Nitrogen release from field pea residues and soil inorganic N in a pea–wheat crop rotation in northwestern Canada

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Lupwayi, N. Z. and Soon, Y. K. 2009. **Nitrogen release from field pea residues and soil inorganic N in a pea–wheat crop rotation in northwestern Canada.** Can. J. Plant Sci. **89**: 239–246. Pea (*Pisum sativum* L.) varieties can differ in morphology, N_2 fixation and straw N content. A study was conducted over 3 site-years to evaluate the influence of pea variety and inoculation with *Rhizobium* on N release from decomposing pea residues. The litterbag technique was used to measure N release over a 52-wk period starting from the time of pea harvest in one season through part of the following season when wheat was grown. Experimental treatments comprised factorial combinations of three pea varieties and either inoculation with 5 kg ha^{-1} of a granular inoculant or none, arranged in a randomized complete block design. Neither pea variety nor inoculation affected amounts or patterns of N released. Patterns of N release over time showed mostly net N mineralization in two of 3 site-years, and some net N immobilization in one site-year. The percentages (up to 19 to 24% over time) and amounts (up to 2.3 to 7.5 kg N ha^{-1}) of N released were low, probably due to the combination of low N concentrations (mostly <1%) in the residues and below-normal rainfall in all 3 site-years. Soil NO_3-N and NH_4-N (0- to 80-cm depth) in the fall after pea harvest (20 to 39 and 27 to 55 kg N ha^{-1}, respectively) and in spring before wheat seeding (23 to 51 and 16 to 40 kg N ha^{-1}, respectively) were not affected by pea variety or inoculation. However, soil NO_3-N was mostly higher after peas than after barley (the control). There is need to measure patterns of N release over several subsequent crops to check if more N is released in the long term.

Key words: Crop residue, N mineralization, *Rhizobium* inoculation, soil inorganic N

Lupwayi, N. Z. et Soon, Y. K. 2009. **Libération de l'azote des résidus de la culture du pois et du N inorganique du sol dans un assolement pois-blé du nord-ouest du Canada.** Can. J. Plant Sci. **89**: 239–246. Les variétés de pois (*Pisum sativum* L.) diffèrent par leur morphologie, leur capacité à fixer l'azote et la teneur en azote de leur paille. Les auteurs ont effectué une étude de trois années-sites afin d'évaluer l'incidence de la variété et de l'inoculation de *Rhizobium* sur la libération d'azote pendant une période de 52 semaines allant de la récolte des pois à la saison suivante où l'on a cultivé du blé. Les traitements expérimentaux consistaient en une combinaison factorielle de trois variétés, bonifiées ou pas avec 5 kg d'inoculant granulaire par hectare, dans une expérience en blocs aléatoires complets. Ni la variété ni l'inoculation n'affectent la quantité d'azote libérée ni la façon dont l'élément est libéré. Le mode de libération de l'azote dans le temps révèle principalement la minéralisation de l'élément à deux années-sites sur trois et une certaine immobilisation nette de l'azote à une année-site. La proportion (jusqu'à 19 à 24 % dans le temps) et la quantité (jusqu'à 2,3 à 7,5 kg de N par hectare) d'azote libéré restent faibles, sans doute à cause de la faible concentration de N (essentiellement moins de 1 %) dans les résidus combinée à des précipitations inférieures à la normale aux trois années-sites. La quantité de N-NO_3 et de N-NH_4 (0 à 80 cm de profondeur) relevée à l'automne, après la récolte de pois (de 20 à 39 et de 27 à 55 kg de N par hectare, respectivement), et au printemps, avant les emblavures de blé (de 23 à 51 et de 16 à 40 kg de N par hectare, respectivement) n'est pas affectée par la variété de pois ni par l'inoculation. La concentration de N-NO_3 dans le sol était généralement plus élevée après la culture de pois qu'après celle de seigle (témoin). Il faudrait déterminer les modes de libération du N au cours de plusieurs cultures successives pour savoir si la quantité d'azote libérée augmente avec le temps.

