Nitrogen contribution of field pea in annual cropping systems. 2. Total nitrogen benefit

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Beckie, H. J., Brandt, S. A., Schoenau, J. J., Campbell, C. A., Henry, J. L. and Janzen, H. H. 1997. **Nitrogen contribution of field pea in annual cropping systems. 2. Total nitrogen benefit.** Can. J. Plant Sci. **77**: 323–331. The total nitrogen (N) benefit of field pea (*Pisum sativum*) to a succeeding non-legume crop was measured 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 total N benefit was calculated as the difference in net N mineralized from soil plus N in the above- and below-ground crop residue between field pea and non-legume stubble-cropped plots over the growing season. Landscape slope position did not affect the total N benefit of field pea to a succeeding wheat crop, and preseeding tillage had an inconsistent effect on the total N benefit between years. The direct N benefit of field pea aboveground residue available to the succeeding crop in the landscape experiment was a minor component of the total N benefit, which averaged 25 kg N ha^{-1}. The total N benefit was equivalent to the N residual effect, defined as the amount of fertilizer N required for a non-legume crop grown on non-legume stubble to achieve the same yield as that of the non-legume crop on field pea stubble. This confirms that the N residual effect of field pea to the succeeding non-legume crop was due to the N contribution; any non-N contribution to the N residual effect was effectively excluded.

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

Beckie, H. J., Brandt, S. A., Schoenau, J. J., Campbell, C. A., Henry, J. L. et Janzen, H. H. 1997. **Apport d'azote par le pois de grande culture à la sole suivante. 2. Gain total de N**. Can. J. Plant Sci. **77**: 323–331. Le gain total de N laissé par une culture de pois sec (*Pisum sativum*) pour une culture non-légumineuse suivante a été mesuré de 1993 à 1995. L'expérience était réalisée en petites parcelles à Scott (Saskatchewan) dans la zone semi-aride à sols brun foncé et en petites parcelles ainsi et en grandes parcelles paysagères près de Melfort, dans la zone subhumide à sols noirs. Le gain total de N correspond à la différence entre le N minéralisé par le sol plus N contenu dans les restes de cultures laissés pour la culture suivante par une sole de légumineuse, et celui laissé par une culture non-légumineuse. L'emplacement sur la pente n'avait pas d'effet sur le gain total de N dû au pois de grande culture pour la culture de blé suivante, tandis que l'effet de la préparation culturale du lit de semence variait d'un an à l'autre. Les avantages directs du N contenu dans les restes de cultures laissés en surface pour la culture suivante dans l'expérience en parcelles grandeur réelle n'était qu'un composant mineur du gain total de N, lequel se montait en moyenne à 25 kg N ha^{-1}. Le gain total de N était équivalent à l'arrière-effet de N, lequel est la quantité d'engrais N requise pour une culture non-légumineuse pour produire autant après une culture non légumineuse qu'après une sole de pois de grande culture. Nos observations confirment que l'arrière-effet N du pois de grande culture pour la non-légumineuse suivante était bien dû à l'apport complémentaire de N, ne laissant pratiquement aucun rôle aux avantages non liés à l'azote.

Mots clés: *Pisum sativum, Triticum aestivum, Hordeum vulgare, Brassica rapa, Linum usitatissumum*, gain de N total

The N residual effect of field pea, 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, was previously documented (Beckie and Brandt 1997). The N residual effect can be partitioned into direct and indirect N benefits (Senaratne and Hardarson 1988). The direct N benefit from grain legume aboveground residue remaining after harvest is generally small. Field pea will have a direct benefit on the soil N status only if the amount of N fixed is greater than the amount of N removed in the seed, i.e., the percentage of plant N derived from the atmosphere (%Ndfa) exceeds the NHI, defined as the proportion of N in the seed relative to total aboveground biomass (seed + stover) N, and provided the stover is not removed from the field. Comparisons of amount of N_2 fixed and seed N harvested, indicate final N balances ranging from –32 to +106 kg N ha^{-1} for field pea (Evans et al. 1989; Maidl et al. 1996). Field pea generally fixes about one-half or more of its N requirements (Bremer et al. 1988; Cowell et al. 1989; Androsoff et al. 1995). In

Abbreviations: **CT**, conventional tillage; **DS**, direct seeding; **L**, lower; **LM**, lower-mid; **N**, nitrogen; **NHI**, nitrogen harvest index; **U**, upper; **UM**, upper-mid landscape studies, Androsoff et al. (1995) and Stevenson et al. (1995) concluded that N_2 fixation was controlled primarily at the micro-scale level (<3-m and 1.5-m distance, respectively) rather than at the landscape-scale level, with available soil N and water being controlling factors. Because field pea may have a high NHI, which is similar to, or higher than the %Ndfa, the contribution to the N status of soil will usually be small at best, even when stover is not removed (Senaratne and Hardarson 1988; Evans et al. 1989; Jensen 1989). A net depletion of soil N will likely occur if the stover is removed. In an attempt to increase the protein content of grain legumes by increasing the NHI (e.g., semi-dwarf versus conventionally leaved taller types), plant breeders may be reducing the potential direct N benefit of pulses to succeeding crops (Senaratne and Hardarson 1988; Armstrong et al. 1994).

