Canadian Journal of Soil Science

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Journal:	<i>Canadian Journal of Soil Science</i>
Manuscript ID	CJSS-2021-0078.R3
Manuscript Type:	Short Communication
Date Submitted by the Author:	20-Sep-2021
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Is the invited manuscript for consideration in a Special Issue?_:	Not applicable (regular submission)
Keywords:	brassica crops, mineral N, nitrogen fertilizer guidelines, rapeseed, site-specific fertilization

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Soil nitrogen dynamics in canola agroecosystems of eastern Canada

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ABSTRACT

Canola (*Brassica napus* L.) is a nitrogen (N)-demanding crop, so tissue N analysis should be related to soil N supply. We evaluated canola N uptake in relation to soil N pools in plots receiving 0, 50, 100 and 150 kg N ha⁻¹ from urea at three sites in eastern Canada in 2012. Soil N pools varied significantly at the rosette, flowering, pod filling and maturity stages, but responded less predictably to urea. Canola N uptake was inconsistently related to soil N pools and urea input. This confirms the importance of site-specific N fertilizer management when growing canola in eastern Canada.

Key words: brassica crops, mineral N, nitrogen fertilizer guidelines, rapeseed, site-specific fertilization

INTRODUCTION

Canola acreage is expanding in eastern Canada due to increased processing capacity of crushing facilities in Quebec and Ontario that can produce edible oil, high-protein meal to supplement animal feed, and biofuel (Ma et al. 2015). Canola is considered a specialty crop in eastern Canada, with 25.7–36.5 thousand Mg oilseed y^{-1} produced in Quebec from 2016–2019 (Institut de la statistique du Québec 2019) whereas Alberta produced 5320–6826 thousand Mg oilseed y^{-1} during the same period (Statistics Canada 2021). Agronomic practices to optimize canola growth, such as nitrogen (N) fertilization guidelines, were developed in western Canada but these may not be suitable in eastern Canada. Nitrogen leaching and gaseous loss are more likely in the humid temperate soils of eastern Canada than in semi-arid western Canada, but N mineralization rates from soil organic matter and residues are also higher (St. Luce et al. 2011). It is possible that canola will benefit from higher fertilizer N rates in eastern Canada.

Region-specific fertilizer N guidelines for canola must consider soil N dynamics in relation to crop N uptake. Our objectives were to: 1) determine soil nitrate (NO_3-N), ammonium (NH_4-N), and microbial biomass N (MBN) concentrations in canola field plots with variable N fertilizer inputs, and 2) relate these soil N pools to canola N uptake at key growth stages, based on data from three canola field sites in eastern Canada.

MATERIALS AND METHODS

Site Descriptions

Field experiments were established in the 2012 growing season. The Emile A. Lods Agronomy Research Centre in Ste-Anne-de-Bellevue, Quebec ($45^{\circ}03' N$, $74^{\circ}11' W$, later referred to as ‘Ste-Anne’) was on a sandy loam soil of the Chicot series (Humic Gleysol) with

pH 5.0 and 34.0 g organic matter kg⁻¹, and fallow in the preceding crop year. The Université Laval Experimental Farm near Saint-Augustin-de-Desmaures, Quebec (46°44' N, 71°31' W, later referred to as 'Quebec'), was on a sandy loam soil of the Orthic series (Dystric Brunisol) with pH 6.1 and 37.0 g organic matter kg⁻¹, and wheat (*Triticum aestivum* L.) grown in the preceding crop year. The Central Experimental Farm of Agriculture and Agri-Food Canada, Ottawa (45°38' N, 74°58' W, later referred to 'Ottawa') was on a sandy loam soil of the Orthic series (Melanic Brunisol) with pH 6.5 and 40.3 g organic matter kg⁻¹, and soybean (*Glycine max* (L.) Merr.) grown in the preceding crop year.

