Particulate organic matter and soil mineral nitrogen concentrations are good predictors of the soil nitrogen supply to canola following legume and non-legume crops in western Canada

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St. Luce, M., Ziadi, N., Zebarth, B. J., Whalen, J. K., Grant, C. A., Gregorich, E, G., Lafond, P., Blackshaw, R. E., Johnson, E. N., O'Donovan, J. T. and Harker, K. N. 2013. **Particulate organic matter and soil mineral nitrogen concentrations are good predictors of the soil nitrogen supply to canola following legume and non-legume crops in western Canada**. Can. J. Soil Sci. **93**: 607–620. Accurate estimation of potential nitrogen (N) availability from preceding crops is essential to improve N fertilizer management in agricultural soils. Labile organic N fractions such as microbial biomass N (MBN), water-extractable organic N (WEON), particulate and light fraction organic matter N (POMN, LFOMN) are sensitive to management-induced changes and have the potential to predict N availability. This study assessed the impact of preceding legume [field pea (*Pisum sativum* L.), faba bean (*Vicia faba* L.), faba bean green manure] and non-legume crops [canola (*Brassica napus* L.) and wheat (*Triticum aestivum* L.)] on labile organic N fractions, mineral N (NH_4-N + NO_3-N), potentially mineralizable N (N_0) and soil N supply (canola grain yield and N uptake), and whether these soil parameters for the top 15 cm of soil could be used as indicators of soil N supply across no-till sites in western Canada. Labile organic N fractions and N_0 were similar regardless of preceding crop. Soil N supply was greatest following faba bean green manure at four of five sites. POMN was the best single predictor of soil N supply ($R^2 = 0.56$ and $R^2 = 0.69$ for yield and N uptake, respectively). Soil N supply was primarily related to the combined effects of POMN, mineral N and sand content, which explained 68 and 71% of the variation in grain yield and N uptake, respectively. This study demonstrated that POMN and mineral N are relatively good predictors of soil N supply to canola in western Canada. Accounting for these parameters as well as soil texture may help improve N fertilizer recommendations for canola.

Key words: Canola, soil N tests, nitrogen supply, organic nitrogen, crop rotation

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Abbreviations: **LFOMN**, light fraction organic matter N; **MBN**, microbial biomass N; $\mathbf{N_0}$, potentially mineralizable N; **PCA**, principal component analysis; **POMN**, particulate organic matter N; **SON**, soil organic N; **WEON**, water-extractable organic N

investigué si ces paramètres peuvent être utilisés comme indicateurs de N disponible du sol sous semis direct dans l'ouest canadien. Les fractions labiles de N et N_0 ont été similaires quel que soit le précédent cultural. Le N disponible du sol a été plus élevé après un précédent de féverole dans quatre des cinq sites. Le POMN semble être le meilleur indicateur de N disponible du sol ($R^2 = 0,56$ et $R^2 = 0,69$ pour le rendement et le N exporté, respectivement). Le N disponible du sol a été principalement lié aux effets combinés du contenu en POMN, N minéral et la teneur du sol en sable, ce qui explique 68 et 71% de la variation du rendement en grain et de N exporté, respectivement. Cette étude a démontré que la teneur en POMN et N minéral sont relativement de bons indicateurs de N disponible du sol pour la culture du canola dans l'ouest canadien. Nous concluons que ces paramètres ainsi que la texture du sol peuvent aider à améliorer les recommandations d'engrais N pour la culture du canola.

Mots clés: Canola, analyse de sol, la fourniture d'azote, azote organique, rotation des cultures

The demand for canola grown in western Canada is increasing due to the healthy fatty acid balance in its edible oil and its suitability for biofuel and animal feed production (Canola Council of Canada 2012a). Given that canola is a major cash crop in western Canada that is mostly grown in rotations to reduce pest and disease build-up (Dosdall et al. 2012) and maintain soil fertility (Malhi et al. 2011a), increased yield per unit area is needed to meet this demand (Harker et al. 2012). Canola has a great N demand and therefore considerable N inputs are required (Malhi and Gill 2004; Cutforth et al. 2009). Previous findings suggest that inclusion of legumes in rotations can increase the soil N supply and possibly reduce N fertilizer inputs (Zentner et al. 2001; Soon and Arshad 2004; Lupwayi and Kennedy 2007; Campbell et al. 2011). Increased N availability following legumes is due to greater mineralizability of legume straw and roots, mostly due to their lower C:N ratio (Campbell et al. 1991b; Soon and Arshad 2004), and to the fact that legumes add N to soils through symbiotic fixation (Kumar and Goh 1999; Campbell et al. 2011). However, the amount of N from the legume crop that is available to a subsequent canola crop is unknown. The ability to accurately estimate this potential N availability would help improve N fertilizer recommendations and reduce external N inputs for canola production.

Prediction of soil N supply is challenging, since it varies temporally and spatially due to agricultural management history, soil properties and environmental conditions (St. Luce et al. 2011). A long-term aerobic incubation study proposed by Stanford and Smith (1972) to estimate potentially mineralizable N (N_0) has long been recognized as the standard measure of the size of the mineralizable N pool. However, this method is not practical for routine use and may not represent actual N supply under field conditions (Malhi et al. 1992; Nyiraneza et al. 2012). Since the late 1960s, preplant soil NO_3-N has been used as the basis for making N fertilizer recommendations in western Canada for both fallow and stubble crops (Soper and Huang 1963; Soper et al. 1971; Carson et al. 1974; Malhi et al. 1992) but it does not directly assess the important contribution of soil N supply originating from soil organic N (SON) (Walley et al. 2002).

Since a large proportion of SON is physically and chemically protected from microbial decomposition, it is the mineralizable (labile) SON that mainly contributes to soil N supply (Haynes 2005). Some SON fractions containing labile organic N include microbial biomass (MBN), water-extractable organic N (WEON), particulate and light fraction organic matter (POMN, LFOMN). Microbial biomass is primarily responsible for the decomposition of organic materials in soils and represents both a source (substrate) and sink (immobilization) of plant nutrients (Brookes 2001). Water-extractable organic N is frequently used as a substitute for soil solution collected in situ and includes the mobile and available portion of total dissolved organic N present in macropores and some smaller pores resulting from microbial decomposition of above- and below-ground residues (Chantigny 2003). Particulate organic matter and LFOM are composed of partially decomposed plant residues together with microbial by-products and are major sources of N for microbes (Gregorich et al. 2006). The LFOM, which contains appreciable quantities of carbohydrates and aliphatic compounds, is thought to be derived primarily from plant tissue whereas POM contains relatively more decomposed organic matter (Gregorich et al. 1996). Since these labile N fractions are actively involved in N cycling, it is hypothesized that they are an important component of soil N supply under field conditions. There are no reported studies relating these labile organic N fractions to soil N supply under field conditions following legume and non-legume crops in western Canada.

The objectives of this study were: (1) to assess the short-term impact of legume and non-legume preceding crops on soil MBN, WEON, POMN, LFOMN, mineral N, N_0, and field-based indices of soil N supply (canola yield and N uptake) and (2) to test the feasibility of using these parameters as predictors of soil N supply. This was evaluated using a series of five experimental sites across western Canada encompassing a range of soil properties under sub-humid and semi-arid conditions.