Mots clés: Résidus de culture, minéralisation du N, inoculation de *Rhizobium*, N inorganique du sol

Pulse crops have become important rotation crops in the Canadian prairies and their acreages have increased (Lupwayi and Kennedy 2007). Field peas (*Pisum sativum* L.) are grown on the greatest acreage (1.38 million ha in 2004) although lentils (*Lens culinaris* L.), chickpeas (*Cicer arietinum* L.), and common beans (*Phaseolus vulgaris* L.) are also grown (Lupwayi and Kennedy 2007). Inclusion of pulse crops in rotations is believed to have N and non-N rotational benefits. Non-N benefits include breaking of pest cycles (Stevenson and van Kessel 1996; Turkington et al. 2006) and improvement of soil structure (Chan and Heenan 1991). The N contributions of legumes vary with legume type or legume use in cropping systems. Grain legumes contribute less N in rotations than legumes that are used as green manure because grain legume seed is harvested and taken off the farm (Lupwayi et al. 2006). In the Canadian prairies, Biederbeck et al. (1996) estimated net N credits of 18 kg N ha^{-1} for field pea, 9 kg ha^{-1} for lentil, and 0 kg ha^{-1} for dry beans, all grown for grain.

The N benefit of including a pulse crop in a crop rotation, compared with a non-legume crop, ultimately depends on the amount of N_2 fixed by the legume since it is the N that will accrue to the following crop. Factors that affect the amount of N_2 fixed will also affect the amount of N returned to the soil in crop residues. Such factors include *Rhizobium* strains and legume genotype. Hobbs and Mahon (1982) and Fesenko et al. (1995) screened *Rhizobium* strain-pea genotype combinations for N_2 fixation potential and reported significant interactions, i.e., some combinations were more effective than others in increasing N_2 fixation. In other pulse crops, Wolyn et al. (1991) found large differences in N_2 fixation by common bean genotypes. Ndiaye et al. (2000) reported up to fourfold difference in the amount of N fixed by 16 cultivars of cowpea (*Vigna unguilata* L.) and Kilian et al. (2001) a 1.8-fold difference between faba bean (*Vicia faba* L.) varieties. The soil environment, including temperature, moisture, pH, and nutrient content, can also affect N_2 fixation through effects on survival of rhizobia and/or growth of legume plants. In soils containing <30 kg $NaHCO_3$-extractable P ha^{-1} (0- to 15-cm depth), application of triple superphosphate significantly increased grain yields of inoculated field pea in 52% of the trials in Alberta, compared with only 6% of the trials in soils containing >30 kg P ha^{-1} (McKenzie et al. 2001b). Rice et al. (2000) reported a linear increase in the number and weight of effective field pea nodules with increasing soil pH (measured in 0.01 M $CaCl_2$ at 1:2 soil:solution ratio) from 4.4 to 6.6. In a sandy loam soil, low available soil moisture (11 – 23% moisture on a volume basis) reduced nodule numbers and weights of common bean and soybean [*Glycine max* (L.) Merr.] by up to 91% relative to the high soil moisture (20–22% moisture) treatment (Buttery et al. 1998).

In the Canadian prairies, soil inoculation of field pea with granular inoculants has become more popular than seed inoculation since the 1990s because granular inoculants often increase N_2 fixation and crop yields more than seed-applied inoculants (Hynes et al. 2001; Clayton et al. 2004a,b). During the same period, different pea varieties have been introduced, particularly semi-leafless varieties that lodge less than normal-leafed varieties (Alberta Agriculture, Food and Rural Development 2005). McKenzie et al. (2001a) reported a significant interaction between these cultivars and inoculation with rhizobia in 6 of 22 trials in Alberta.

Although differences between legume genotypes in N_2 fixation have been documented, it is not clear how they translate into differences in N released from their residues, particularly in northwestern Canada. We conducted a study over 3 site-years to quantify N release from residues of three pea varieties, uninoculated or inoculated with *Rhizobium leguminosarum* bv. *viceae*. Inoculation treatments were included to increase the range of N_2 fixed by the different varieties. From the same trial, pea dry matter (DM), N concentrations, N_2 fixed, N budgets, and N uptake by wheat grown after field pea have been reported in a separate paper (Soon and Lupwayi 2008). In this paper, patterns of N release from decomposing pea residues and concentrations of soil inorganic N are reported.

