fertilizer rates, for barley and flax grown on cereal, oilseed and pulse stubble, were calculated from the equations of the response curves and the magnitude of the N residual effect were determined (Table 4). The N residual effect tended to be greater at Melfort than at Scott, greater in 1995 than in 1994 and greater for flax compared with barley sequences. The N residual effect averaged 27 kg N ha^{-1} at Melfort and 12 kg N ha^{-1} at Scott. Greater average amount of field pea stover remaining after harvest at Melfort (3.3 t ha^{-1}) than at Scott (2.7 t ha^{-1}) may at least partly explain site differences. Drier soil water conditions in the spring of 1995 likely retarded field pea residue decomposition and subsequent N availability. Based on field pea seed yields in year 1 and the calculated N residual effect, the N credit (N fertilizer replacement value) of field pea to a succeeding non-legume crop was 13 kg N ha^{-1} for every

Table 4. Parameter estimates (standard errors in parentheses) of the equations for the regression curves for the yield response of barley and flax, grown on wheat, canola and field pea stubble, to N fertilization in the small plot experiment at Melfort and Scott, Saskatchewan in 1994 and 1995: calculation of economic N rate and N residual effect

Crop	Stubble	a^z		b		c		R^2	Econ. N rate (kg ha^{-1})	N res. effect (kg ha^{-1})
Melfort 1994										
Barley	Wheat	1189	(161)	32.4	(6.3)	–0.119	(0.052)	0.99	119	23
Barley	Canola	2211	(155)	33.2	(6.0)	–0.129	(0.050)	0.99	112	16
Barley	Field pea	3337	(224)	18.1	(8.7)	–0.072	(0.073)	0.94	96	–
Flax	Wheat	791	(75)	15.0	(3.1)	–0.061	(0.028)	0.99	102	61
Flax	Canola	628	(127)	7.1	(5.3)	–0.023	(0.047)	0.90	100	59
Flax	Field pea	1520	(19)	5.4	(0.8)	–0.034	(0.007)	0.96	41	–
Melfort 1995										
Barley	Wheat	3141	(106)	16.6	(4.3)	–0.053	(0.037)	0.99	116	7
Barley	Canola	3658	(46)	12.8	(2.2)	–0.033	(0.022)	0.99	130	21
Barley	Field pea	3939	(50)	12.6	(2.6)	–0.038	(0.029)	0.99	109	–
Flax	Wheat	1165	(49)	6.8	(2.2)	–0.044	(0.022)	0.95	48	13
Flax	Canola	892	(95)	12.1	(5.2)	–0.092	(0.061)	0.92	52	17
Flax	Field pea	1280	(12)	4.5	(0.7)	–0.027	(0.009)	0.99	35	–
Scott 1994										
Barley	Wheat	2323	(159)	13.3	(7.2)	–0.050	(0.068)	0.94	90	19
Barley	Canola	3265	(100)	20.5	(4.8)	–0.117	(0.047)	0.98	70	0
Barley	Field pea	3579	(58)	14.8	(3.6)	–0.074	(0.044)	0.99	71	–
Flax	Wheat	897	(4)	6.3	(0.2)	–0.040	(0.003)	0.99	47	23
Flax	Canola	1334	(70)	10.0	(4.4)	–0.101	(0.056)	0.87	37	13
Flax	Field pea	1727	(29)	8.4	(2.4)	–0.124	(0.040)	0.93	24	–
Scott 1995										
Barley	Wheat	1774	(114)	12.1	(6.9)	–0.135	(0.080)	0.76	29	8
Barley	Canola	1648	(38)	16.2	(2.8)	–0.182	(0.040)	0.98	33	12
Barley	Field pea	1914	(12)	13.1	(1.6)	–0.212	(0.036)	0.99	21	–
Flax	Wheat	509	(31)	5.5	(2.4)	–0.062	(0.036)	0.90	24	24
Flax	Canola	449	(15)	2.4	(1.5)	–0.014	(0.028)	0.94	0	0
Flax	Field pea	583	(3)	0.5	(0.7)	–0.010	(0.029)	0.67	0	–

[z]Quadratic function equation: $y = a + bx + cx^2$ where a = intercept, b = linear coefficient and c = curvilinear coefficient; y is seed yield (kg ha^{-1}) and x is fertilizer rate (kg N ha^{-1}).