MATERIALS AND METHODS

Site Description

Samples used in this study were taken from an experiment established in 2009 at five sites across western

Canada to investigate the influence of preceding legume and non-legume crops on soil fertility and canola production. The sites were at Brandon, Manitoba (lat. 50°02′N, long. 99°89′W); Indian Head, Saskatchewan (lat. 50°32′N, long. 103°40′W); Lacombe, Alberta (lat. 52°28′N, long. 113°44′W); Lethbridge, Alberta (lat. 49°41′N, long. 112°46′W); and Scott, Saskatchewan (lat. 52°21′N, long. 108°51′W). Soil characteristics and climatic conditions at each site are given in Tables 1 and 2, respectively. Before the experiment was initiated, the sites were cropped with either barley (*Hordeum vulgare* L.) or spring wheat.

Experimental Design

The experiment was designed to accommodate a split-plot two-factor experiment in the subsequent year (2010) when canola was grown as the succeeding crop. Field pea, faba bean managed for grain, faba bean managed as green manure, canola and wheat were established as the main plots in 2009. Sowing rates of 50, 100, 150 and 300 seeds m^2 were used for faba bean, field pea, canola and wheat, respectively. The legumes were inoculated at each site. Fertilizer rates at each site are given in Table 3. Weeds were controlled with imazamox (20 g a.i. ha^{-1}) with Merge® adjuvant added at 0.5% vol/vol. Following grain harvest, the straw of field peas, faba beans, canola and wheat were returned and evenly spread by hand over each plot and left on the soil surface. In comparison, the entire plant was returned to the soil (sprayed at the flat-pod stage with glyphosate (900 g a.e. ha^{-1}) and clopyralid (50 g a.i. ha^{-1}) and mowed in the fall if necessary) in the faba bean green manure plots. Straw yield and estimated crop residue N returned are provided in Table 3. No-till practices were used at all the sites.

In 2010, the main plots were split into five sub-plots as N rates. However, this study considered only the zero N rate. A small amount of N was applied in the control plots in the mono-ammonium phosphate that was used to supply P to canola at seeding (Table 3). The plot sizes differed according to location (2 m × 5 m in Brandon, 3.9 m × 10.7 m in Indian Head, 4.25 m × 12 m in Lethbridge, and 3.65 m × 15 m in Lacombe and Scott), based on the seeding equipment available. Weeds were burnt-off chemically prior to seeding canola. Hereafter, weeds were controlled with a post-emergence application of glyphosate at 450 g a.i. ha^{-1}.

Plant Analysis

Canola grain yield and total N uptake from the zero N rate plots were used as field based measures of soil N supply. Subsamples of the harvested straw and grain were dried (25–30°C) and ground to pass a 1-mm screen. Grain yield was corrected to 10% moisture while straw yield was calculated on dry weight basis. Total N concentrations in straw and grain were determined by dry combustion with a Carlo-Erba C and N analyzer (Carlo-Erba Instruments, Milan, Italy). Total N uptake (kg N ha^{-1}) was calculated as: (total N concentration in grain × grain yield) + (total N concentration in straw × straw yield). Total N uptake was subsequently corrected to field soil N supply by subtracting 75% of the starter N fertilizer input (Fox and Piekielek 1978; Hong et al. 1990) based on the assumption that 75% of the starter N was absorbed by the canola plant. Although this value was used for corn (*Zea mays* L.), there is no published value for canola.

Soil Sampling

Soil samples from the 0- to 15-cm depth were a composite of two to four random samples per plot, collected from the control plots (0 kg N ha^{-1}) in spring 2010 prior to the establishment of the canola crop. The samples were air-dried and passed through a 2-mm mesh sieve.

Labile Organic N Fractions

Chloroform fumigation-direct extraction of incubated soil (Voroney et al. 2008) followed by persulphate digestion (Cabrera and Beare 1993) was used to determine the MBN concentrations. Briefly, 10 g of air-dried soil was incubated in a dark climate controlled chamber at 25°C and 60% water-filled pore space for 7 d. Subsequently, 5 g (dry weight) of soil was either directly extracted or fumigated for 24 h followed by extraction with 0.5 M K_2SO_4 (1:4 soil:extractant). The persulphate reagent (50 g $K_2S_2O_8$ + 30 g H_3BO_4 + 15 g NaOH in 1 L deionized water) was added to the 0.5 M K_2SO_4 extracts

Table 1. Soil characteristics at five sites in 2009 before the establishment of legume and non-legume preceding crops

Site	Preceding Crop	Total N[z]	Organic C[z]	Sand[y]	Silt[y]	Clay[y]	Textural class	Soil type	pH[x]
		(g kg^{-1})							
Brandon	Barley	3.1	31	486	255	259	Sandy Clay Loam	Black Chernozem	7.5
Indian Head	Wheat	2.5	26	64	275	661	Heavy Clay	Orthic Black Chernozem	7.3
Lacombe	Barley	4.7	47	395	340	265	Loam	Black Chernozem	6.4
Lethbridge	Wheat	1.9	14	308	462	230	Loam	Dark Brown Chernozem	7.8
Scott	Wheat	2.2	23	404	401	195	Loam	Dark Brown Chernozem	5.7

[z]Dry combustion using an Elementar CN Analyzer (Elementar Analysensysteme GmbH, Hanua, Germany). Carbonates were removed before analysis (Skjemstad and Baldock 2008).
[y]Soil texture was determined using the pipette method after organic matter removal (Kroetsch and Wang 2008).
[x]1:1 soil: water slurry (Hendershot et al. 2008).

Table 2. Total precipitation and mean air temperature during the growing season (May – September) in 2009 and 2010 at the five sites in comparison to the 30-y average (1971–2000)[z]

	Total precipitation (mm)			Mean air temperature (°C)		
Site	2009	2010	30-yr avg.	2009	2010	30-yr avg.
Brandon	298	446	322	14.6	14.6	15.0
Indian Head	233	293	296	13.6	13.7	15.0
Lacombe	232	506	320	13.1	11.8	12.9
Lethbridge	241	394	249	15.5	14.1	15.0
Scott	218	497	244	13.6	13.0	14.0

[z]Environment Canada (climate.weatheroffice.gc.ca/climate_normals/results_e.html).

(ratio 1:1) in a Kimax glass tube, capped and autoclaved at 120°C for 30 min. The MBN was subsequently calculated as [(total N in digests of fumigated soil extracts – total N in non-fumigated soil extracts)/k_{EN}] where k_{EN} is the extraction coefficient 0.54 (Brookes et al. 1985).

For WEON extraction, 15 mL of 5 mM calcium chloride ($CaCl_2$) was added to 7.5 g of air-dried soil (1:2 soil:solution ratio) and gently stirred at room temperature for 1 min followed by centrifugation at 9000 rpm for 10 min (Chantigny et al. 2008). The supernatant was then filtered through a vacuum filter unit equipped with a 0.45 µm nylon membrane filter (Pall Corp., Ann Arbor, MI). The WEON concentration was subsequently calculated as the difference between the total dissolved N and the mineral N concentration (NH_4-N + NO_3-N), which were quantified on a QuickChem 8000 Lachat autoanalyzer (Lachat Instruments, Loveland, CO).