MATERIALS AND METHODS

Two experiments (hereafter named exps. A and B) were conducted during 2002–2003 and 2003–2004 at Beaverlodge, Alberta, and one experiment (exp. C) during 2003–2004 at Fort Vermillion, Alberta. The soil was a Dark Gray Luvisol at both Beaverlodge (Albright clay loam, pH 5.9 in 0.01M $CaCl_2$ and 35 g organic C kg^{-1}) and Fort Vermillion (Leith sandy loam, pH 6.5 and 17 g organic C kg^{-1}). Monthly rainfall and temperatures during the growing season were recorded (Table 1). Pea was grown in the first year and wheat the following year. Experimental treatments comprised factorial combinations of three pea varieties and either inoculation with 5 kg ha^{-1} of a granular inoculant or none. The inoculant used was Soil Implant™, a commercial granular pea inoculant that contains *Rhizobium leguminosarum* bv. *viceae* strain Nitragin128C56G (Nitragin Inc., Brookfield, WI). The check was a barley (*Hordeum vulgare* L.)–wheat sequence which during the first year provided the reference crop for determination of N_2 fixation. Pea cultivars Carrera and Swing were used in all three experiments. Carrera is an early maturing, semi-leafless variety with a short vine length (52 cm); Swing is also semi-leafless and early maturing with a vine length of 63 cm (Alberta Agriculture, Food and Rural Development 2005). The third cultivar for exp. A was Grande and for exps. B and C, Eiffel. Grande is a normal-leafed, late-maturing variety with a vine length of 88 cm, while Eiffel is a semi-leafless, medium maturing cultivar with a vine length of 77 cm. Maturity is estimated to be about 5 d later in Grande than in Swing, the earliest maturing of cultivars tested. Pea varieties with different plant heights and canopy architecture (normal-leafed vs. semi-leafless) were chosen to give a wide spectrum of total plant N. The barley variety was AC Harper and wheat was Teal variety. Each treatment was replicated four times in a randomized complete block design. Plot size was 4 m $\times$ 12 m.

Pea and barley received 55 kg ha^{-1} of ammonium monophosphate (12-51-0) at seeding. The plots were managed under zero tillage, and weeds were controlled chemically as required. No N fertilizer was added to the first year crops other than N added with ammonium monophosphate. In exp. A, wheat following pea received 50 kg N ha^{-1}, while wheat following barley received 70 kg N ha^{-1}, in addition to 55 kg ha^{-1} of ammonium monophosphate. In exp. B, wheat grown in the second year received 40 kg N ha^{-1}, and in exp. C 50 kg N ha^{-1}, with 30 kg ha^{-1} of ammonium monophosphate. Nitrogen was side-banded as urea (46-0-0).

After harvest, chopped pea straw proportional to its dry matter production (per hectare) was placed into 30 cm $\times$ 30 cm nylon litter bags with 1-mm mesh, and left on the soil surface. Eight bags (corresponding to eight sampling times) were placed in each plot. The bags were

Table 1. Monthly and 30-yr average rainfall and air temperatures at Beaverlodge and Fort Vermillion during the experimental growing seasons

Month	Beaverlodge				Fort Vermilion		
	2002	2003	2004	30-yr mean	2003	2004	30-yr mean
			Rainfall (mm)				
April	14.0	9.5	1.2	9.5	8.5	9.7	8.5
May	22.1	7.7	14.8	37.3	5.6	22.3	36.8
June	50.4	54.6	48.7	73.6	39.3	14.6	58.7
July	54.8	43.3	95.6	70.7	76.7	25.1	57.5
August	31.1	69.5	85.5	62.4	54.0	43.7	62.2
September	50.6	31.0	77.7	44.0	27.6	44.2	33.2
October	10.2	14.9	11.9	14.5	38.2	6.2	16.8
Total	233.2	230.5	335.4	312.0	249.9	165.8	273.7
			Mean air temperature (°C)				
April	−1.6	2.0	5.1	3.9	4.2	3.5	2.7
May	6.6	8.4	8.2	9.8	11.1	6.8	10.6
June	14.9	13.9	14.8	13.4	15.2	15.5	15.1
July	15.9	16.3	16.4	15.3	17.9	19.2	16.9
August	14.3	14.2	14.1	14.5	16.1	14.6	14.8
September	8.5	9.5	7.8	9.9	9.9	8.2	8.7
October	2.2	5.4	2.1	4.2	4.4	0.1	2.1