1000 kg of field pea seed at Melfort, but only 4 kg N ha^{-1} per 1000 kg of seed at Scott. This compares well with current recommendations of 5 to 10 kg N ha^{-1} per 1000 kg seed yield.

Landscape Experiment

YEAR 1. Preseeding tillage had no effect on field pea and flax seed yield, aboveground biomass or harvest index (HI), except in 1994 when flax seed yield and HI were higher under DS than CT (Table 5). Slope position did not have a significant effect on seed yield of both crops in 1993 and 1994. This may have been due to the favorable amount and distribution of precipitation during the growing season of both years and to the relatively fertile U slope positions. Field pea yields in 1993 (average of 1605 kg ha^{-1}) were 14% lower than long term area-average yields on Melfort soils (1835 kg ha^{-1}), whereas yields in 1994 (2263 kg ha^{-1}) were 23% above area-average yields. Flax yields in 1993 (1608 kg ha^{-1}) were about 33% higher than area-average yields on Melfort soils (1210 kg ha^{-1}), whereas yields in 1994 were equal to area-average yields (1220 kg ha^{-1}). Growing season weather differences between 1993 and 1994 (i.e., temperature), and/or preceding crop (canola at site 1, flax at site 2) may largely explain crop seed yield differences. HI of field pea averaged 0.40 in 1993, being highest on the U slope position because equivalent seed yield was achieved with less stover produced, and 0.32 in 1994, with no differences detected among slope positions. The tillage × slope interaction was not significant for seed yield or HI.

Table 5. Mature field pea and flax seed yields and harvest indices (HI) in the landscape experiment located near Melfort, Saskatchewan

	Tillage		Slope position			
	CT[z]	DS	L	LM	UM	U
1993 (site 1)						
Seed yield (kg ha^{-1})						
Field pea	1583	1626	1525	1662	1666	1566
Flax	1619	1598	1593	1774	1558	1506
HI						
Field pea	0.39	0.40	0.37*c*	0.40*b*	0.40*ab*	0.42*a*
Flax	0.37	0.38	0.36*b*	0.40*a*	0.38*b*	0.37*b*
1994 (site 2)						
Seed yield						
Field pea	2339	2188	2199	2223	2450	2180
Flax	1024*b*	1417*a*	1186	1182	1205	1308
HI						
Field pea	0.34	0.30	0.30	0.34	0.31	0.34
Flax	0.22*b*	0.26*a*	0.23	0.23	0.24	0.25

[z]CT, conventional tillage; DS, direct seeding; L, lower; LM, lower-mid; UM, upper-mid; U, upper.
*a,b*Means within crop followed by the same letter (for significant *F*-test) are not significantly different, using Fisher's (protected) least significant difference (LSD) test ($P \leq 0.10$).