The amount of N in field aboveground pea residues is small, usually less than 35 kg N ha^{-1} and not more than 25 kg ha^{-1} over the amount found in cereal residues (Wright 1990a), and thus is frequently not enough to account for the yield increase of the cereal after the pulse crop. Generally less than 15% of the total amount of N in grain legumes, at the time of peak biomass N, is in roots (Armstrong et al. 1994). However, of the residual N remaining after the seed has been harvested, about 25% is in below-ground biomass. Furthermore, a study on lupin using ^{15}N indicated that root N may be almost three-fold higher than that calculated using only N contained in recoverable root material (Peoples et al. 1995). The rhizodeposition of N, defined as root-derived N present in the soil after removal of visible roots and root fragments, was found to account for 7% of total field pea N at maturity (Jensen 1996). Thus, the direct N benefit may be underestimated because the contribution of fixed N in nodulated roots usually is excluded.

In addition to the small amount of N in pulse aboveground residue, usually no more than 25–30% of the N in mature field pea residue is made available to the next one or two crops, through decomposition and mineralization (Muller and Sundman 1988; Rees et al. 1993). Of 116 kg N ha^{-1} in aboveground field pea residue, 9 kg (8%) was used by the succeeding wheat (*Triticum aestivum* L.) crop (Stevenson and van Kessel 1996). Recovery of residue N to a succeeding non-legume crop usually is less than 5% (Jenson 1994). Of the residue N released during decomposition over a 3-yr period (59%), only 15% was recovered by three succeeding spring-sown crops. Thus the total residue N recovery was only 9%. However, pea residue N will increase the pool of soil organic N and in the long term, contribute to the supply of available N by mineralization.

Indirect or secondary N benefits include the "N-conserving or sparing effect", whereby field pea may take up less available soil N than non-legume crops since part of the plant's N requirement is met by N_2 fixation (Jensen 1989; Evans et al. 1991). Thus, postharvest levels of available soil N following grain legumes are generally higher than after cereals (Reeves et al. 1984; Maidl et al. 1996). The average amount of spared nitrate-N in the six studies cited by Herridge (1986) was 30 kg N ha^{-1}. Spared soil N and fixed N derived from the mineralization of legume residues contributed approximately equal proportions to the N benefit measured in barley following lupins compared with barley following wheat (Chalk et al. 1993). Greater uptake of soil N (higher N yield) by crops grown on legume stubble also may be due to increased soil N mineralization (Birch and Dougall 1967). Generally, plant residues with an N content of less than 1.2–1.3% (C:N ratio of about 30) will immobilize soil N (and fertilizer N, if present); however, if the percent N is more than 1.8–2.0 (C:N ratio of about 20), considerable mineralization usually occurs (Jenkinson 1981; Janzen and Kucey 1988). Indirect calculations of net N mineralization (wheat total N yield minus preseeding soil nitrate-N levels), suggested greater mineralization after a legume than non-legume crop (Francis et al. 1994). In a laboratory study, Jensen (1996) found greater mineralization of N in soils collected from field pea than barley (*Hordeum vulgare* L.) stubble. This was attributed to differences in net mineralization of N from roots and rhizodeposits, which was greater after field pea than barley. Rhizodeposits and roots contributed 35% of the N mineralized after field pea; rhizodeposits made a minor contribution relative to roots. Ultimately, the impact of legumes on seed yield and protein content of a succeeding non-legume crop depends on rainfall and temperature, which regulates the rate of soil plus residue N mineralization and thus N availability. The combination of conserved soil N and greater mineralization potential in soil containing pulse above- and below-ground residues may explain why the indirect N benefit of annual legumes to subsequent non-legume crops can be considerable, even when there apparently are only modest returns of fixed N in aboveground vegetative residues — typically defined as the direct N benefit (Doyle et al. 1988). The discrepancy between the small direct N contribution from pulse aboveground residues relative to documented yield increases of succeeding cereals indicates the greater relative importance of the indirect N benefit and non-N benefit provided by pulses in rotation (Stevenson and van Kessel 1995, 1996).

Past research has documented the direct N benefit of pulses to succeeding cereals in rotation. However, the total N benefit, and relative importance of its components – the direct and indirect N benefits — have not been quantified. Moreover, if the N residual effect of field pea (Beckie and Brandt 1997) excludes any non-N benefit (Lory et al. 1995), then it should be similar to the total N benefit. Therefore, the objectives of this study were to determine the total N benefit of field pea to a succeeding non-legume crop (1) in a small plot experiment in a Dark Brown and a Black Chernozemic soil, and (2) across the landscape in a Black Chernozemic soil, and to determine if the total N benefit was synonymous with the N residual effect.