sampled periodically over a 52-wk period to determine N remaining in the residues, and the amount of N released (i.e., mineralized N) was estimated by difference from the initial amount of residue N. Crop residue total N concentration was determined using automated dry combustion (LECO Model FP 428). Therefore, residue N loss patterns were described from the time of residue placement following pea harvest through part of the following season when wheat was grown. Pea DM production, residue N concentration and accumulation (N returned by residues) are given in a separate paper (Soon and Lupwayi 2008).

Soil was sampled to 80-cm depth (0- to 5-cm, 5- to 15-cm, 15- to 40-cm and 40- to 80-cm intervals) after harvest of the first crop and before sowing the subsequent wheat crop the following spring. The soil samples were extracted with 1 M KCl (1:5 soil:extractant ratio) and the filtered extracts were analyzed for NH_4-N and NO_3-N by standard auto-analyzer techniques (Stainton 1974; Kempers and Zweers 1988).

Nitrogen release data over time were analyzed as a repeated measures design, with time of sampling as a repeated measurement, using Statistix 8 (Analytical Software 2003). Nitrogen release from barley residue was not determined. Treatment means were separated by the least significant difference (LSD) method when analysis of variance (ANOVA) indicated significant treatment effects at $P = 0.05$. Soil NO_3-N and NH_4-N data for each site and sampling time were subjected to ANOVA using PROC GLM with cultivar and inoculation as sources of variation and differences were declared significant at $P = 0.05$ (SAS Institute, Inc. 1990). The data were also analyzed with data from the check (i.e., barley) plots included. Single degree-of-freedom contrasts were executed to compare pea cultivar and barley effects on residual soil inorganic N. Standard errors for comparison between groups with unequal replications were calculated according to Steele and Torrie (1960).

RESULTS

Percentage of Nitrogen Remaining in Residues and Amounts Released

The average percentage of N that remained in pea residues during 52 wk of decomposition did not differ between pea varieties or inoculation treatments (variety and inoculation means not presented). Interaction between pea variety and inoculation was not significant. The patterns of N release with time showed that in exps. A and C, rapid net N mineralization occurred within 4 wk of residue placement on the soil, and little extra N was mineralized thereafter (Fig. 1a and c). In exp. B, the first 5 wk of decomposition were characterized mostly by net N immobilization (>100% of applied N in pea residues), but net N mineralization occurred thereafter and continued into the summer before reverting to net N immobilization (Fig. 1b). Over the 54-wk decomposition period, pea residues released up to 19% of their N in exp. A (because 81% of applied N still remained in residues 54 wk after placement – Fig. 1a), up to 20% in exp. B, and up to 24% in exp. C.

The average amounts of N that were released by pea residues during 52 wk of residue decomposition also did not differ between pea varieties or inoculation treatments (variety and inoculation means not presented). Interaction between pea variety and inoculation was not significant. The patterns of amounts of N released (Fig. 2a–c) over time mirrored the patterns of the percentages of N remaining in residues described above (Fig. 1a–c), i.e., mostly N mineralization in exps. A and C and initial net N immobilization (< 0 kg N ha^{-1} released) in exp. B (Fig. 2b). Over the 54-wk period, pea residues released