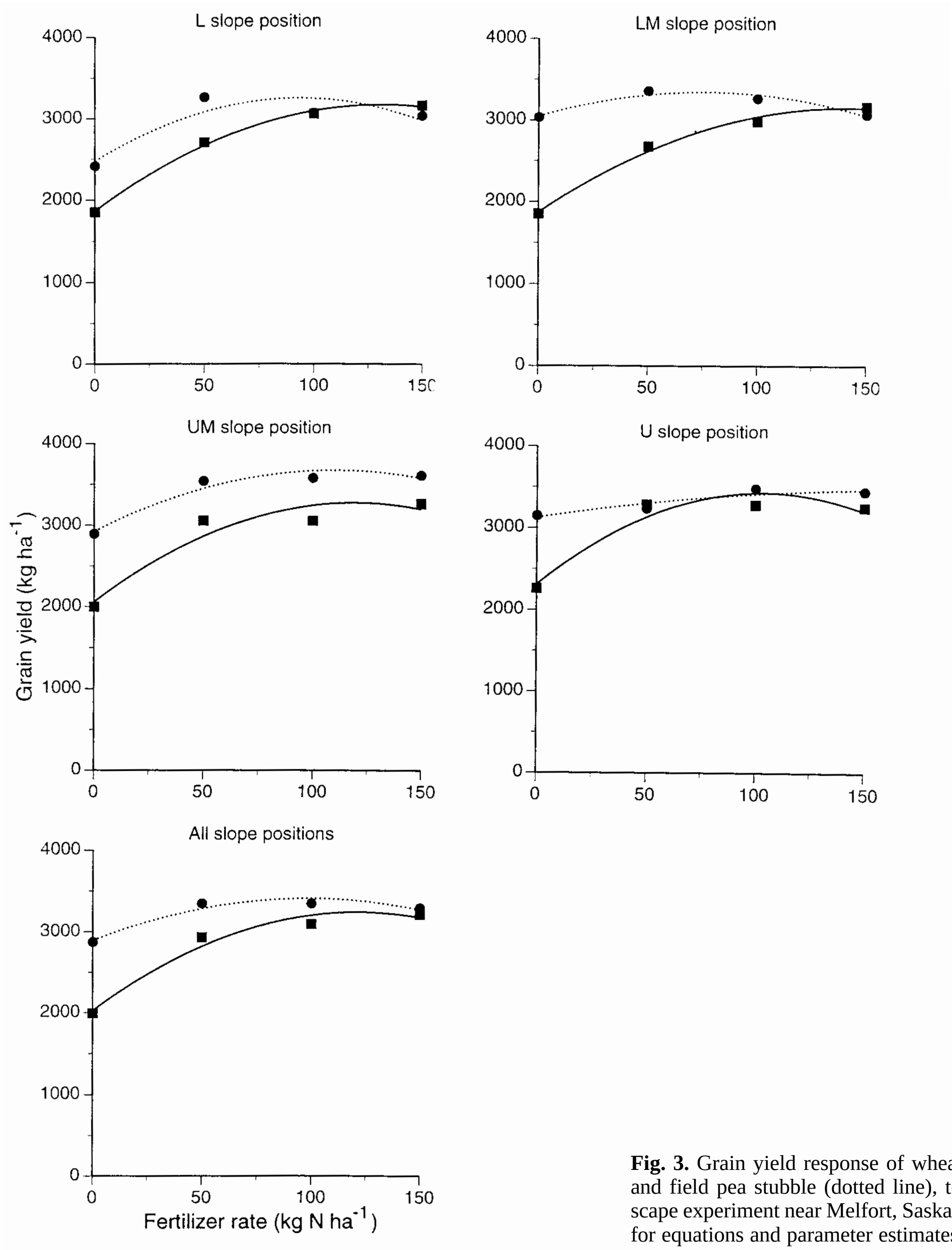

Fig. 3. Grain yield response of wheat, grown on flax (solid line) and field pea stubble (dotted line), to N fertilization in the landscape experiment near Melfort, Saskatchewan in 1994. See Table 6 for equations and parameter estimates.

YEAR 2. Wheat grain yield response to N fertilization in 1994 differed between field pea and flax stubble and among slope positions, but not between tillage system (Fig. 3). The stubble × fertilizer interaction and the slope × stubble × fertilizer interaction were significant. Parameter estimates of the equations for the regression curves are given in Table 6. The yield advantage of wheat on field pea stubble compared with wheat on flax stubble in unfertilized plots was 33% for L slope, 63% for LM slope, 42% for UM slope, and 35% for U slope positions (43% yield increase or +870 kg ha^{-1} when averaged across slope positions). When averaged across fertilizer rates, wheat on either field pea or flax stubble had lower yields on the L slope positions relative to U slope positions, possibly due to greater weed interference. For the L and LM slope positions, wheat yields on flax stubble equalled wheat yields on field pea stubble at fertilizer rates of between 100 and 150 kg N ha^{-1}. For the UM slope position, wheat yields on flax were always less than wheat yields