A modification of the procedure described by Gregorich and Beare (2008) was used to separate the POM. Briefly, 25 g of air-dried soil was dispersed by shaking in 100 mL of deionized water and 10 glass beads for 16 h. The dispersed soil was passed through a 53-µm sieve. The retained sand and macroorganic matter were dried at 50°C, weighed and then ground using a mortar and pestle to pass through a 250-µm sieve. The density fractionation procedure was used to separate the LFOM (Gregorich and Beare 2008) from 25 g air-dried soil by shaking in a sodium iodide solution (specific gravity of 1.8 g cm^{-3}) for 1 h and allowing the soil mineral particles to settle for 48 h before recovering the suspended LFOM. The N contents of the POM and LFOM were determined by dry combustion using an Elementar CN Analyzer (Elementar Analysensysteme GmbH, Hanua, Germany).

Table 3. Fertilizer rates, straw yield and crop residue N returned at each site

Crop	Brandon	Indian Head	Lacombe	Lethbridge	Scott
			Fertilizer rates (kg ha^{-1}) at seeding in 2009		
Legumes	18 kg N 25 kg P_2O_5 15 kg S	6 kg N 26 kg P_2O_5	6 kg N 26 kg P_2O_5	6 kg N 26 kg P_2O_5	4 kg N 18 kg P_2O_5
Canola	69 kg N 20 kg P_2O_5 15 kg S	81 kg N 26 kg P_2O_5	118 kg N 38 kg P_2O_5 76 kg K_2O 10 kg S	82 kg N 23 kg P_2O_5	102 kg N 16 kg P_2O_5 12 kg K_2O 7 kg S
Wheat	70 kg N 30 kg P_2O_5 15 kg S	44 kg N 26 kg P_2O_5	95 kg N 26 kg P_2O_5 52 kg K_2O 7 kg S	44 kg N 15 kg S	82 kg N 18 kg P_2O_5 15 kg S
			Straw yield in 2009 (kg ha^{-1})		
Canola	3700	6688	9088	6091	5348
Faba Bean	2215	3617	6765	2139	4615
Field Pea	4462	5237	5035	4095	ND[z]
Green Manure	3262	4596	5033	5247	4296
Wheat	3264	6349	7152	1278	6348
			Estimated crop residue N returned in 2009 (kg N ha^{-1})		
Canola	27	19	45	22	29
Faba Bean	29	27	60	16	29
Field Pea	51	54	72	29	ND
Green Manure	64	140	141	157	115
Wheat	26	30	27	11	30
			Fertilizer rates (kg ha^{-1}) at seeding in 2010		
Canola	15 kg N 30 kg P_2O_5 10 kg S	6 kg N 29 kg P_2O_5 47 kg K_2O 16 kg S	7 kg N 31 kg P_2O_5 31 kg K_2O 10 kg S	7 kg N 13 kg P_2O_5 26 kg K_2O 10 kg S	6 kg N 29 kg P_2O_5 33 kg K_2O 10 kg S

[z]Not determined.

Potentially Mineralizable N

A 24-wk aerobic incubation procedure, based on the method of Curtin and Campbell (2008), was used to estimate N_0. Briefly, soils were mixed with an equal amount of sand for light-textured soils and twice the amount of sand for fine-textured soils, packed into leaching tubes, and wetted to 55% of the soil's water-holding capacity by leaching with 100 mL of 0.01 M $CaCl_2$ followed by suction ($\sim$10 kPa) and incubated at 25°C for 24 wk. Thereafter, the soil moisture content was kept at 55% of the water-holding capacity. The first leaching represented the initial NO_3-N and NH_4-N concentrations. The soils were leached every 2 wk for the first 12 wk and every 4 wk thereafter with 100 mL 0.01 M $CaCl_2$ followed by a 25-mL zero-N nutrient solution (Curtin and Campbell 2008). Leachates were filtered through a Whatman No. 42 filter paper and analyzed colorimetrically for NO_3-N and NH_4-N (Zebarth and Milburn 2003). Mineral N in the sum of NO_3-N + NH_4-N in the first 2-wk period, herein considered as Pool I (Sharifi et al. 2007b), was not used in the curve fitting procedure because it represented the initial flush of mineralization upon rewetting. Cumulative N mineralized between weeks 2 and 24 represented total mineralized N and was referred to as Pool II (Sharifi et al. 2007b).

To estimate N_0, the following first order kinetic model was fitted to the data using the Marquardt iteration method:

$$N_{\min} = N_0[1 - \exp(-kt)]$$

where N_{min} is the cumulative amount of N mineralized (mg N kg^{-1}) at time t, N_0 is the potentially mineralizable N (mg N kg^{-1}) and k is mineralization rate coefficient (wk^{-1}). The model was fitted to data using both fixed and unfixed k approaches (Wang et al. 2003). The fixed k approach ($k = 0.054$ wk^{-1}) substantially reduced the coefficient of variation of the N_0 data from 94 to 40% and was therefore used in this study. All measurements were expressed as concentration per kilogram of soil.

Statistical Analyses

All statistical analyses were performed using SAS software (SAS Institute, Inc. 2004). Data were checked for normality based on the Shapiro–Wilk test and transformed when appropriate. Analysis of variance was performed using the GLM procedure based on a randomized complete block design to evaluate the effect of each preceding crop on soil MBN, WEON, POMN, LFOMN, mineral N, N_0, mineralizable N pools, and canola grain yield and N uptake in control plots (N uptake minus starter N fertilizer applied in 2010) for each site. When significant ($P < 0.05$) effects were observed, means were compared with a post-hoc Least Significant Difference (LSD) test at $P < 0.05$. It was hypothesized that legumes would increase the concentration of labile organic N fractions and contribute more to soil N supply than non-legumes; therefore, a pre-planned contrast was constructed to distinguish legume and non-legume effects.

Single linear regression using PROC REG was used to assess the proportion of the variability in yield and N uptake that could be explained by each of the labile organic N fractions, mineral N, N_0, Pool I, Pool II and other soil chemical and physical properties. The linear model was used since it provided a better fit than the quadratic model. Multivariate analysis was also used to explain the variability in soil N supply. Since climatic conditions play a significant role in N dynamics and crop performance, mean air temperature and total precipitation for the 2010 growing season were included in the analysis. The data were subjected to the Kaiser's measure of sampling adequacy (MSA) to detect unique correlations (Kaiser 1974). Small values of MSA indicate that the correlation between paired variables are unique, that is, not related to remaining variables outside of each simple correlation (Wuensch 2004). Kaiser (1974) described MSA's < 0.6 not suitable for principal component analysis (PCA). The MSA of the entire data set was 0.5 and therefore was not suitable for the PCA. Because clay, sand and silt, as well as mineral N (NO_3-N + NH_4-N), NO_3-N and NH_4-N were highly intercorrelated, silt, NO_3-N and NH_4-N were removed from the data set. The recalculated MSA was 0.67; hence the PCA could be performed. The PCA, using the PROC FACTOR of SAS, was then used to develop artificial variables (PCs) that accounted for much of the variance contained in the variables. The retained PCs (eigenvalues > 1) were rotated orthogonally with the VARIMAX option of SAS (Nyiraneza et al. 2009). A soil parameter was assigned to a PC for which it had the highest loading value. The scoring coefficients were obtained using the SCORE procedure of SAS software. Stepwise regression was then conducted using canola yield or N uptake as the dependent variables and the scoring coefficients of the retained PCs as the independent variables. The significance level to enter the model was $P = 0.15$ and the significance to stay was $P \leq 0.05$.