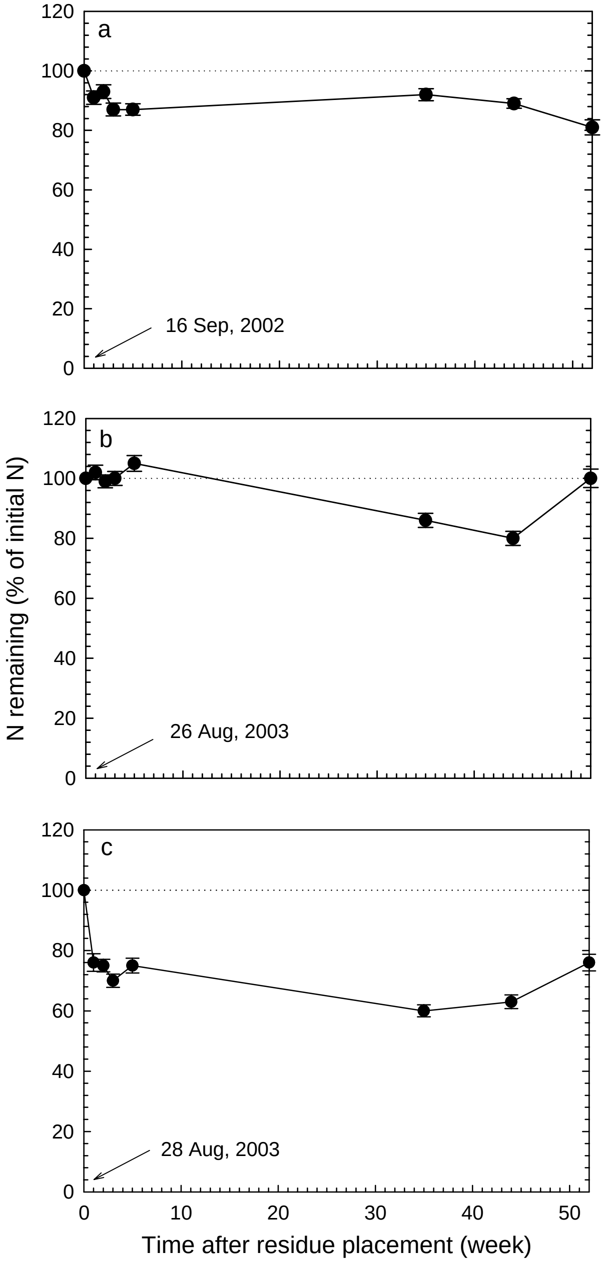

Fig. 1. Percent N remaining in pea residues over time in exps. A (a), B (b), and C (c). Each data point ($n = 24$) is an average of all pea varieties and inoculation treatments because variety or inoculation effects were not significant. The error bars are standard errors.