Experimental Design

Plots in this study were a subset of treatments from a larger field experiment described by Ma et al. (2015) and Ma et al. (2019). Briefly, the field experiment had 26 treatment combinations, arranged in a randomized complete block design with four replicate blocks. We investigated the N treatment factor (fertilizer N application rate) with four levels (0, 50, 100, 150 kg N ha⁻¹) and four blocks at each site, giving 16 plots per site and 48 plots in total at the three sites. Plot dimensions were 2.6 m x 4 m with a 0.50 m spacing between each plot and 1.3 m wide buffer zone between blocks.

Urea [(NH₂)₂CO, 46-0-0] was broadcast on the soil surface, then incorporated to a depth of 0.10 m about 24–48 h before seeding canola (*B. napus* L. cv. InVigor 5440, LL) at a rate of 5 kg ha⁻¹ and seeding depth of 1–2 cm. If necessary, the plots received a basal application of phosphorus and potassium fertilizers according to the soil test recommendation for the site, but no sulfur or boron was applied, and the fields were not irrigated. Cultural practices (basal

fertilization, tillage, weed control) and the daily mean temperature and precipitation at each site are described in Ma et al. (2015).

Plant Sampling and Analysis

In 2012, canola plants were collected from each plot at four growth stages: i) rosette (May), ii) 20% flowering (June), iii) 80% pod filling (July), and iv) 90% physiological maturity (August). Five representative plants were randomly uprooted from the first seven rows of each plot. Roots and shoots were separated, washed, dried at 60°C, and weighed to determine biomass. Dried plant components were finely ground (<0.1 mm) and N concentration was analyzed by combustion at 900°C with a Thermo Finnigan Flash EA 1112 series C/N analyzer (Carlo Erba, Milan, Italy). Unfortunately, samples were lost from flowering and pod filling stages at Ste-Anne. Canola N uptake was the sum of the biomass x N concentration for roots and shoots in each plot, and the complete dataset is provided in Gurung (2014).

Soil Sampling and Analysis

Composite soil samples (0–20 cm, sieved < 4 mm in the field) were collected from each plot at the canola growth stages described above. Soil was stored at 4°C until analysis, within 7 d. The soil mineral N ($\text{NH}_4\text{-N}$ + $\text{NO}_3\text{-N}$) concentration was determined in a 10 g subsample of field-moist soil extracted with 0.5 M K_2SO_4 (1:4 soil:extractant) followed by colorimetric analysis of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ concentrations at 650 nm using a modified indophenol blue method. Soil MBN concentration was analyzed by chloroform fumigation-direct extraction after comparing the dissolved N concentration in persulphate digests of fumigated and unfumigated

field-moist soils extracted with 0.5 M K_2SO_4 (1:4 soil:extractant). Soil MBN concentration was calculated as [(total N in fumigated soil extracts - total N in unfumigated soil extracts)/0.54].

Net N mineralization during an aerobic soil incubation was assessed with ~25 g of sieved, field-moist soil from each plot that was moistened to 60% water-filled pore space and placed in an incubator at 21°C for 28 d. Mineral N concentration in 0.5 M K_2SO_4 extracts of the incubated soil (after 28 d) was determined colorimetrically, as described above. Net mineralization rate ($mg\ NH_4\ kg\ soil^{-1}\ d^{-1}$) and net nitrification rate ($mg\ NO_3-N\ kg\ soil^{-1}\ d^{-1}$) was the difference in NH_4-N or NO_3-N concentration of the collected field-moist soil (initial) and the incubated soil divided by incubation time. Soil mineral N supply was the sum of the net mineralization and net nitrification rates for a given soil, at a given sampling point.

Statistical Analysis

Data residuals were tested for normality with the Kolmogorov-Smirnov test in the PROC UNIVARIATE procedure of SAS (version 9.1). For each site, the effects of fertilizer N and canola growth stage on soil NH_4-N , NO_3-N , soil MBN, and soil mineral N supply were evaluated with a repeated measures ANOVA using PROC MIXED with canola growth stage as the repeated measure. The effect of fertilizer N and canola growth stage on canola N uptake at each site was assessed with PROC GLIMMIX, to account for missing data at the Ste-Anne site, with canola growth stage as the repeated factor. Significant effects ($P < 0.05$) were analyzed using Scheffe's multiple comparisons test at the 95% confidence level.