MATERIALS AND METHODS

Small Plot Experiment

Site descriptions, experimental design and management practices have previously been detailed (Beckie and Brandt 1997). In year 2 of the experiment, aboveground plant biomass was hand-harvested at maturity (based on seed moisture content) from four 0.25-m^2 areas per plot, bulked into a composite sample and dried. Seed was harvested from a 10-m^2 area using a plot combine. Harvested seed and straw samples were digested using the standard micro-Kjeldahl method, and N was measured using the autoanalyzer (Milbury et al. 1970; Anonymous 1984; Winkleman 1994). Soil was sampled immediately prior to seeding and after harvest. A 5-cm-diameter soil core was taken in each plot and divided into 0.15-m segments to a depth of 0.3 m, and 0.3-m segments to 0.9-m (Scott) and 1.2-m depths (Melfort). Each segment of soil was air-dried and analyzed for ammonium- and nitrate-N concentration (Hamm et al. 1970; Gentry and Willis 1988; Winkleman 1994). Root biomass was sampled after harvest using a rectangular soil corer (5 × 20 cm) centered across the crop row to include the row and inter-row areas. Two cores were taken per plot and divided into 0.10-m segments to a depth of 0.3 m. Roots were washed from soil using the hydropneumatic elutriation system (Smucker et al. 1982). Root dry matter was weighed, and analyzed for N content using the same procedure as for aboveground biomass. Predetermined bulk densities were used to express results in kg ha^{-1}. Apparent N mineralization over the growing season was estimated as the sum of aboveground biomass N yield, root N yield and soil residual nitrate-N at harvest, minus preseeding soil nitrate-N and fertilizer N. The total N benefit of field pea to the succeeding non-legume crop was calculated as the difference in apparent N mineralization between the legume and non-legume stubble cropping systems.

Landscape Experiment

Site descriptions, experimental design and management practices have previously been outlined (Beckie and Brandt 1997).

YEAR 1. Nitrogen fixation by field pea was measured using the isotope dilution method (Bremer et al. 1988) at site 1 in 1993 and site 2 in 1994. Five kg ha^{-1} of 10 atom % excess ammonium nitrate (34–0–0) was applied immediately after seeding to 1-m^2 microplots located in the CT field pea plots at the four slope positions. The non-fixing reference crop was barley (cv. Harrington), which was seeded in adjacent microplots. Samples were analyzed by continuous flow mass spectroscopy — CARLO ERBA® coupled with an OPIMA® (Carlo Erba Strumentazione, Milan, Italy; V.G. Isogas Ltd., Middlewich, Cheshire, UK). Field pea and flax seed and stover (straw) samples were digested using the standard micro-Kjeldahl method, and N was measured using the autoanalyzer in order to calculate N yield (uptake). Preseeding and postharvest soil ammonium- and nitrate-N levels were measured at increments of 0–0.15, 0.15–0.3, 0.3–0.6, 0.6–0.9 and 0.9–1.2 m.

YEAR 2. To determine the total N benefit of field pea to a succeeding wheat crop, N mineralization was measured at 4-wk intervals from June to September in unfertilized wheat plots, using 15-cm diameter, 60-cm deep lysimeters (Campbell et al. 1977; Campbell and Paul 1978). During this same period, N mineralization was measured using anion exchange membranes, which were buried for 2-wk periods in CT plots (Qian and Schoenau 1995). Total N benefit of field pea to the succeeding wheat crop was calculated as the difference in N mineralization between the legume and non-legume stubble cropping systems.

Wheat grain and straw N concentration and N yield were determined. Grain protein content was estimated by multiplying percentage N (dry wt basis) by 5.7. Data analyses are described in Beckie and Brandt (1997).

Table 1. Apparent N mineralized over the growing season in wheat, canola and field pea stubble cropped to barley and flax in the small plot experiment at Melfort and Scott, Saskatchewan in 1994 and 1995

		Apparent N mineralization (kg ha^{-1})			
		Melfort		Scott	
Crop	Stubble	1994	1995	1994	1995
Barley	Wheat	105*b*	132*ab*	149	144
Barley	Canola	105*b*	125*b*	164	163
Barley	Field pea	121*a*	136*a*	166	136
Flax	Wheat	81*b*	93*b*	108*b*	103
Flax	Canola	66*c*	94*b*	146*a*	125
Flax	Field pea	126*a*	108*a*	162*a*	128

*a–c*Means within a crop and site-year followed by the same letter (for significant *F*-test) are not significantly different using Fisher's (protected) least significant difference (LSD) test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Small Plot Experiment

Apparent N mineralization generally was greater in plots of barley or flax (*Linum usitatissimum*) grown on field pea stubble than in plots on wheat or canola stubble at Melfort in 1994 and 1995 and at Scott (flax) in 1994 (Table 1). Greater shoot N yield and reduced fertilizer inputs, not greater root N yield or net (postharvest minus preseeding) available soil N levels, were responsible for the more positive N balances in the cropping systems that included field pea. Apparent N mineralization for flax rotations were less than barley rotations, primarily because flax shoot N yield was lower than that of barley. A significant crop × stubble interaction was observed only at Melfort in 1994. The stubble × site interaction was significant only for flax cropping systems in 1994. Similarly, the stubble × year interaction was significant only for flax cropping systems at Melfort, but not for barley at either site. The stubble × site × year interaction was not significant for flax and barley cropping systems.