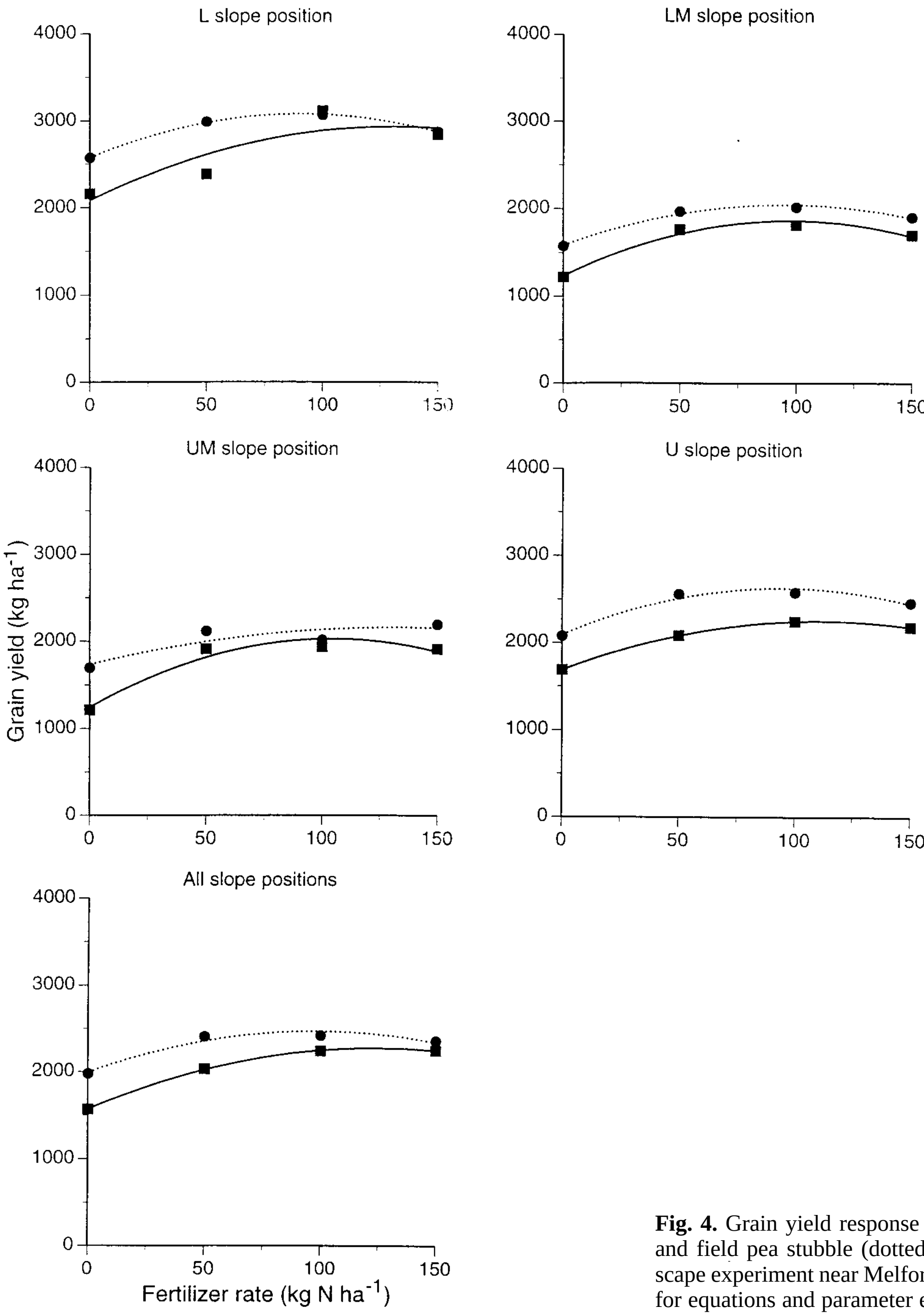

Fig. 4. Grain yield response of wheat, grown on flax (solid line) and field pea stubble (dotted line), to N fertilization in the landscape experiment near Melfort, Saskatchewan in 1995. See Table 6 for equations and parameter estimates.