RESULTS AND DISCUSSION

The mineral N concentration varied significantly with growth stage ($P < 0.001$), but did not respond consistently to fertilizer N rates across sites (Table 1). At Ste-Anne, soil $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ concentrations, as well as soil $\text{NO}_3\text{-N}$ concentration in Ottawa, varied significantly with higher fertilizer N rates ($P < 0.001$), but did not affect the $\text{NH}_4\text{-N}$ concentration in Ottawa or the mineral N concentration in Quebec, (Table 1). The fertilizer N source was urea, which is hydrolyzed to ammonia and protonated as $\text{NH}_4\text{-N}$, so we expect $\text{NH}_4\text{-N}$ to be biologically transformed, i.e., through ammonia oxidation. This was the case at the Quebec and Ottawa sites, which generally had $<10 \text{ mg NH}_4\text{-N kg}^{-1}$ in topsoil (0–20 cm depth) during the 2012 season (Gurung 2014). However, at the Ste-Anne site, the higher extractable $\text{NH}_4\text{-N}$ concentration in fertilized plots at the rosette stage (from 5.0 to 43 $\text{mg NH}_4\text{-N kg}^{-1}$ in the 0–5 cm depth) compared to the unfertilized control (0.8 $\text{mg NH}_4\text{-N kg}^{-1}$ in the same depth; Gurung 2014) suggests that ammonia oxidation was constrained during early canola growth, possibly because of a limited carbon supply due to no crop residues from the previous season. By canola maturity, the $\text{NH}_4\text{-N}$ concentration at the Ste-Anne site was $<4 \text{ mg NH}_4\text{-N kg}^{-1}$ in topsoil (Gurung 2014). Ammonia oxidation and nitrification likely contributed to the elevated $\text{NO}_3\text{-N}$ concentration in N fertilized plots at Ste-Anne (from 34 to 79 $\text{mg NO}_3\text{-N kg}^{-1}$ with N fertilizer vs. 15 $\text{mg NO}_3\text{-N kg}^{-1}$ in unfertilized plots at 0–5 cm depth, rosette stage) and Ottawa (from 18 to 56 $\text{mg NO}_3\text{-N kg}^{-1}$ with N fertilizer vs. 10 $\text{mg NO}_3\text{-N kg}^{-1}$ in unfertilized plots at 0–5 cm depth, rosette stage; Gurung 2014). Another study of soil N dynamics in canola fields around the Ottawa region reported 6 to 10 times greater $\text{NO}_3\text{-N}$ concentration than $\text{NH}_4\text{-N}$ concentration in this humid temperate region (Ma and Herath 2016). The biological processes that transform fertilizer N to $\text{NO}_3\text{-N}$ need to be monitored due to the vulnerability of $\text{NO}_3\text{-N}$ to run-off, leaching, and denitrification (St Luce et al. 2011).

The MBN concentration and soil mineral N supply varied significantly with growth stage ($P < 0.001$) but were not affected by the fertilizer N rate (Table 1). This suggests that the microbial biomass has a fixed capacity to immobilize fertilizer N and remains relatively constant, regardless of changing soil conditions and nutrient availability during the growing season, which is similar to other reports (Puri and Ashman 1998). Furthermore, varying the fertilizer N rate did not change the net N mineralization and nitrification rates, meaning that soil mineral N supply at these field sites were more dependent on organic N in the soil than fertilizer N application.