RESULTS

Soil Characteristics and Climatic Conditions

Surface soils at the experimental sites varied in soil texture and were classified as loam at Lacombe, Lethbridge and Scott, sandy clay loam at Brandon and heavy clay at Indian Head (Table 1). Soil total N and organic C ranged from 1.9 to 4.7 g N kg^{-1} and 26 to 47 g C kg^{-1}, respectively. The soils tended to be slightly acidic to calcareous with pH > 7.0 at three of the five sites. Precipitation during the growing season in 2009, during growth of the preceding crops, ranged from 73 to 97% of climate normals (Table 2). In comparison, in 2010, growing season precipitation was near normal at Indian Head but was above normal at other sites including more than 50% above normal at Lacombe and Lethbridge

Table 4. Concentration of labile organic nitrogen fractions, mineral N and mineralizable N pools[z] at the 0- to 15-cm depth in spring 2010. The preceding crops were harvested in fall 2009 and crop residues left on the soil surface in a no-till system

Site	Preceding crop	MBN	WEON	POMN	LFOMN	MinN	N_0	Pool I	Pool II
		(mg N kg^{-1})							
Brandon	Canola	45 (2)[y]	5.8 (0.7)	173 (16)	50 (6)	10.3 (0.9)	59*bc* (4)	29 (2)	32 (3)
	Faba bean	47 (3)	5.8 (0.4)	181 (17)	56 (3)	10.6 (1.8)	70*ab* (3)	19 (2)	37 (3)
	Field pea	39 (2)	5.3 (0.2)	176 (7)	45 (5)	12.2 (1.2)	55*c* (3)	28 (2)	30 (2)
	Green manure	42 (3)	6.0 (0.5)	181 (21)	44 (3)	11.1 (0.7)	76*a* (7)	21 (6)	41 (4)
	Wheat	47 (2)	5.3 (0.4)	197 (22)	55 (6)	10.1 (1.4)	60*bc* (4)	30 (5)	34 (3)
	P value	NS	NS	NS	NS	NS	*	NS	NS
	Contrast[x]	NS	NS	NS	NS	NS	NS	NS	NS
Indian Head	Canola	51 (1)	3.9 (0.2)	214 (13)	91 (28)	5.1*c* (0.3)	63 (10)	8 (2)	32 (2)
	Faba bean	47 (3)	4.0 (0.1)	203 (13)	63 (25)	6.1*bc* (0.2)	51 (1)	11 (3)	30 (0.3)
	Field pea	43 (3)	4.3 (0.2)	178 (22)	52 (7)	9.3*a* (1.7)	79 (6)	23 (2)	46 (2)
	Green manure	48 (2)	4.4 (0.3)	174 (38)	64 (18)	9.9*a* (0.7)	66 (4)	14 (2)	36 (4)
	Wheat	49 (2)	4.2 (0.3)	229 (20)	79 (20)	8.4*ab* (1.1)	60 (11)	16 (6)	38 (8)
	P value	NS	NS	NS	NS	*	NS	NS	NS
	Contrast	NS	NS	*	NS	NS	NS	NS	NS
Lacombe	Canola	57 (2)	4.2 (0.7)	634 (76)	48 (7)	11.0 (3.5)	97 (10)	30 (6)	48 (4)
	Faba bean	41 (10)	4.9 (1.0)	600 (50)	53 (15)	10.7 (0.5)	109 (19)	22 (9)	57 (9)
	Field pea	47 (8)	4.5 (1.2)	610 (69)	49 (7)	11.5 (3.4)	115 (18)	34 (11)	58 (6)
	Green manure	32 (6)	5.7 (0.6)	643 (100)	77 (15)	16.4 (1.4)	139 (21)	53 (11)	80 (11)
	Wheat	41 (4)	5.5 (0.9)	618 (69)	51 (10)	8.8 (1.4)	112 (12)	39 (4)	63 (7)
	P value	NS	NS	NS	NS	NS	NS	NS	NS
	Contrast	NS	NS	NS	NS	*	NS	NS	NS
Lethbridge	Canola	54 (4)	5.0 (0.8)	212 (22)	41 (9)	6.8 (0.6)	79 (24)	12 (2)	45 (15)
	Faba bean	51 (3)	4.0 (0.3)	187 (17)	25 (5)	8.4 (1.2)	80 (22)	17 (2)	52 (14)
	Field pea	57 (5)	5.1 (1.2)	290 (62)	47 (11)	8.7 (0.8)	85 (23)	11 (4)	48 (13)
	Green manure	47 (1)	4.6 (0.3)	268 (53)	42 (14)	11.8 (1.9)	80 (21)	18 (2)	51 (15)
	Wheat	48 (4)	4.1 (0.3)	237 (43)	49 (7)	8.4 (1.1)	90 (9)	11 (4)	44 (8)
	P value	NS	NS	NS	NS	NS	NS	NS	NS
	Contrast	NS	NS	NS	NS	NS	NS	NS	NS
Scott	Canola	30 (1)	5.9 (1.1)	295 (51)	126 (18)	6.7*b* (0.8)	132 (14)	30 (4)	68 (10)
	Faba bean	25 (2)	5.9 (0.3)	283 (21)	136 (12)	6.5*b* (0.7)	127 (11)	34 (5)	68 (8)
	Field pea	28 (2)	5.4 (0.5)	235 (38)	104 (19)	7.7*b* (1.3)	106 (12)	29 (6)	60 (6)
	Green manure	29 (3)	6.4 (0.4)	286 (12)	123 (7)	13.0*a* (0.7)	123 (10)	38 (1)	69 (7)
	Wheat	32 (3)	5.6 (0.6)	382 (31)	145 (5)	8.4*b* (0.2)	133 (10)	33 (1)	77 (6)
	P value	NS	NS	NS	NS	***	NS	NS	NS
	Contrast	NS	NS	*	NS	NS	NS	NS	NS

[z]MBN, microbial biomass N; WEON, water-extractable organic N; POMN, particulate organic matter N; LFOMN; light fraction organic matter N; MinN, initial mineral N (NH_4-N + NO_3-N); N_0, potentially mineralizable N; Pool I, cumulative amount of N mineralized in the first 2 wk following rewetting; Pool II, cumulative amount of N mineralized between 2 and 24 wk.
[y]Standard error of mean ($n = 4$).
[x]Legumes vs. non-legumes.
a–c Means followed by different lower case letters are significantly different at $P < 0.05$.
*, ** Significant at $P < 0.05$ and $P < 0.001$, respectively; NS, not significant at $P < 0.05$.

and over 100% above normal at Scott. Mean air temperature during the growing season was within 0.5°C of the climate normal in all cases except for Scott, where the mean air temperature was 1.4°C below normal in both years. At each site, the straw yield was generally greater for the preceding non-legumes (canola and wheat), while the estimated crop residue N was greater for preceding faba bean green manure than the other preceding crops (Table 3).

Labile Organic N Fractions

The POMN was the largest fraction measured in this study, accounting for 5.7 to 12.7% of total soil N (Table 4). The MBN and LFOMN accounted for 0.9 to 2.7% and 1.1 to 5.3% of total N, respectively, whereas WEON accounted for about 0.2%. There was no effect ($P > 0.05$) of preceding crop on soil MBN, WEON, POMN or LFOMN at any site (Table 4). Contrast analysis showed that POMN was significantly ($P < 0.05$) greater following preceding non-legume than legume crops at Indian Head and Scott.