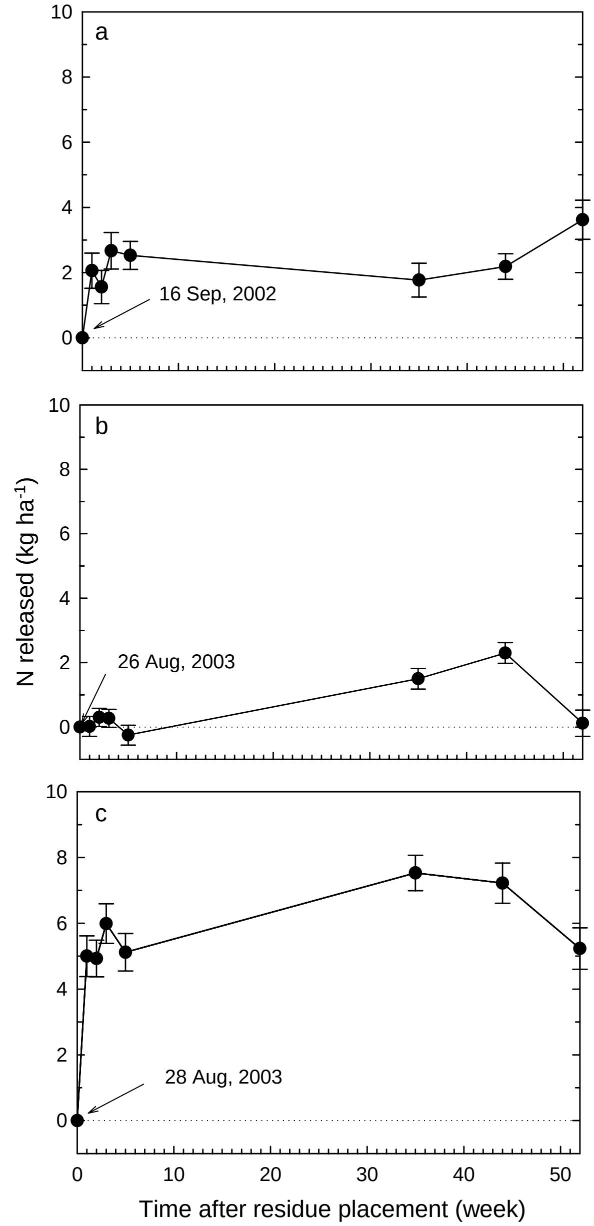

Fig. 2. Nitrogen released from pea residues over time in exps. A (a), B (b), and C (c). Each data point ($n = 24$) is an average of all pea varieties and inoculation treatments because variety or inoculation effects were not significant. The error bars are standard errors.

up to 3.6 kg N ha^{-1} in exp. A, up to 2.3 kg N ha^{-1} in exp. B, and up to 7.5 kg N ha^{-1} in exp. C.

Soil Inorganic Nitrogen

In exp. A, soil NO_3-N was higher in the top 15 cm of soil, in the fall and spring, following pea than following barley (Table 2). There was virtually no difference in soil NO_3-N content between plots that had been grown to the three pea cultivars. Most of the NO_3-N present in the top 5 cm of soil in the fall had apparently moved to deeper soil layers in the following spring. Plots previously under barley and pea also showed a substantial increase in NO_3-N in the 15- to 80-cm depth. Preceding crops had no effect on exchangeable NH_4-N in the 0- to 80-cm depth (62 vs. 55 kg N ha^{-1} for barley vs. pea in the fall, and decreasing to 38 vs. 40 kg N ha^{-1} in spring).

Table 2. Soil nitrate in various soil depths after crop harvest in 2002 and in spring 2003 (exp. A)

	NO_3-N (kg ha^{-1})				
Soil depth (cm)	Barley	Carrera pea	Grande pea	Swing pea	SED[z] (18 df[y])
Fall 2002					
0-5	4.0	11.8*	12.2*	10.7*	2.96
5-15	0.5	5.8	6.5*	3.9	2.82
15-40	0.2	1.7*	1.3	1.5*	0.65
40-80	<0.1	1.0	2.0	1.6	1.03
0-80	4.7	20.3*	21.3*	17.6[x]	6.78
Spring 2003					
0-5	3.3	5.0*	5.5**	4.8	0.81
5-15	4.6	8.8*	10.1**	10.4**	1.64
15-40	12.9	10.9	9.3	13.6	4.03
40-80	7.3	8.5	9.4	11.2	4.15
0-80	28.1	33.7	34.8	40.0	6.56

[z]SED = standard error of difference between barley and pea cultivar means. $n = 4$ for barley and $n = 8$ for pea cultivars.
[y]df = degrees of freedom for error.
[x]P value was 0.07 for 1 df contrast vs. barley. No differences between pea cultivars.
*, ** indicate that pea cultivar mean is significantly different from barley mean at $P = 0.05$ and $P = 0.01$, respectively.

In exp. B, since there was no cultivar effect on the N economy of the pea or on soil inorganic N, results for soil inorganic N are shown only for the means of the cultivars (Table 3). Less NO_3-N remained in the 0–5 cm soil in pea plots than in barley plots following crop harvest. On average in the soil to 80-cm depth, approximately 17 kg ha^{-1} less NO_3-N remained in pea plots than in barley plots. In the following spring, soil NO_3-N was higher in the plots previously cropped to pea, especially in the 5- to 15-cm depth. Therefore, between fall and spring more N was apparently mineralized in soil previously under peas, whereas soil previously cropped to barley appeared to have lower NO_3-N in the spring compared with the previous fall.