The lowest canola N uptake at Ste-Anne was measured at rosette stage in the 0 kg N ha⁻¹ treatment, but at 90% maturity, canola N uptake was similar across fertilizer rates (Fig. 1). Still, the soil NO₃-N concentration remained elevated in the 150 kg N ha⁻¹ treatment at maturity, with 6.9 mg NO₃-N kg⁻¹ in the 0–5 cm depth, relative to plots that received 0, 50, or 100 kg N ha⁻¹ and contained ≤ 1.6 mg NO₃-N kg⁻¹ (Gurung 2014). This indicates that canola did not use all of the mineral N supplied in the 150 kg N ha⁻¹ treatment, an undesirable agro-environmental outcome. At the Ottawa site, soil NO₃-N was highest in plots receiving 150 kg N ha⁻¹ at maturity (15 mg NO₃-N kg⁻¹ in the 0–5 cm depth) and lowest in unfertilized plots (3.9 mg NO₃-N kg⁻¹ in the 0–5 cm depth; Gurung 2014), but canola N uptake was similar among fertilizer N rates at each growth stage (Fig. 1). At Quebec, canola required at least 50 kg N ha⁻¹ for optimal growth and there was no change in canola N uptake when 100 or 150 kg N ha⁻¹ was applied. Previous work by Ma and Herath (2016) on canola in eastern Canada found that the majority (>50%) of canola N uptake was from soil mineral N rather than fertilizer N, based on three canola growing seasons. Therefore, the recommended rate of 100–150 kg N ha⁻¹ for canola in Quebec and Ontario will meet the crop requirements, based on canola N uptake.

We acknowledge that canola N uptake does not always translate into greater yield or NUE. In a companion paper, Ma et al. (2020) found that canola yield plateaued when 150 kg N ha⁻¹ was applied to the Quebec and Ste-Anne sites, whereas maximum yield was achieved with 75 kg N ha⁻¹ plus supplemental sulfur (S) at 20-40 kg S ha⁻¹ at the Ottawa site. Consequently, there is an opportunity to fine-tune the fertilizer N recommendation in eastern Canada on a site-specific basis, and it is important to also consider S requirements of canola.

CONCLUSION

The contrasting response to soil N pools, N fertilization, and canola N uptake at three sites highlights the importance of site-specific management practices for growing canola in eastern Canada. Three sites within 400 km of each other responded uniquely to the same fertilizer N rate applied to the same canola hybrid. Diagnostic tools based on nutritional indices or proximal chlorophyll meters may have potential to resolve the spatio-temporal heterogeneity in canola N nutrition to make timely fertilizer decisions in eastern Canada.

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Table 1. Analysis of variance of the effects of nitrogen fertilizer rate and plant growth stage on soil nitrogen pools in canola fields at three sites in eastern Canada in 2012.

Soil Characteristic	Source of Variation		
	Fertilizer N Rate	Growth Stage	Rate*Stage Interaction
Ste-Anne			
NO ₃ -N (mg kg ⁻¹)	< 0.001	< 0.001	< 0.001
NH ₄ -N (mg kg ⁻¹)	< 0.001	< 0.001	< 0.001
MBN (mg kg ⁻¹)	NS	< 0.001	NS
Mineral N supply (mg kg ⁻¹ d ⁻¹)	NS	< 0.001	NS
Quebec			
NO ₃ -N (mg kg ⁻¹)	NS	< 0.001	< 0.001
NH ₄ -N (mg kg ⁻¹)	NS	< 0.001	NS
MBN (mg kg ⁻¹)	NS	< 0.001	NS
Mineral N supply (mg kg ⁻¹ d ⁻¹)	NS	<0.001	NS
Ottawa			
NO ₃ -N (mg kg ⁻¹)	<0.001	<0.001	NS
NH ₄ -N (mg kg ⁻¹)	NS	<0.001	NS
MBN (mg kg ⁻¹)	NS	<0.001	NS
Mineral N supply (mg kg ⁻¹ d ⁻¹)	NS	<0.001	NS

Note: NS = not significant. Mineral N supply refers to the net nitrogen mineralization and nitrification rates.

FIGURE CAPTIONS

Figure 1. Canola N uptake (g N plant⁻¹) at three sites in eastern Canada in 2012 (Ste-Anne, Quebec, and Ottawa sites). Canola received four different fertilizer rates (0, 50, 100, and 150 kg N ha⁻¹) and canola N uptake was measured at four growth stages (rosette, flowering, pod filling, and maturity). Different lowercase letters indicate significant differences among fertilizer N rates within each growth stage at a given site. Canola N uptake differed between growth stages ($P < 0.001$ for all sites), but the N rate $\times$ growth stage interaction was not significant ($P > 0.05$ for all sites). Data from flowering and pod filling stages were missing from the Ste-Anne site.