Soil Mineral N

Soil mineral N concentration ranged from 5.1 to 16.4 mg N kg^{-1} in the 0- to 15-cm layer (Table 4). Soil NO_3-N was the dominant form of mineral N at these sites (data not shown), accounting for more than 80% of the total mineral N at Brandon, Indian Head and Lethbridge, and between 60 and 70% at Lacombe and Scott. Significant differences in soil mineral N concentration among the preceding crops were observed at only two (Indian Head and Scott) of the five sites (Table 4). At Indian Head, soil mineral N was greater for preceding faba bean green manure and field pea crops than for preceding faba bean grain and canola crops (Table 4). At Scott, soil mineral N was greater for a preceding faba bean green manure than for all other preceding crops. Contrast analysis showed significantly greater soil mineral N concentrations following preceding legume than non-legume crops at Lacombe.

Mineralizable N Pools

N_0 ranged from 51 to 139 mg N kg^{-1} and represented 2 to 5% of total soil N. Pools I and II represented an average of 0.8 and 1.8% of total soil N, respectively. The N_0 varied significantly among the preceding crops only at Brandon (Table 4). At this site, N_0 was greater for a preceding faba bean green manure crop than for preceding canola, field pea and wheat crops (Table 4).

Soil N Supply

Canola grain yield from unfertilized plots ranged from 582 to 4283 kg ha^{-1}, while N uptake in the above-ground plant ranged from 26 to 229 kg N ha^{-1}. Canola grain yield varied significantly among preceding crops at all sites except Brandon (Table 5). At Indian Head, canola grain yield was greater for preceding faba bean green manure crop than faba bean grain, canola and wheat crops. At Lacombe, canola grain yield was greater for preceding faba bean green manure crop than field pea, canola and wheat crops. Canola grain yield at Lethbridge was greater for preceding faba bean green manure than canola, while at Scott, canola grain yield was greater for a preceding faba bean green manure than all other crops. A comparison between preceding legume and non-legume crops showed that canola grain yield was greater following legumes than non-legumes at Lacombe and Lethbridge.

Crop N uptake varied significantly among the preceding crops at three (Indian Head, Lacombe and Scott) sites (Table 5). At Indian Head, canola N uptake was greater for preceding faba bean green manure crop than faba bean grain, canola and wheat crops. At Lacombe, canola N uptake was greater for preceding faba bean green manure crop than field pea and canola crops. Canola grain yield at Scott was greater for a preceding faba bean green manure than all other preceding crops. Contrast analysis showed significantly greater canola N uptake following preceding legume than non-legume crops at Scott.

Relationship Between Soil N Supply and Individual Soil Parameters

Canola grain yield was related to N uptake ($r = 0.97$, $P < 0.001$, data not shown). The best single predictor of soil N supply was POMN ($R^2 = 0.56$ and $R^2 = 0.69$ for grain yield and crop N uptake, respectively; Fig. 1). Soil mineral N concentration (Fig. 1) and total soil N

Table 5. Canola grain yield and N uptake in 2010 following legume and non-legume crops at five sites. The preceding crops were harvested in fall 2009 and crop residues left on the soil surface in a no-till system

Site	Preceding crop	Grain yield (kg ha^{-1})	N uptake (kg N ha^{-1})
Brandon	Canola	1505 (221)[z]	56 (13)
	Faba bean	1719 (217)	67 (11)
	Field pea	1852 (243)	71 (12)
	Green manure	2000 (324)	73 (16)
	Wheat	1525 (410)	64 (17)
	P value	NS	NS
	Contrast[y]	NS	NS
Indian Head	Canola	1041 (416)*bc*	42 (15)*bc*
	Faba bean	582 (56)*c*	26 (6)*d*
	Field pea	1244 (38)*ab*	54 (4)*ab*
	Green manure	1621 (90)*a*	74 (3)*a*
	Wheat	879 (150)*bc*	43 (11)*bc*
	P value	**	*
	Contrast	NS	NS
Lacombe	Canola	2635 (334)*b*	125 (8)*c*
	Faba bean	3457 (123)*ab*	199 (15)*ab*
	Field pea	2766 (444)*b*	141 (19)*bc*
	Green manure	4283 (52)*a*	229 (26)*a*
	Wheat	2772 (657)*b*	161 (39)*ab*
	P value	*	*
	Contrast	*	NS
Lethbridge	Canola	1547 (86)*c*	64 (7)
	Faba bean	1990 (49)*abc*	80 (4)
	Field pea	2383 (323)*ab*	114 (24)
	Green manure	2637 (312)*a*	117 (22)
	Wheat	1979 (176)*abc*	90 (11)
	P value	*	NS
	Contrast	*	NS
Scott	Canola	1253 (194)*b*	50 (6)*b*
	Faba bean	1134 (259)*b*	65 (14)*b*
	Field pea	1398 (172)*b*	61 (3)*b*
	Green manure	2100 (124)*a*	97 (7)*a*
	Wheat	1185 (143)*b*	58 (11)*b*
	P value	*	*
	Contrast	NS	*

[z]Standard error of mean ($n = 4$).
[y]Legumes vs. non-legumes.
a–c Means followed by different lower case letters are significantly different at $P < 0.05$.
*, ** Significant at $P < 0.05$ and $P < 0.01$, respectively; NS, not significant at $P < 0.05$.

(Table 6) accounted for similar variations in N uptake but mineral N gave a slightly better prediction for yield. The N_0 and Pool II were poor predictors of soil N supply, explaining < 25 and < 30% of the variability in yield and N uptake, respectively (Table 6). Pool I explained only 22 and 25%, respectively, of the variation in canola grain yield and N uptake.

Prediction of Soil N Supply Using Multivariate Analysis

The PCA retained four PCs, accounting for 92% of the total variance (Table 7). The retained PCs explained > 80% of all parameters, except mineral N. The first PC accounted for 49% of the total variance and had positive loadings for LFOMN, WEON and N_0, and negative