on field pea stubble, even at the highest N rate. However for the U slope position, wheat yields on flax stubble equalled wheat yields on field pea stubble at between 75 and 100 kg N ha^{-1}. When averaged across slope positions, the curves tended to converge as fertilizer rates increased, indicating that the non-N or secondary benefit (rotational effect) of field pea to the succeeding wheat crop, relative to flax, was small.

In 1995, wheat grain yield on field pea stubble was 27% higher (+420 kg ha^{-1}) than wheat yield on flax stubble in unfertilized plots when averaged across slope positions (Fig. 4). The smaller yield increase on field pea versus flax stubble in 1995 than in 1994 and lower crop yields in general, likely reflected the drier spring growing conditions. In contrast to 1994, yields were highest on the L slope position, likely due to greater water availability early in the growing season. Yields were affected by fertilization, previous crop and slope position, but there were no significant treatment interactions. Similar to 1994, tillage had no significant

Table 6. Parameter estimates (standard errors in parentheses) of the equations for the regression curves for the response of wheat grain yield and harvest index (HI) to N fertilization in the landscape experiment near Melfort, Saskatchewan

	a^z		b		c (*10^1)		R^2
1994 (site 1)							
Yield (kg ha^{-1})							
L slope position							
Pea stubble	2475	(262)	16.5	(8.4)	–0.88	(0.54)	0.82
Flax stubble	1867	(56)	19.8	(1.8)	–0.75	(0.12)	0.99
LM slope position							
Pea stubble	3050	(70)	7.7	(2.2)	–0.51	(0.14)	0.93
Flax stubble	1872	(88)	18.1	(2.8)	–0.64	(0.18)	0.99
UM slope position							
Pea stubble	2924	(131)	13.6	(4.2)	–0.61	(0.27)	0.95
Flax stubble	2060	(277)	20.3	(8.9)	–0.85	(0.57)	0.92
U slope position							
Pea stubble	3126	(93)	4.1	(3.0)	–0.12	(0.19)	0.88
Flax stubble	2311	(217)	21.7	(7.0)	–1.05	(0.44)	0.94
All slope positions							
Pea stubble	2894	(92)	10.5	(3.0)	–0.53	(0.19)	0.94
Flax stubble	2028	(159)	20.0	(5.1)	–0.82	(0.33)	0.97
HI							
L slope position	0.26	(0.02)	0.0012	(0.0005)	–0.00006	(0.00001)	0.90
LM slope position	0.30	(0.01)	–0.0001	(0.0001)	–0.00001	(0.00001)	0.99
UM slope position	0.27	(0.01)	0.0005	(0.0004)	–0.00002	(0.00001)	0.81
U slope position	0.33	(0.01)	–0.0002	(0.0001)	0.00001	(0.00001)	0.99
All slope positions	0.29	(0.01)	0.0003	(0.0002)	–0.00002	(0.00001)	0.78
1995 (site 2)							
Yield (kg ha^{-1})							
L slope position							
Pea stubble	2574	(15)	11.0	(0.5)	–0.60	(0.03)	0.99
Flax stubble	2084	(328)	12.9	(10.5)	–0.49	(0.67)	0.80
LM slope position							
Pea stubble	1582	40)	9.8	(1.3)	–0.51	0.08)	0.99
Flax stubble	1234	(70)	13.0	(2.2)	–0.66	(0.14)	0.98
UM slope position							
Pea stubble	1735	(174)	6.4	(5.6)	–0.24	(0.36)	0.78
Flax stubble	1245	(136)	15.0	(4.4)	–0.72	(0.28)	0.95
U slope position							
Pea stubble	2091	72)	11.4	(2.3)	–0.60	(0.15)	0.97
Flax stubble	1685	(1)	10.2	(0.1)	–0.46	(0.01)	0.99
All slope positions							
Pea stubble	1996	(75)	9.7	(2.4)	–0.49	(0.16)	0.96
Flax stubble	1572	(13)	11.4	(0.4)	–0.46	(0.03)	0.99
HI							
L slope position	0.30	(0.04)	0.0003	(0.0014)	–0.00001	(0.00001)	0.11
LM slope position	0.22	(0.02)	0.0004	(0.0006)	–0.00003	(0.00001)	0.36
UM slope position	0.25	(0.01)	–0.0003	(0.0004)	0.00003	(0.00001)	0.83
U slope position	0.30	(0.01)	–0.0001	(0.0001)	0.00001	(0.00001)	0.99
All slope positions	0.28	(0.01)	–0.0001	(0.0001)	0.00001	(0.00001)	0.90