To determine if there was a significant relationship between the difference in apparent N mineralization between cereal and oilseed versus pulse stubble cropping systems and N residual effect (Beckie and Brandt 1997), the slope of the regression line was analyzed to determine if it was significantly different from zero (using the *t* test on parameter estimates of the equation for the line). The slope was significantly different from zero and the coefficient of determination (R^2) was significant at $P \leq 0.01$ (Fig. 1). Furthermore, the ideal 1:1 line that passed through the origin

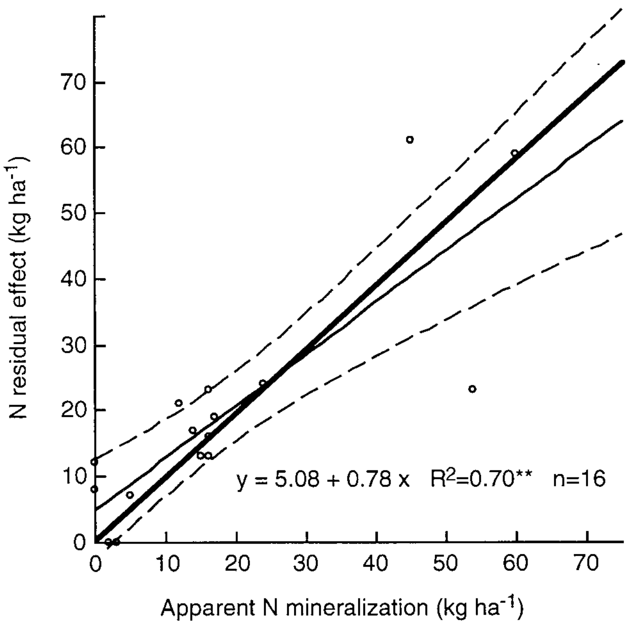

Fig. 1. Relationship between N residual effect and difference in apparent N mineralization between cereal and oilseed versus pulse stubble cropping systems at Melfort and Scott, Saskatchewan in 1994 and 1995 (dashed curves denote 95% confidence band; heavy solid line denotes ideal 1:1 line).

fell within the 95% confidence band, indicating that the N residual effect of field pea to the succeeding non-legume crop was due to the N contribution. As suggested by Lory et al. (1995) and confirmed in this study, any non-N contribution was effectively excluded from the N residual effect by using the revised N credit method.

Landscape Experiment

YEAR 1. Slope position did not have a significant effect on N fixation by field pea in 1993 and 1994 (Table 2). Generally favorable soil moisture conditions over the growing season, and/or interaction of water with available soil N, may have negated any potential slope position effects on fixation. On average, 62 and 57% of total plant N was obtained from the atmosphere (%Ndfa) in 1993 and 1994, respectively. These results are similar to those reported in previous studies (Bremer et al. 1988; Cowell et al. 1989), although lower than reported by Stevenson et al. (1995). Based on the aboveground biomass N yield (Table 3), the average amount of N fixed in 1993 and 1994 was 81 and 97 kg N ha^{-1}, respectively.

Tillage did not influence seed, stover and aboveground biomass N yields and NHI (Table 3). Although flax seed N yield differed among slope positions in 1993, no trend was apparent. Field pea stover N yield was greater on lower (L) versus upper (U) slope positions in 1993 due to greater stover production (Beckie and Brandt 1997), but not in 1994. As expected, aboveground biomass N yield of field pea was lowest on U slope positions in 1993 and 1994, reflecting lower biomass yields and lower plant N concentrations to a lesser extent. NHI of field pea tended to be the lowest on the L slope position, because of increased stover relative to U slope positions. There were no tillage × slope interactions for the plant N parameters in 1993 and 1994. The NHI of field pea in 1993 and 1994 averaged 0.56 and 0.47, respectively. These values are significantly lower than NHI of field pea reported in Europe (Senaratne and Hardarson 1988) and Australia (Armstrong et al. 1994). This discrepancy may be caused by varietal differences or by climate and soil conditions in western Canada. If NHI of field pea is generally lower in western Canada, the implication is that the direct N benefit (N fixed minus NHI) will be

Table 2. Nitrogen fixation by field pea in the landscape experiment located near Melfort, Saskatchewan

	1993 (site 1)		1994 (site 2)	
Slope	% Ndfa[z]	N fixed (kg N ha^{-1})	% Ndfa	N fixed (kg N ha^{-1})
L	68	93	56	104
LM	55	75	49	80
UM	56	74	56	105
U	69	83	67	100
Avg	62	81	57	97

[z]% Ndfa = % of crop N derived from atmospheric N_2, measured in CT plots; N fixation was not significantly affected by slope position ($P \leq 0.10$).

Table 3. Mature field pea and flax N yields and N harvest indices in the landscape experiment located near Melfort, Saskatchewan

	Tillage		Slope position			
	CT	DS	L	LM	UM	U
1993 (site 1)						
Seed N yield (kg N ha^{-1})						
Field pea	72	74	71	75	75	70
Flax	55	55	53*bc*	62*a*	56*ab*	49*c*
Stover N yield (kg N ha^{-1})						
Field pea	57	59	65*a*	61*b*	57*c*	50*d*
Flax	23	20	24	22	19	20
Aboveground biomass N yield[z] (kg N ha^{-1})						
Field pea	129	133	136*a*	136*a*	132*a*	121*b*
Flax	78	75	76*ab*	84*a*	75*ab*	70*b*
NHI[y]						
Field pea	0.56	0.56	0.52*c*	0.55*b*	0.57*ab*	0.58*a*
Flax	0.71	0.74	0.69*c*	0.74*ab*	0.75*a*	0.71*bc*
1994 (site 2)						
Seed N yield (kg N ha^{-1})						
Field pea	79	76	80	78	83	71
Flax	33	46	39	37	39	43
Stover N yield (kg N ha^{-1})						
Field pea	83	104	106	86	104	78
Flax	24	26	29	21	24	26
Aboveground biomass N yield (kg N ha^{-1})						
Field pea	163	180	186	163	187	150
Flax	57	72	68	58	63	70
NHI						
Field pea	0.50	0.44	0.44	0.49	0.46	0.49
Flax	0.58	0.64	0.57	0.63	0.62	0.62

[z]Aboveground biomass N yield = seed N yield + stover N yield.
[y]NHI = seed N yield / aboveground biomass N yield.
*a–d*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 ($P \leq 0.10$).