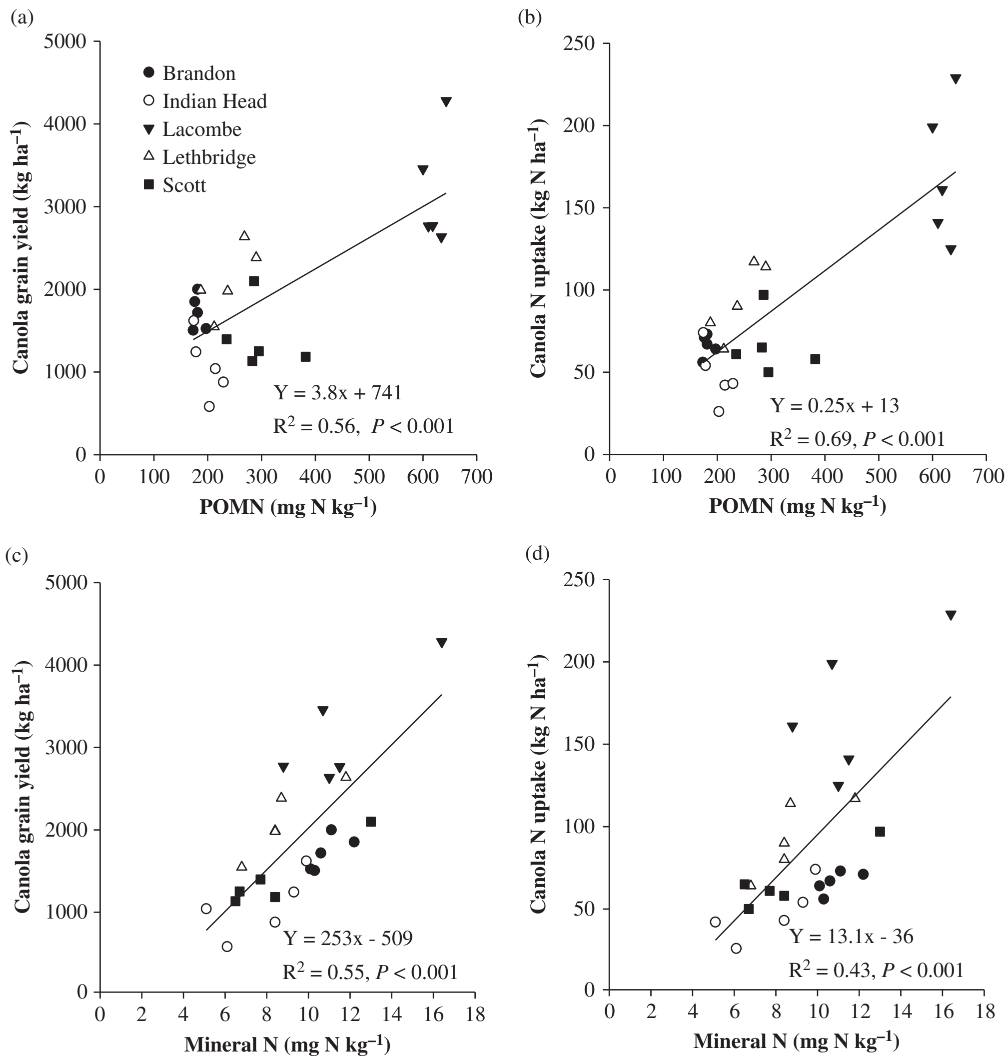

Fig. 1. Relationships between canola grain yield and N uptake and particulate organic matter N (POMN) (a and b) and initial mineral N (c and d) at the 0- to 15-cm depth. Initial mineral N (NH_4-N + NO_3-N) extracted with 0.01 M $CaCl_2$ prior to the start of the long-term incubation.

loadings for MBN and soil pH (Table 7). About 18% of the total variance was explained by PC_2 and was mainly composed of POMN, total soil N and mean air temperature. The third PC explained 15% of the total variance and had positive loading values for sand and total precipitation, and a negative value for clay. The fourth PC explained 10% of the total variance and was mainly composed of mineral N, Pool I and C:N ratio. Stepwise regression analysis was used to relate canola grain yield and N uptake, respectively, as the dependent variables and the retained PCs as independent variables. The combined PCs explained 75 and 71%, respectively, of the variations in canola grain yield and N uptake (Table 8). While three of the four PCs were significant to remain in the model for N uptake, all four PCs remained in the model for grain yield (Table 8). The PC_2 was the first selected in each model, accounting for 30 and 44%, respectively of canola grain yield and N uptake (Table 8). This was followed by PCs 3, 4 and 1 for grain yield and PCs 3 and 4 for N uptake. The proportion of the total variability of grain yield and N uptake explained by PC_3 was 20 and 15%, respectively, while the proportion explained by PC_4 was 18 and 12%, respectively.

DISCUSSION

Canola Grain Yield and N Uptake

The trend towards greater canola grain yield at four of five sites and greater N uptake at three of five sites following preceding faba bean green manure versus other preceding legume and non-legume crops suggests that faba bean green manure can reduce the need for external N inputs in canola production. This result is

Table 6. Linear regressions relating labile organic N fractions, N_0, mineralizable N pools and other soil properties at the 0- to 15-cm depth to canola grain yield and N uptake following legume and non-legume crops across five sites

	Canola grain yield (kg ha^{-1})			Canola N uptake (kg N ha^{-1})		
Independent variable[z]	Intercept	slope	R^2	Intercept	slope	R^2
LFOMN (mg N kg^{-1})	2485	−8.53	0.11	112	−0.34	0.05
MBN (mg N kg^{-1})	1860	0.92	0.00	102	−0.32	0.00
WEON (mg N kg^{-1})	1130	153	0.02	51	7.54	0.01
N_0 (mg N kg^{-1})	673	13.7	0.20*	4.59	0.94	0.27**
Pool I (mg N kg^{-1})	1018	36.1	0.22**	33.2	2.28	0.25*
Pool II (mg N kg^{-1})	697	24.2	0.18*	5.75	1.67	0.25*
Clay (mg kg^{-1})	3036	−4.66	0.28**	148	−0.24	0.22*
Silt (mg kg^{-1})	966	2.19	0.02	46	0.10	0.01
Sand (mg kg^{-1})	892	3.04	0.15*	36	0.16	0.13
Total N (g N kg^{-1})	386	502	0.40***	−8.41	32.3	0.47***
pH	2690	−113	0.02	180	−13.05	0.06

[z]LFOMN, light fraction organic matter N; MBN, microbial biomass N; WEON, water-extractable organic N; N_0, potentially mineralizable N; Pool I, cumulative amount of N mineralized in the first 2 wk following rewetting; Pool II, cumulative amount of N mineralized between 2 and 24 wk.
*, **, *** Significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.

partly due to the larger amount of crop residue N returned by the preceding faba bean green manure crop compared with the other crops where the seeds were harvested. Although straw yield of the faba bean green manure crop was lower than canola, wheat and field pea at all sites, except that field pea was greater at Lethbridge, only the straw of field pea, canola and wheat were returned as crop residues, while the entire faba bean plant was present as crop residues in the faba bean green manure plots. The presence of a greater amount of N-rich residues may have caused higher net N mineralization in the faba bean green manure plots during the growing season compared with the other plots and mineralization may have varied according to soil properties and climatic conditions across the sites. No information on the quantity and quality of below-ground plant residues was collected in this study but Unkovich and Pate (2000) reported that about 40% of the total plant N in faba bean is found below ground. The greater N_2-fixation potential of faba bean (12–330 kg N_2 ha^{-1} yr^{-1}) (Lupwayi and Kennedy 2007) than field pea may also account for these results. It was estimated that field pea fixed about 90 kg N_2 ha^{-1} yr^{-1} in the Canadian prairies (Biederbeck et al. 1996), while in Australia, Unkovich and Pate (2000) reported that faba bean fixed 144 kg N_2 ha^{-1} in comparison with 96 kg N_2 ha^{-1} by field pea. It should also be noted that a considerable amount of N is removed from the soil-plant system in legume crops when they are harvested for seed, unlike when grown as green manure crop. Many studies reported increased N availability following legumes (Soon et al. 2001; Campbell et al. 2011; Zotarelli et al. 2012) as a result of faster decomposition of N-rich legume residues. In our study, canola grain yield was greater following legumes than non-legumes at Lacombe and Lethbridge only, while N uptake was

