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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

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 the more decomposable legume straw and roots (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.

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).

Since a large proportion of soil organic N (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). 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.

The objectives of this study were to (1) assess the short-term impact of legume and non-legume preceding crops on soil MBN, WEON, POMN, LFOMN, mineral N, potentially mineralizable N (N_0), and field-based indices of soil N supply (canola yield and N uptake) and (2) test the feasibility of using these parameters as predictors of soil N supply.

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; Indian Head, Saskatchewan; Scott, Saskatchewan; Lacombe, Alberta; and Lethbridge, Alberta. Before the experiment was initiated, the sites were cropped with either barley or spring wheat.

Experimental design

The experiment compared five preceding crop treatments established in 2009 in a randomized complete block design with four blocks. Field pea, faba bean managed for grain, faba bean managed as green manure, canola, and wheat were established as the main plots in 2009. 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 in the faba bean green manure plots. No-till practices were used at all sites.

Plant analysis

For canola plots receiving only starter fertilizer in 2010, canola grain yield and total N uptake in the above-

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ground plant were used as field-based measures of soil N supply. Total N uptake (kg N ha^{-1}) was calculated as: (total N concentration in grain x grain yield) + (total N concentration in straw x 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 taken up by the canola plant.

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 (data not shown). 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 (data not shown). 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 (data not shown).

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 (data not shown). 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 (data not shown). 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 0-15 cm layer (data not shown). 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 to 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 (data not shown). 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 (data not shown). 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

The N_0 represented 2 to 5% of total soil N. The N_0 varied significantly among the preceding crops only at Brandon (data not shown). At this site, N_0 was greater for a preceding faba bean green manure crop (data not shown).

Soil N supply

Canola grain yield varied significantly among preceding crops at all sites except Brandon (Table 1). 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 1). 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 strongly 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; data not shown). Soil mineral N concentration (data not shown) and total soil N (data not shown) accounted for similar variations in N uptake but mineral N gave a slightly better prediction for yield.

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 partly due to the larger amount of crop residue N returned by the preceding faba bean green manure crop compared to the other crops where the seeds were harvested. The presence of a greater amount of N-rich residues may have caused greater net N mineralization in the faba bean green manure plots during the growing season compared to the other plots. The greater N_2-fixation potential of faba bean (12-330 kg N_2 ha^{-1} y^{-1}) (Lupwayi and Kennedy 2007) than field pea may also account for these results. In our study, canola grain yield was greater following legumes than non-legumes at Lacombe and Lethbridge only, while N uptake was 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).

Table 1. *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, MB	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[y]	NS
	Contrast[x]	NS	NS
Indian Head, SK	Canola	1041 (416)bc[w]	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[x]	NS	NS
Lacombe, AB	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[x]	*	NS
Lethbridge, AB	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[x]	*	NS
Scott, SK	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[x]	NS	*

[z] Standard error of mean (n=4)
[y] Not significant at P < 0.05
[x] Legumes vs. non-legumes
[w] Means followed by the same lower case letter are not significantly different at $P < 0.05$
* Significant at $P < 0.05$
** Significant at $P < 0.01$

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. 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 from this one-year 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).

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 bean 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.

Mineralizable N pools

The N0 differed among the preceding crops only at Brandon, implying that N0 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.

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 differences in soil N supply at each site after one rotation cycle were 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 particulate organic matter (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).

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. 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). In spite of these findings, the 0-15 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, 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).

The N_0 was not an accurate predictor of soil N supply in this study, suggesting that N_0 may be not be a good estimator of the fertilizer N needs of crops. Other studies reported similar findings and suggested that N_0 used alone cannot accurately simulate microbial activity, nor reflect crop effects and possible N losses under field conditions (Sharifi et al. 2007a; Nyiraneza et al. 2012).

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 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.