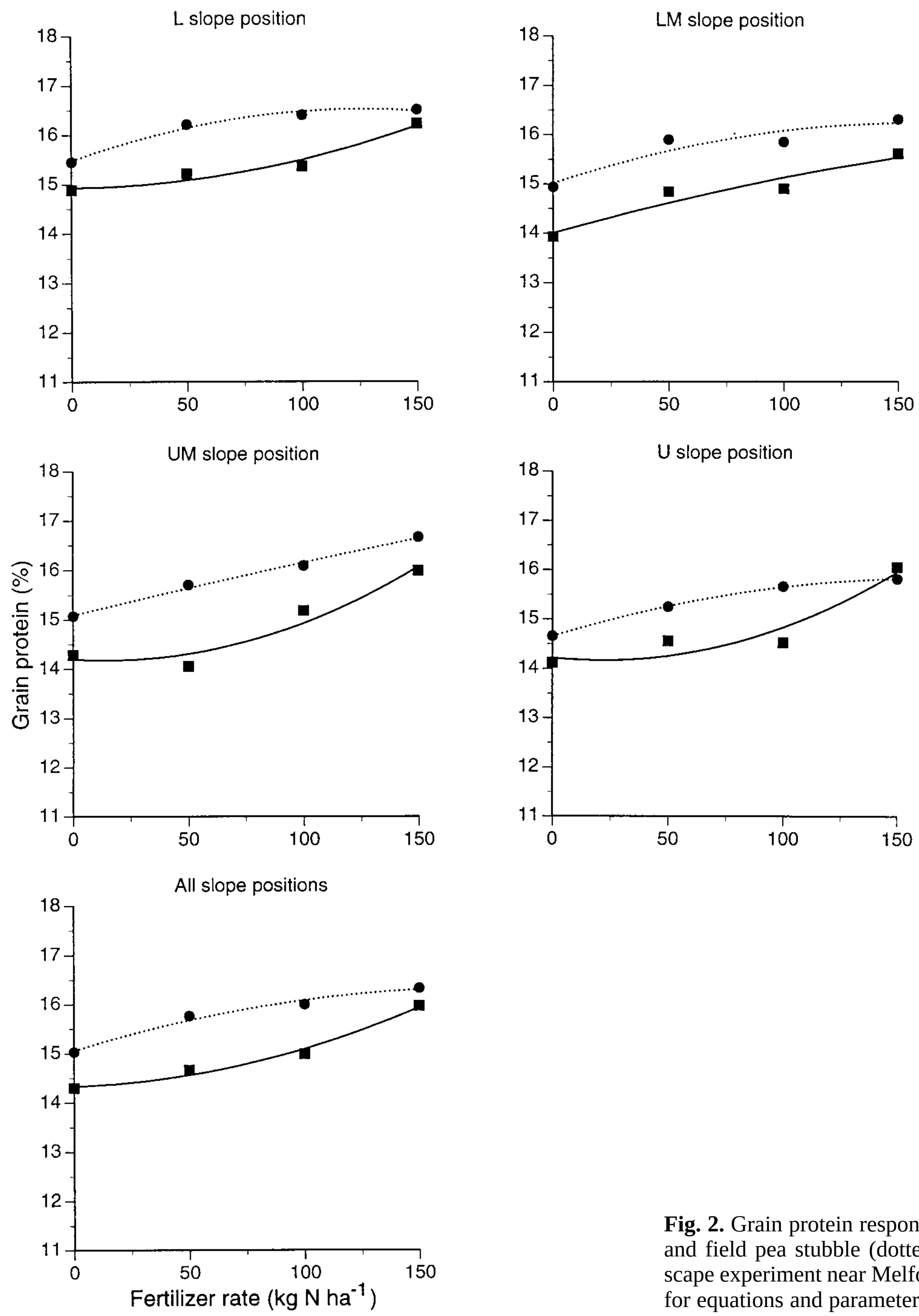

Fig. 2. Grain protein response of wheat, grown on flax (solid line) and field pea stubble (dotted line), to N fertilization in the landscape experiment near Melfort, Saskatchewan in 1994. See Table 4 for equations and parameter estimates.

considerably higher, assuming similar contributions of atmospheric-derived N to the plant's N requirements.

On average, the "direct N benefit" was positive, since the amount of N fixed (Table 2) exceeded NHI (Table 3) in 1993 and 1994. The direct N benefit was +8 kg N ha^{-1} in 1993 and +19 kg N ha^{-1} in 1994, within the range reported in other studies. The greater N benefit in 1994 resulted from a lower NHI due to greater stover production compared to 1993. Assuming that 8% of field pea residue N was recovered by the succeeding wheat crop (Stevenson and van Kessel 1996), then only a small amount (6 kg N ha^{-1}) was directly available to wheat.