Table 7. Rotated principle components (PCs) and total communality estimates (CE) for prediction of soil N supply to canola following legume and non-legume crops across five sites

Parameters[z]	PC_1	PC_2	PC_3	PC_4	CE
LFOMN (mg N kg^{-1})	0.94				0.92
POMN (mg N kg^{-1})		0.93			0.98
MBN (mg N kg^{-1})	−0.91				0.90
WEON (mg N kg^{-1})	0.59				0.88
MinN (mg N kg^{-1})				0.78	0.70
N_0 (mg N kg^{-1})	0.61				0.92
Pool I (mg N kg^{-1})				0.62	0.89
Clay (g kg^{-1})			−0.90		0.95
Sand (g kg^{-1})			0.97		0.97
Total N (g N kg^{-1})		0.78			0.94
pH	−0.86				0.99
Mean Temperature (°C)		−0.93			0.97
Total Precipitation (mm)			0.72		0.94
C/N				0.58	0.85
Eiegenvalues	6.87	2.53	2.05	1.36	
Variance proportion	0.49	0.18	0.15	0.10	
Cumulative variance	0.49	0.67	0.82	0.92	

[z]LFOMN, light fraction organic matter N; POMN, particulate organic matter N, MBN, microbial biomass N; WEON, water-extractable organic N; MinN, initial mineral N (NH_4-N + NO_3-N); N_0, potentially mineralizable N; Pool I, cumulative amount of N mineralized in the first 2 wk following rewetting; C/N, soil C/N ratio.

Table 8. Stepwise regression models relating canola grain yield and N uptake to retained PCs

Equation	R^{2z}
Canola grain yield (kg ha^{-1})	
$Y = 1899 + 460 \times PC_2$	0.30
$Y = 1899 + 460 \times PC_2 + 384 \times PC_3$	0.50
$Y = 1899 + 460 \times PC_2 + 384 \times PC_3 + 358 \times PC_4$	0.68
$Y = 1899 + 460 \times PC_2 + 384 \times PC_3 + 358 \times PC_4 - 225 \times PC_1$	0.75
Canola N uptake (kg N ha^{-1})	
$Y = 89 + 33 \times PC_2$	0.44
$Y = 89 + 33 \times PC_2 + 19 \times PC_3$	0.59
$Y = 89 + 33 \times PC_2 + 19 \times PC_3 + 18 \times PC_4$	0.71

[z]All models were significant at $P < 0.001$.

greater following legumes at Scott only. This suggests that the relative benefit of legumes in crop rotations may not be obvious in the short-term and depends on the specific legume species, the quality of the legume residue, the legume biomass yield, whether the legume is grown for seed or as a green manure crop since considerable N is removed in the harvested seed, and the effect of soil and climatic conditions (Kumar and Goh 1999; Thorup-Kristensen et al. 2003).

Labile Organic N Fractions and Mineral N

A major goal of this study was to determine how residues from the preceding crops affected other components of the soil N supply, namely soil MBN, POMN, LFOMN, WEON and soil mineral N concentrations. This study showed no influence of preceding crops on soil MBN, WEON, POMN and LFOMN at any sites. These labile organic N fractions are known to be relatively variable and responsive to changes in management (Griffin and Porter 2004; Haynes 2005) but this was not detectable after a single rotation in this study. Although the N concentrations of the crop residues were higher for the preceding legumes than preceding non-legumes, the total quantity of crop residue returned was greater for the non-legumes. This could also have contributed to the similar labile organic N concentrations among the preceding crops in the short-term. Previous findings suggest that changes in labile organic N fractions due to crop rotations may not be obvious in the short-term but rather in the long-term (Biederbeck et al. 1998; Campbell et al. 2001). Nonetheless, the results of this 1-yr study are similar to some long-term studies on the effect of crop rotation on MBN (Griffin and Porter 2004; Franchini et al. 2007; Sainju et al. 2007), POMN and LFOMN (Sharifi et al. 2008b; Sequeira and Alley 2011). In a 2-yr study in Alberta, Canada, Soon et al. (2001) found similar MBN concentrations following spring wheat, red clover (*Trifolium pratense* L.) green manure and field pea. Even after 20 yr, Balota et al. (2003) found similarities in MBN concentrations at 0- to 5-cm soil depth among soybean [*Glycine max* L.]–wheat, corn–wheat and cotton [*Gossypium* spp.]–wheat rotations in a no-till soil in Brazil. Conversely, Biederbeck et al. (2005) found greater (>60%) MBN concentrations after 6 yr at the 0- to 10-cm depth in legume green manure-wheat rotations compared with conventional fallow–wheat and continuous wheat rotations in a conventionally tilled semi-arid Canadian prairie soil. The legumes used by Biederbeck et al. (2005) were black lentil (*Lens culinaris* Medikus), Tangier flatpea (*Lathyrus tingitanus* L.), chickling vetch (*Lathyrus sativus* L.) and field pea (*Pisum sativum* L.). Furthermore, Griffin and Porter (2004) reported that the inclusion of red clover as cover crop in 2-yr potato (*Solanum tuberosum* L.) rotations increased the proportion of total soil N as POMN by 13–20% compared with rotations that did not contain a legume cover crop. The proportion of total soil N attributed to the labile organic N fractions was within the reported range for MBN (Campbell et al. 1991a; Willson et al. 2001; Biederbeck et al. 2005), WEON (Zsolnay 1996; Chantigny et al. 2010), POMN and LFOMN (Janzen et al. 1992; Gregorich et al. 2006; Sharifi et al. 2007b, 2008a; Sequeira and Alley 2011).

Soil mineral N concentrations varied at only two (Indian Head and Scott) of the five sites and were greater following faba bean green manure at these sites. This was attributed to the higher N_2-fixation potential of faba bean (Lupwayi and Kennedy 2007) and greater quantities of crop residue N returned by faba been green manure (Unkovich and Pate 2000) resulting in greater residual soil N at the two sites. The slow decomposition of N-poor residues (non-legumes) and possible volatilization of N from the N-rich residues (legumes) on the soil surface (Schoenau and Campbell 1996) could also account for the similarities in mineral N concentrations. Another possible explanation could be due to the duration of the experiment since studies (Zebarth et al. 2009a,b) show that management of preceding crops may have limited impact on soil mineral N in the subsequent year. Finally, the sampling depth (0–15 cm) used in this study was possibly not adequate to fully account for residual N from the preceding legumes in these prairie soils (Soper and Huang 1963; Soper et al. 1971). Additional N might have been found if soil samples were taken to a depth of 60 cm, since NO_3-N was probably leached below the 15-cm depth (Malhi et al. 2009).