[z]Quadratic function equation: $y = a + bx + cx^2$ where a = intercept, b = linear coefficient and c = curvilinear coefficient; y is the plant variable and x is fertilizer rate (kg N ha^{-1}).

effect on yield, although yields tended to be higher in DS than CT plots (data not shown). When averaged across slope positions, the position of the response curves suggest there was a small or negligible non-N benefit of field pea to the succeeding wheat crop, even though the curves failed to intersect over the range of N rates for all slope positions. The lack of preceding crop effect on preseeding soil water, weed populations and disease incidence and severity in wheat plots in the landscape study supports this conclusion (data not shown). The non-N benefit was effectively marginalized in both years by using an oilseed-cereal reference rotation.

HI of wheat in response to N fertilization was not influenced by preceding crop or tillage treatment in 1994 and 1995 (data not shown). However, in both years, HI tended to be higher on the U and L slope positions relative to mid-slopes, although the slope effect and slope × fertilizer interaction was significant in 1995 only. Although HI declined with increasing rates of fertilizer in the LM and U slope positions in 1994 and U slope position in 1995, HI was unaffected by fertilization when averaged across slope positions (Table 6).

Based on the equations of the response curves of wheat yield on field pea and flax stubble, averaged across slope positions, the N residual effect of field pea to the succeeding wheat crop calculated by the difference method was 37 kg N ha^{-1} in 1994 and 18 kg N ha^{-1} in 1995. There was no apparent relationship between slope position and magnitude of the N residual effect. The N residual effect was lower in 1994 probably because of the drier spring soil water conditions. These values are generally lower than those reported in previous studies. Because past studies used a cereal monoculture reference rotation, the non-N benefit was relatively large. When this occurs, the traditional method overestimates the N residual effect (Lory et al. 1995). The yield response curve of wheat on field pea stubble relative to wheat on flax stubble indicates that the non-N benefit of field pea relative to flax was very minor in this study and that the benefit of field pea to the succeeding wheat crop was due overwhelmingly to the N contribution. Based on field pea seed yields in year 1 and the calculated N residual effect, the N credit of field pea to the succeeding wheat crop was 16 kg N ha^{-1} per 1000 kg of field pea seed. These results, when combined with those from the small plot experiment, suggest that fertilizer recommendations in the moist Black soil climatic zone for non-legume crops grown after field pea should be reduced by 15 kg N ha^{-1} for every 1000 kg of field pea seed produced. This recommendation is slightly higher than the current recommendation of 5 to 10 kg N ha^{-1}.