Post-harvest available soil N levels were higher in DS than CT plots in 1993, but vice-versa in 1994 (data not shown). These differences are at least partially related to plant N uptake differences in 1993 and 1994. Available N in the soil profile after harvest averaged 24 kg ha^{-1} greater in field pea than flax plots in 1993 and 1994 (the "N conserving effect"). Slope position did not have a significant effect on postharvest available soil N levels.

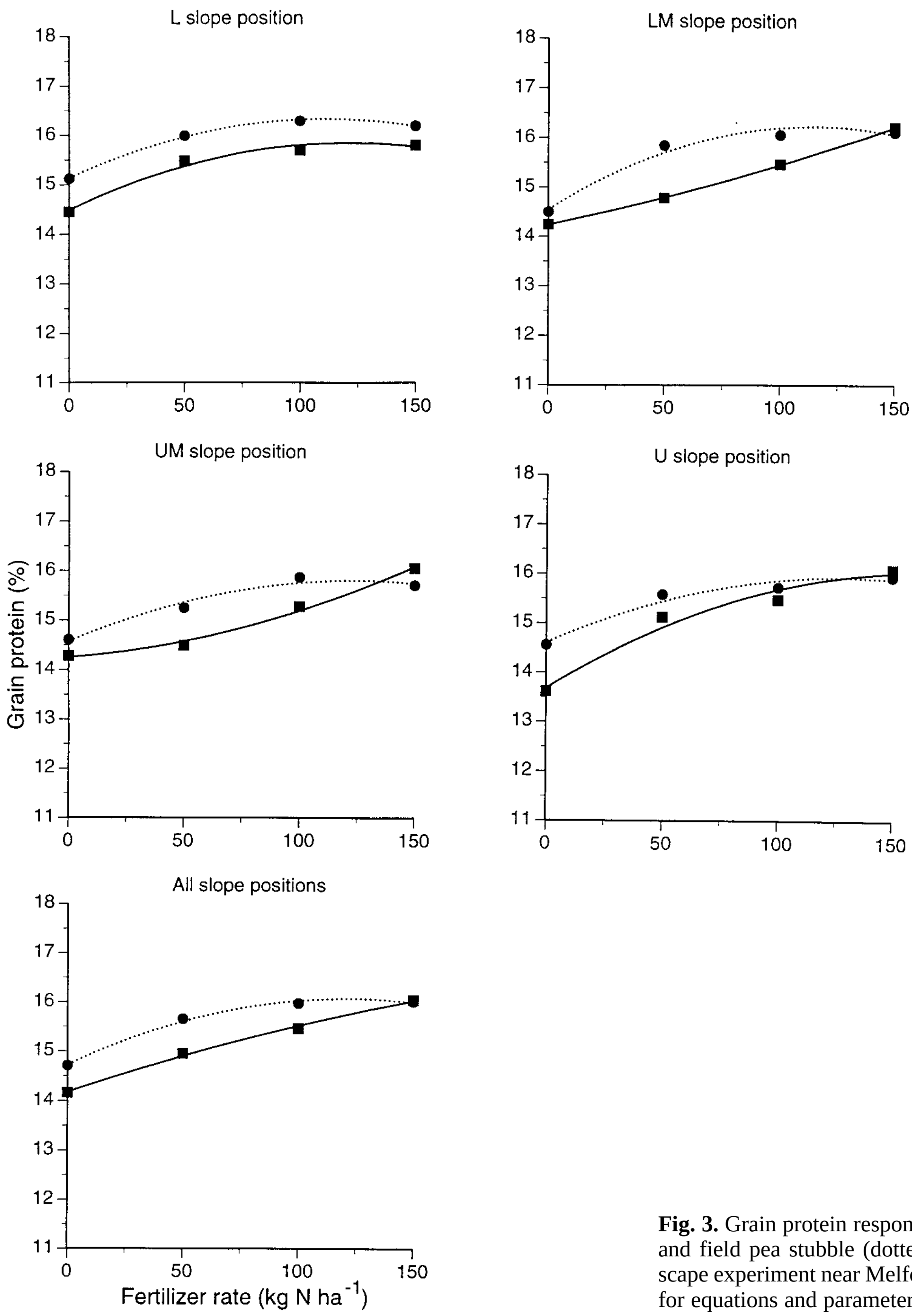

Fig. 3. Grain protein response of wheat, grown on flax (solid line) and field pea stubble (dotted line), to N fertilization in the landscape experiment near Melfort, Saskatchewan in 1995. See Table 4 for equations and parameter estimates.

YEAR 2. Wheat grain protein content differed between stubble type and among slope positions in 1994 (Fig. 2). In unfertilized plots, protein contents were 0.44, 0.89, 1.01 and 0.55% units higher when wheat was grown on field pea than flax stubble for the U, upper-mid (UM), lower-mid (LM) and L slope positions, respectively. Averaged across slope positions, unfertilized wheat on field pea stubble had grain protein content 0.73 and 0.55% units higher than wheat grown on flax stubble in 1994 and 1995 (Fig. 3), respectively. This compares to previous reports of 0.6% unit increase (Wright 1990b), 0.7% unit increase (Stevenson and van Kessel 1996) and 1.7% unit increase (Rowland et al. 1994) in wheat protein attributable to field pea residue. Grain protein differences between tillage treatments were insignificant in both years.