Mineralizable N Pools

In this study, the fixed-k approach was used to estimate N_0. Wang et al. (2003) suggested using a fixed k value to eliminate the confounding effect of k on N_0 thereby allowing N_0 to be a single indicator of the size of the mineralizable N pool. The N_0 differed among the preceding crops only at Brandon, implying that N_0 was more influenced by site-specific conditions than the preceding crops (Wang et al. 2003; Dessureault-Rompre et al. 2010) since this was the first year of the study. Dessureault-Rompre et al. (2010) argued that N_0 is a reflection of mineralizable N that is a function of soil properties, climatic zones and organic amendments and less responsive to recent cropping. In a 30-yr crop rotation study in a thin Black Chernozem soil, N_0 was greater in legume green manure-wheat rotations than fallow-wheat-wheat rotations (Campbell et al. 1991b). Pool I, which is very labile and more responsive to recent cropping, did not vary among the preceding crops. In soils with low SON content under humid conditions in eastern Canada, Zebarth et al. (2009a) found no effect of fertilizer N management on Italian ryegrass (*Lolium multiflorum* Lam.) crop on labile mineralizable N, while Sharifi et al. (2009) reported higher concentrations of Pool I in 2-yr potato rotations that included legumes in comparison with non-legumes. In both of these studies, the preceding crop residues were incorporated, but were left on the soil surface in the current study. The N_0, Pool I and Pool II values were similar to those reported in other studies using annual crops (Sharifi et al. 2007a, 2009; Nyiraneza et al. 2012), but slightly lower than in others (Campbell et al. 1991b; Sharifi et al. 2008a, 2011) where long-term crop rotations, tillage, and organic amendment history were investigated.

Prediction of Soil N Supply

A major objective of this study was to identify parameter(s) that could be used as an indicator of soil N supply for canola production. The significant relationship between canola grain yield and N uptake suggests that N was a limiting factor across these sites. Hence, the use of grain yield as a measure of soil N supply was valid. We found that POMN was the best single predictor of soil N supply to canola in this study. However, the relationship was driven to a large extent by two clusters of data points, one cluster for the Lacombe site and the other cluster for the four remaining sites. This was due to the greater total soil N concentration at the Lacombe site relative to the other sites. Furthermore, the relationship within each site was not particularly robust. This suggests that the differences in soil N supply at each site after one rotation cycle was not accurately accounted for by POMN, most likely due to the differences in quantity of returned residues and their mineralization rates. Studies show that POMN may vary monthly or seasonally, depending on site characteristics, timing, quantity and quality of organic residue inputs and the time of soil sampling for POM extraction (Boone 1994). Hence, POMN is a dynamic pool that changes over time.

The POMN is an intermediate pool between fresh plant residues and stabilized organic N that is mostly associated with sand-sized particles in soils (Gregorich et al. 2006). The fact that POMN was the largest labile organic N fraction measured indicates that there was possibly an accumulation of POMN due to slow decomposition of crop residues resulting from the no-till practices and the sub-humid to semi-arid conditions at the sites (Biederbeck et al. 1994; Liang et al. 2004; Malhi et al. 2008, 2011b). Slow decomposition of crop residues on the soil surface in no-till systems is mainly due to enhanced aggregate formation that can protect the residues from microbial access (Six et al. 1999) and to reduced contact of crop residues with the soil particles, resulting in lower nutrient availability to microbes colonizing the surface residues (Schoenau and Campbell 1996). Additionally, reduced moisture availability in semi-arid conditions can constrain decomposition. During the growing season, the accumulated POMN could have mineralized, thereby increasing soil mineral N availability, particularly in the faba bean green manure plots. Studies reported that POM is a readily available substrate for microbes and a major source of N to crops (Whalen et al. 2000; Gregorich et al. 2006). The relationship between POMN and soil N supply was better than reported in some studies (Sharifi et al. 2007a, 2008b), but weaker than in others (Spargo et al. 2011). However, these studies were conducted under wetter conditions, with different crops and over a longer period of time in comparison with the current study. This was the first study to relate POMN to soil N supply in canola production. Pre-plant soil mineral N and total soil N were also good indicators of soil N supply in this study. Other studies reported comparable results for soil mineral N as a predictor of soil N supply (Hong et al. 1990; Sharifi et al. 2007a, 2008b), while the predictions were better in others (Soper et al. 1971; Malhi et al. 1992; Nyiraneza et al. 2009; Sharifi et al. 2009). It is well documented that NO_3-N measured up to the 60-cm depth plays a major role in determining soil N supply in prairie soils (Soper and Huang 1963). Soper et al. (1971) found a better relationship between barley N uptake and NO_3-N measured at 61 cm ($R^2 = 0.84$) than NO_3-N measured at 30 cm ($R^2 = 0.64$) or at 15 cm ($R^2 = 0.32$). In spite of these findings, the 0- to 15-cm sampling depth was used in our study since soil biochemical activity is more pronounced at the soil surface. Hence, most indices of N availability reflect surface processes. In addition, the potential to detect differences in soil mineral N concentration and other parameters, such as POMN, in these no-till sites would be greatly diluted if greater sampling depths were used, particularly as the crop residues were not incorporated in the soil. Nevertheless, regardless of the sampling depth, the use of soil mineral N or NO_3-N to predict soil N supply could be problematic since soil mineral N concentration changes rapidly, making the values sensitive to sampling date (Sharifi et al. 2007a).

N_0 was not an accurate predictor of soil N supply in this study, suggesting that N_0 may not be a good estimator of the fertilizer N needs of crops. Other studies reported similar findings and suggested that N_0 cannot accurately simulate microbial activity, or reflect crop effects and possible N losses under field conditions (Sharifi et al. 2007a; Nyiraneza et al. 2012). In addition, Campbell et al. (1991b) argued that the initial potential rate of N mineralization (N_0k) was a more sensitive parameter than N_0 and may be a more useful index for identifying the beneficial effects of legume green manures in cereal rotations. Conversely, Spargo et al. (2011) reported that N_0 was a reliable predictor of corn grain yield ($r = 0.87$, $P < 0.001$) and N uptake ($r = 0.83$, $P < 0.001$) across different organic and conventional cropping systems at one site in Maryland, USA.

Combining soil physio-chemical properties and climatic variables (e.g., precipitation) gave the best prediction of soil N supply to canola. Up to 68 and 71% of the variations in yield and N uptake, respectively, were explained when PC_2, PC_3 and PC_4 were added to the statistical model. Taking into account the loading values, PC_2 was interpreted as POMN across a temperature gradient. The PC_3 represented soil texture effect across a precipitation gradient, while PC_4 represented plant-available N. The PC_1 represented a minor source of mineralizable N in which soil pH played a significant role. Because PC_1 accounted for only 7% of the total variability in grain yield, it can be concluded that POMN and soil mineral N accounted for much of the variation in soil N supply to canola across these no-till sites with soil texture influencing the magnitude of N supply.

CONCLUSION

Although some effects of preceding legume crops on soil N supply were identified in this study, the magnitude of the impact varied across legume species, soil properties and climatic conditions. This study demonstrated that soil MBN, WEON, POMN and LFOMN may not be responsive to preceding crops in the short-term in no-till systems. Due to possible accumulation and subsequent mineralization of POMN, the results indicate that POMN and mineral N are relatively good predictors of soil N supply to canola under sub-humid and semi-arid conditions in western Canada and that soil texture also influences the soil N supply. This suggests that canola N fertilizer recommendations may be improved by taking into account POMN and pre-plant soil mineral N concentrations as well as soil texture. The POMN was the largest pool of labile organic N in soils under no-tillage and may represent a fraction of SON that is decomposed early in the growing season, thereby furnishing plant-available N to canola during early vegetative growth and when N requirements are greatest (five-leaf stage to full bloom; Canola Council of Canada 2012b). More research on the mechanisms controlling the formation and dynamics of POMN are needed to better understand its role in agricultural soils for improved N management.

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