Table 3. Soil nitrate in various soil depths after crop harvest in 2003 and in spring 2004 (exp. B)

	NO_3-N (kg ha^{-1})		
Soil depth (cm)	Barley	Pea cultivar means	SED[z] (18 df[y])
Fall 2003			
0-5	17.6	9.2	2.75**
5-15	7.0	5.7	1.64
15-40	5.1	7.9	2.53
40-80	26.0	15.9	7.18
0-80	55.6	38.8	10.09
Spring 2004			
0-5	7.9	11.1	2.05
5-15	7.7	13.1	2.06*
15-40	8.7	9.6	1.02
40-80	13.5	16.9	4.22
0-80	37.8	50.7	5.63*

[z]SED, standard error of difference between barley and pea cultivar means. $n = 4$ for barley and $n = 24$ for mean of pea cultivars.
[y]df, degrees of freedom for error.
*, ** indicate that pea cultivar mean is significantly different from barley mean at $P = 0.05$ and $P = 0.01$, respectively.

Extractable (exchangeable) NH_4-N after crop harvest and in the following spring showed no effects of the previous crop: 40-45 kg N ha^{-1} in the 0–80 cm soil at harvest, and 35-40 kg N ha^{-1} in the following spring.

In exp. C, after harvest soil NO_3-N in the 0- to 80-cm depth was significantly higher in pea plots than in check plots (Table 4), especially the 15- to 80-cm depth, however, exchangeable NH_4-N was similar regardless of crop type (26 kg ha^{-1} to 80-cm depth under barley compared with an average of 27 kg ha^{-1} under pea). By the following spring, only soil NO_3-N in the 0- to 80-cm depth was higher in plots previously under Eiffel variety compared with barley plots. Exchangeable NH_4-N in the 0- to 80-cm depth averaged 16 kg ha^{-1} under barley compared with a range of 16–19 kg ha^{-1} under pea.

DISCUSSION

There were no differences between pea varieties or inoculation treatments in N released by pea residues, and differences in soil inorganic N were inconsistent. This was observed even in exp. A, where variety Grande fixed more N_2 (91 kg ha^{-1} vs. 38 and 50 kg ha^{-1} fixed by Swing and Carrera, respectively) and its residues returned more N to the soil (37 kg ha^{-1} vs. 20 and 25 kg ha^{-1} returned by Swing and Carrera, respectively) than the other varieties (Soon and Lupwayi 2008). Nonsignificant treatment differences in N release were also observed in exp. C, where inoculated peas fixed more N_2 (31 kg ha^{-1}) than uninoculated peas (4 kg ha^{-1}) (Soon and Lupwayi 2008). Grande was the tallest, latest-maturing, and only normal-leafed variety used in these experiments. It was hypothesized that these characteristics of Grande would not only result in more N_2 fixed and more N returned to the soil than semi-leafless varieties, but also result in more N released from its residues. Little N was released from Grande residues,

Table 4. Soil nitrate in various soil depths after crop harvest in 2003 and in spring 2004 (exp. C)

	NO_3-N (kg ha^{-1})				
Soil depth (cm)	Barley	Carrera pea	Eiffel pea	Swing pea	SED[z] (18 df[y])
Fall 2003					
0-5	4.2	5.1	5.3	4.2	0.92
5-15	3.5	5.0	3.8	3.1	0.88
15-40	1.0	2.5	5.2*	4.9*	1.51
40-80	1.6	5.5**	5.3**	4.9*	1.21
0-80	10.3	18.1*	19.6**	17.1*	3.01
Spring 2004					
0-5	1.8	2.0	2.5	1.9	0.39
5-15	3.9	4.0	5.2	5.4	0.98
15-40	3.8	4.0	4.3	5.2	0.82
40-80	10.9	11.2	12.2	11.1	1.38
0-80	20.4	21.1	24.2*	23.5[x]	1.58

[z]SED, standard error of difference between barley and pea cultivar means. $N = 4$ for barley and $n = 8$ for pea cultivars.
[y]df, degrees of freedom for error.
[x]P value was 0.07 for 1 df contrast vs. barley.
*, ** indicate that pea cultivar mean is significantly different from barley mean at $P = 0.05$ and $P = 0.01$ levels, respectively.

probably due to below-normal rainfall (see below). Varietal differences in residue quality did not seem to matter because in exp. A, varieties Grande and Carrera had higher N concentrations (1.2 and 1.1%, respectively) than Swing (0.9%), but there were no varietal differences in N released. Still, only Grande variety resulted in balanced soil N (exported N = fixed N). The other varieties had negative N balances (N deficits) of $7-38$ kg N ha^{-1} for Carrera, 20–37 kg N ha^{-1} for Swing and 18–37 kg N ha^{-1}for Eiffel (Soon and Lupwayi 2008). Therefore, normal-leafed varieties probably have potential to release more N to the soil than semi-leafless varieties.