Grain protein of wheat grown on either field pea or flax stubble tended to increase with increasing rates of N fertilizer. In 1994, grain protein of wheat grown on field pea stubble exceeded that of wheat grown on flax stubble across the range of fertilizer N rates, except for the U slope position at the highest N fertilizer rate (Fig. 2 and Table 4). In 1995, N fertilizer applied at rates greater than 100 kg N ha^{-1} to wheat on flax stubble was able to achieve the same grain protein levels as wheat on field pea stubble, except for the L slope position (Fig. 3). The stubble × fertilizer and stubble × slope × fertilizer interactions were significant in 1995, but not in 1994.

Wheat N yield (uptake) was unaffected by slope position or tillage in 1994; as expected, N uptake was significantly higher on field pea than flax stubble in both years (Table 4). In 1995, N uptake of wheat was highest in field pea stubble plots on the L slope position.

Net N mineralization (gross mineralization minus immobilization), measured using 15-cm diameter, 60-cm deep lysimeters, was 39% greater where unfertilized wheat was grown on field pea than flax stubble in 1994 (Table 5). As well, net mineralization was 32% greater in CT than DS plots, due to either greater gross N mineralization, less immobilization, or both. Although there was no significant slope effect, more N tended to be mineralized on the L slope compared to the U slope position over the growing season. There were no significant treatment interactions. Favorable soil moisture conditions during the growing season and relatively fertile soil on the upper slopes may have negated significant slope effects on N mineralization. Results using anion exchange membranes, which measure relative rather than absolute mineralization between treatments, corresponded well with lysimeter results. On average, net N mineralization over the growing season was 42% greater in field pea than flax stubble plots (data not shown). Wheat N yields in unfertilized field pea and flax stubble plots (Table 4) corresponded well with the amount of N mineralized over the growing season.

Net N mineralization in 1995 was similar to 1994. N mineralization in field pea stubble plots was 17% greater than in flax stubble plots. However, there were no significant tillage or slope effects, or interactions. Measurements from the buried anion exchange membranes indicated 20% greater mineralization in field pea than flax stubble plots. Thus, good agreement was obtained between the lysimeter and exchange membrane methods of determining soil N mineralization.

To test whether a laboratory incubation method for determining N mineralization using anion exchange membranes (Qian and Schoenau 1995) could accurately predict treatment effects in the field, soil samples (0- to 15-cm depth) were collected prior to seeding in 1994 and 1995 from tilled field pea and flax stubble plots on the U and L slope positions. N mineralized over a 2-wk period using anion exchange membranes, indicated that 30% more N was mineralized in soil from field pea than flax stubble plots in 1994; there was no slope effect on N mineralization (Table 6). Therefore, the laboratory measurements conducted prior to the 1994 growing season coincided closely with field measurements conducted during the growing season. However in 1995, the laboratory incubation measurements indicated a significant effect of slope position on N mineralization, but no effect of previous crop. Therefore, laboratory measurements of N mineralization may give different

Table 4. Parameter estimates (standard errors in parentheses) of the equations for the regression curves for the response of wheat grain protein and aboveground biomass N yield to N fertilization in the landscape experiment near Melfort, Saskatchewan

	a^z	b	c (10^1)	R^2
1994 (site 1)				
Grain protein (%)				
L slope position				
Pea stubble	15.5 (0.1)	0.016 (0.003)	–0.0006 (0.0002)	0.98
Flax stubble	14.9 (0.2)	0.001 (0.006)	0.0005 (0.0004)	0.96
LM slope position				
Pea stubble	15.0 (0.3)	0.015 (0.011)	–0.0005 (0.0007)	0.88
Flax stubble	14.0 (0.3)	0.013 (0.011)	–0.0002 (0.0007)	0.92
UM slope position				
Pea stubble	15.1 (0.1)	0.011 (0.003)	–0.0001 (0.0002)	0.99
Flax stubble	14.2 (0.4)	–0.003 (0.012)	0.0010 (0.0008)	0.94
U slope position				
Pea stubble	14.7 (0.2)	0.014 (0.001)	–0.0004 (0.0001)	0.99
Flax stubble	14.2 (0.4)	–0.005 (0.014)	0.0011 (0.0009)	0.90
All slope positions				
Pea stubble	15.1 (0.1)	0.014 (0.004)	–0.0004 (0.0003)	0.98
Flax stubble	14.3 (0.2)	0.001 (0.005)	0.0006 (0.0003)	0.98
Plant N yield (kg N ha^{-1})				
Pea stubble	115 (4)	0.552 (0.134)	–0.0173 (0.0086)	0.98
Flax stubble	73 (7)	0.739 (0.214)	–0.0224 (0.0137)	0.98
1995 (site 2)				
Grain protein (%)				
L slope position				
Pea stubble	15.1 (0.1)	0.022 (0.001)	–0.0010 (0.0001)	0.99
Flax stubble	14.5 (0.2)	0.022 (0.005)	–0.0009 (0.0003)	0.98
LM slope position				
Pea stubble	14.6 (0.2)	0.029 (0.007)	–0.0013 (0.0004)	0.97
Flax stubble	14.2 (0.1)	0.010 (0.001)	0.0002 (0.0001)	0.99
UM slope position				
Pea stubble	14.6 (0.2)	0.020 (0.005)	–0.0008 (0.0003)	0.97
Flax stubble	14.2 (0.1)	0.004 (0.004)	0.0006 (0.0003)	0.99
U slope position				
Pea stubble	14.6 (0.2)	0.021 (0.006)	–0.0008 (0.0004)	0.96
Flax stubble	13.7 (0.3)	0.029 (0.010)	–0.0009 (0.0006)	0.97
All slope positions				
Pea stubble	14.7 (0.1)	0.022 (0.002)	–0.0009 (0.0002)	0.99
Flax stubble	14.2 (0.1)	0.016 (0.002)	–0.0002 (0.0002)	0.99
Plant N yield (kg N ha^{-1})				
L slope position				
Pea stubble	123 (8)	0.670 (0.250)	–0.0324 (0.0160)	0.91
Flax stubble	103 (3)	0.346 (0.100)	–0.0037 (0.0064)	0.99
LM slope position				
Pea stubble	82 (8)	0.622 (0.256)	–0.0237 (0.0163)	0.94
Flax stubble	63 (4)	0.808 (0.138)	–0.0331 (0.0088)	0.99
UM slope position				
Pea stubble	83 (7)	0.695 (0.217)	–0.0330 (0.0139)	0.94
Flax stubble	60 (4)	0.946 (0.137)	–0.0429 (0.0087)	0.99
U slope position				
Pea stubble	87 (1)	1.152 (0.016)	–0.0615 (0.0010)	0.99
Flax stubble	74 (4)	0.747 (0.126)	–0.0293 (0.0080)	0.99
All slope positions				
Pea stubble	94 (6)	0.785 (0.177)	–0.0377 (0.0113)	0.97
Flax stubble	75 (1)	0.712 (0.007)	–0.0273 (0.0004)	0.99