SUMMARY AND CONCLUSION

The N residual effect of field pea averaged 27 and 12 kg N ha^{-1} in the small plot experiment at Melfort, Saskatchewan in the moist Black soil climatic zone and at Scott, Saskatchewan in the moist Dark Brown soil climatic zone, respectively. In the landscape experiment located near Melfort, the N residual effect averaged 28 kg N ha^{-1}, similar to results from the small plot experiment. The difference method used to calculate the N residual effect presumably excluded any non-N contribution. There was no apparent relationship between slope position and N residual effect. However, in different landscapes, soils or climates, slope position may have a more pronounced impact on the N residual effect; if this is true, small plot results may not accurately reflect landscape-scale or field results. Convergence of the yield response curves of wheat on flax stubble with that of wheat on field pea stubble, with increasing rates of N fertilizer in the landscape experiment, indicated that the non-N or secondary benefit of field pea relative to flax was minor. Since both rotations comprised a broadleaf-cereal sequence, this benefit was effectively minimized. Slope position affected yield response of wheat to N fertilization, but no consistent trends were discerned. Based on field pea seed yields, and the calculated N residual effect, the N credit of field pea to a succeeding non-legume crop was 15 kg N ha^{-1} for every 1000 kg of pea seed in the moist Black soil climatic zone. This is slightly higher than the current recommendation of 5 to 10 kg N ha^{-1}. Results from the small plot study at Scott indicate that the current N credit given to field pea in the moist Dark Brown soil climatic zone is appropriate.

Results from this study suggest that producers should strive to alternate cereal and broadleaf crops in rotation, rather than grow cereals or oilseeds in monoculture. Previous studies have documented a relatively large N residual effect, yet small direct N benefit of pulse crops to a succeeding cereal crop. Both the comparison of the pulse-cereal rotation to a reference cereal monoculture rotation, which gave a large non-N benefit of the pulse, and the traditional method of calculating the N residual effect, which was inaccurate when the non-N benefit was large, contributed to overestimating the N residual effect. By choosing a non-legume broadleaf-cereal crop reference rotation, the non-N benefit of field pea, relative to the broadleaf crop, was very small in this study. This suggests that the benefit of the pulse crop to the succeeding crop was overwhelmingly due to the N benefit provided by the legume. Results of the landscape study suggest that annual crop production systems can be better sustained, in terms of amount of external inputs, crop productivity and profitability, by including pulse crops such as field pea in the rotation.

ACKNOWLEDGMENTS

Support of this study through funding by the Saskatchewan Pulse Crop Development Board and Agriculture and Agri-Food Canada (AAFC) is greatly appreciated. Technical assistance from Colleen Kirkham, Larry Sproule and Glenn Galloway (AAFC) and AAFC-PFRA, Melfort, is gratefully acknowledged. Appreciation is extended to the internal reviewers, Drs. S.S. Malhi and W.F. Nuttall, and to the external reviewers, for their useful suggestions and constructive comments.

Baldock, J. O., Higgs, R. L., Paulson, W. H., Jacobs, J. A. and Schrader, S. D. 1981. Legume and mineral N effects on crop yields in several crop sequences in the upper Mississippi Valley. Agron. J. **73**: 885–890.

Borstlap, S. and Entz, M. H. 1994. Zero-tillage influence on canola, field pea and wheat in a dry subhumid region: Agronomic and physiological responses. Can. J. Plant Sci. **74**: 411–420.

Campbell, C. A., Zentner, R. P., Janzen, H. H. and Bowren, K. E. 1990. Crop rotation studies on the Canadian prairies. Research Branch, Agriculture and Agri-Food Canada, Ottawa, ON. Publ. 1841/E. 133 pp.

Coxworth, E. and Wright, A. T. 1988. Energy and economic benefits of pulse crops in continuous cropping systems using zero or minimum tillage. Saskatchewan Research Council Publ. R-812-1-E-88, Saskatoon, SK.

Elliott, L. F., Papendick, R. I. and Bezdicek, D. F. 1987. Cropping practices using legumes with conservation tillage and soil benefits. Pages 81–89 *in* J. F. Power, ed. Soil Conservation Society of America, Madison, WI.

Freund, R. J. and Littell, R. C. 1986. SAS system for regression. SAS Institute Inc., Cary, NC. pp. 103–126.