In exps. A and C, net N mineralization occurred in the first 4 wk of pea residue placement on the soil, but net N immobilization occurred in the first 5 wk in exp. B. The residues in exp. B had low N concentrations (all less than 1%) due to a drier-than normal spring at Beaverlodge in 2003, particularly at seeding time in May when there was only 21% of normal rainfall (Table 1). Spring, and often summer, rainfall was below normal in all three experiments, but air temperatures did not deviate much from normal during these times (Table 1). The soil moisture deficit that resulted from low rainfall probably affected pea growth (and N accumulation) and reduced microbial activity for pea residue decomposition (and N release). However, pulse crop residues generally do not seem to contribute much N to the soil even in normal seasons. In other studies in the region, pea residues released -0.9 to 12.1 kg N ha^{-1} (Soon and Arshad 2002) and 4 to 18 kg N ha^{-1} (Lupwayi et al. 2006). Elsewhere, a nonlegume crop grown after a grain legume crop has been shown to recover 2–26% of the N applied through grain legume residues (Bremer and van Kessel 1992; Giller et al. 1997; Mohr et al. 1998; Fillery 2001).

The reason for the low amounts of N usually mineralized from pulse crop residues, even in normal seasons, is that most of the N is in the grain, which is removed from the farm at harvest in the high-protein legume seeds. The removal of N through grain harvest means that (a) little N is returned to the soil with pulse crop residues, e.g., 22 kg N ha^{-1} in pea residues in northwestern Alberta (Soon and Clayton, 2002), and (b) the crop residues have wide C:N and lignin:N ratios and therefore decompose slowly, which means that the little N that they contain is released even more slowly or immobilized by the decomposing microflora. For example, field peas cut at flowering stage had an average C:N ratio of 20 and lignin:N ratio of 2, but the residues after grain harvest had a C:N ratio of 63 and a lignin:N ratio of 14 (Lupwayi et al. 2006). Residue C and lignin concentrations were not measured in the work reported here, but N concentrations were mostly below 1% (Soon and Lupwayi 2008). However, even when legume crop residues release little N in the short-term, they increase soil organic matter when used in crop rotations. Soil organic matter improves the soil physical structure, which may reduce soil erosion and increase water and nutrient retention (Schjonning et al. 2007; Wuddivira and Camps-Roach 2007). Long-term measurements of N release patterns are required to check if the N immobilized in the early stages of residue decomposition is mineralized in later stages.

Differences between pea varieties in amounts of N_2 fixed in exp. A (Soon and Lupwayi 2008) had little effect on extractable NO_3-N in the soil following crop harvest. In this experiment, virtually all of the increase in soil NO_3-N between soil samplings in fall and spring in plots previously cropped to barley as well as pea (averaging about 16 kg N ha^{-1}) can be attributed to nitrification of extractable NH_4-N. There was, on average to 80-cm depth, more soil NO_3-N in pea plots than in barley plots, probably due to N_2 fixation and sparing of soil N by pea (Soon and Lupwayi 2008).

CONCLUSION

The effects of pea varieties or inoculation on N released by the pea residues were not statistically significant, and the effects on soil inorganic N contents were inconsistent. Patterns of N release over a 52-wk period showed net N mineralization in two experiments, and some net N immobilization in one experiment. Even when net N mineralization occurred, the percentages (up to 19–24% of applied N) and amounts (up to 2.3–7.5 kg N ha^{-1}) released were low, partly due to below-normal rainfall. There is a need to monitor patterns of N release for periods longer than a year, i.e., over several subsequent crops, to check if more N is released in the long term.

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