[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 the fertilizer rate (kg N ha^{-1}).

Table 5. Net N mineralized during the growing season in unfertilized wheat plots in the landscape experiment located near Melfort, Saskatchewan

	1994 (site 1)	1995 (site 2)
	(kg N ha^{-1})	
Stubble		
Field pea	117*a*	110*a*
Flax	84*b*	94*b*
Tillage		
CT	115*a*	97
DS	87*b*	108
Slope		
L	110	106
U	92	98

*a,b*Means followed by the same letter (for significant *F*-test) are not significantly different, using Fisher's (protected) least significant difference (LSD) test ($P \leq 0.10$).

Table 6. Relative N mineralized over a 2-wk period in soil collected in conventional tillage plots prior to seeding at the landscape experiment located near Melfort, Saskatchewan: laboratory measurements using anion exchange membranes

Stubble	Slope	1994 (site 1)	1995 (site 2)
		(μg 10 cm^{-2})	
Field pea	L	1486*a*	1170*a*
Field pea	U	1379*a*	996*b*
Flax	L	1153*b*	1204*a*
Flax	U	1053*b*	974*b*

*a,b*Means followed by the same letter are not significantly different, using Fisher's (protected) least significant difference (LSD) test ($P \leq 0.05$).

results than "in situ" measurements of N mineralized over the growing season.

Of particular importance was the close relationship between the N residual effect (37 and 18 kg N ha^{-1} in 1994 and 1995, respectively) and the difference in the amount of N mineralized between field pea and flax stubble-cropped plots over the growing season (33 and 16 kg N ha^{-1} in 1994 and 1995, respectively). Since N mineralization is from above- and below-ground field pea residue and soil organic matter, and because preseeding available soil N levels are taken into account in the calculation (i.e., the "N conserving effect"), the difference in net N mineralization between field pea and non-legume stubble cropping systems is equivalent to the total N benefit of the legume, which, in turn, is equated with the N residual effect. The fact that N mineralization is similar to the N residual effect in both the small plot and landscape experiment, validates the revised N credit methodology of Lory et al. (1995). This signifies that the total N benefit of field pea to a succeeding non-legume crop can be estimated by determining the N residual effect.

Past studies have documented a small direct N benefit, yet large N residual effect of field pea to a succeeding cereal crop. A similar conclusion can be made if the direct N benefit, estimated at 6 kg ha^{-1} available N, is compared with the N residual effect that averaged 28 kg N ha^{-1}. However according to convention, the direct N benefit only includes the aboveground biomass N contribution of the pulse crop. Given that the total N benefit of field pea to the succeeding wheat crop averaged 25 kg N ha^{-1}, it can be concluded that the indirect N benefit was the primary source of the total N benefit.

CONCLUSION

The total N benefit was calculated as the difference in net N mineralized from soil plus N in the above- and below-ground crop residue between field pea and non-legume stubble-cropped plots over the growing season. Landscape slope position did not affect the total N benefit of field pea to a succeeding wheat crop, and preseeding tillage had an inconsistent effect on the total N benefit between years. The direct N benefit of field pea available to the succeeding crop was a minor component of the total N benefit. In the landscape experiment located in the moist Black soil climatic zone, the total N benefit of field pea to a succeeding non-legume crop averaged 25 kg N ha^{-1}. The total N benefit was equivalent to the N residual effect, defined as the amount of fertilizer N required for a non-legume crop grown on non-legume stubble to achieve the same yield as that of the non-legume crop on field pea stubble.

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