Gomez, K. A. and Gomez, A. A. 1984. Pages 421–422 *in* Statistical procedures for agricultural research. 2nd ed. John Wiley & Sons, New York, NY.

Herridge, D. F. 1986. Nitrogen fixation dynamics by rain-fed grain legume crops: Potential for improvement. Proc. 13th Int. Soc. Soil Sci. Cong., Hamburg, Germany. pp. 794–804.

Lafond, G. P., Loeppky, H. and Derksen, D. A. 1992. The effects of tillage system and crop rotations on soil water conservation, seedling establishment and crop yield. Can. J. Plant Sci. **72**: 103–115.

Lory, J. A., Russelle, M. P. and Peterson, T. A. 1995. A comparison of two nitrogen credit methods: traditional vs. difference. Agron. J. **87**: 648–651.

Mahler, R. L. and Auld, D. L. 1989. Evaluation of the green

manure potential of Austrian winter peas in Northern Idaho. Agron. J. **81**: 258–264.
McEwen, J., Darby, R. J., Hewitt, M. V. and Yeoman, D. P. 1989. Effects of field beans, fallow, lupins, oats, oilseed rape, peas, ryegrass, sunflowers and wheat on nitrogen residues in the soil and on the growth of a subsequent wheat crop. J. Agric. Sci: **115**: 209–219.
Moldenhauer, W. C., Langdale, G. W., Frye, W., McCool, D. K., Papendick, R. I., Smika, D. E. and Fryear, D. W. 1983. Conservation tillage for erosion control. J. Soil Water Cons. **38**: 144–151.
Ratkowsky, D. A. 1983. Nonlinear regression modelling. Marcel Dekker, New York, NY.
Rice, E. L. 1983. Pest control with nature's chemicals. University of Oklahoma Press, Norman, OK. p. 34.
Ries, S. K., Wert, V., Sweeley, C. C. and Leavitt, R. A. 1977. Triacontanol: A new naturally occurring plant growth regulator. Science **195**: 1339–1341.
Rowland, I. C., Mason, M. G., Pritchard, I. A. and French, R. J. 1994. Effect of field peas and wheat on the yield and protein content of subsequent wheat crops grown at several rates of applied nitrogen. Aust. J. Exp. Agric. **34**: 641–646.
Rutherford, A. and Gimby, M. 1987. Farm fuel requirements. Energemo project results. Saskatchewan Research Council Rep. No. 199, Publ. R-812-6-B-87, Saskatoon, SK.
Stevenson, F. C. and van Kessel, C. 1996a. The nitrogen and non-nitrogen rotation benefits of pea to succeeding crops. Can. J. Plant Sci. **76**: 735–745.
Stevenson, F. C. and van Kessel, C. 1996b. A landscape-scale assessment of the nitrogen and non-nitrogen rotation benefits of pea in a crop rotation. Soil Sci. Soc. Am. J. **60**: 1797–1805.
Strong, W. M., Harbison, J., Nielsen, R. G. H., Hall, B. D. and Best, G. K. 1986. Nitrogen availability in a Darling Downs soil following cereal, oilseed and grain legume crops. 2. Effects of residual soil N and fertilizer N on subsequent wheat crops. Aust. J. Exp. Agric. **26**: 353–359.
Toogood, J. A. and Lynch, D. L. 1959. Effect of cropping systems and fertilizers on mean weight and diameter of aggregates of Breton plot soils. Can. J. Soil Sci. **39**: 151–156.
Walley, F. L., van Kessel, C. and Pennock, D. J. 1996. Landscape-scale variability of N mineralization in forest soils. Soil Biol. Biochem. **28**: 383–391.
Wright, A. T. 1990. Yield effect of pulses on subsequent cereal crops in the northern prairies. Can. J. Plant Sci. **70**: 1023–1032.
Zentner, R. P., Campbell, D. W., Campbell, C. A. and Reid, D. W. 1984. Energy considerations of crop rotations in southwestern Saskatchewan. Can. Agric. Eng. **26**: 25–29.