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Relating soil microbial properties to yields of no-till canola on the Canadian prairies

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ABSTRACT

Soil microorganisms mediate many important biological processes for sustainable agriculture. However, correlations between soil microbial properties and crop productivity cannot always be demonstrated. We collected soil microbial data from a canola (*Brassica napus* L.) study that was conducted at seven sites on the Canadian prairies about agricultural practices focused on increasing canola yields. The treatments consisted of two canola seeding rates (75 or 150 seeds m^{-2}), two nitrogen rates (1× and 1.5× soil test recommendation) and three nitrogen form–fungicide (prothioconazole) combinations (uncoated urea, no fungicide; uncoated urea + fungicide; and 50% polymer-coated urea + fungicide) in a 2 × 2 × 3 factorial arrangement. Microbial biomass C (MBC), β-glucosidase enzyme activity and functional bacterial diversity (based on C substrate utilization patterns) were determined in canola rhizosphere and in bulk soil and related to canola yields. The effects of seeding rate, nitrogen (N) rate and N form on soil microbial biomass, enzyme activity or bacterial functional diversity were usually not statistically significant. In the few cases where significance occurred, doubling the seeding rate from 75 to 150 seeds m^{-2} usually increased these microbial properties in canola rhizosphere or bulk soil. Increasing N rate to 1.5× the recommended rate had mostly positive effects in canola rhizosphere and negative effects in bulk soil. The effects of N form (including addition of fungicide) were inconsistent. Soil MBC and β-glucosidase enzyme activity correlated positively with canola grain yield at the five sites where yields were <4000 kg ha^{-1} ($r = 0.51^{**}$ to 0.76^{**}), but no or weak negative correlations were observed at the two sites with yields >4000 kg ha^{-1}. The functional diversity of soil bacteria was not or was weakly negatively correlated with grain yields. Some of these relationships appeared to be influenced by canola root maggot damage because root damage was usually negatively correlated with the soil microbial characteristics, but the correlations were too weak to be relevant. These results suggest underground feedback interactions between crops and soil microbes, i.e., crop/soil management practices that enhance crop growth also enhance soil microbial communities and their activities, and vice versa.

1. Introduction

Soil microorganisms drive many biological processes that are critical for sustainable agriculture. These processes include nitrogen fixation (Nimmo et al., 2013), organic matter degradation and nutrient cycling (Bedard-Haughn et al., 2013), and biological disease and pest control (Pankhurst et al., 2005). Therefore, crop management practices that foster the development of large, diverse and active soil microbial communities are likely to be more

Abbreviations: ANOVA, analysis of variance; CLPPs, community-level physiological profiles; CT, conventional tillage; H', Shannon index of diversity; MBC, microbial biomass carbon; MBN, microbial biomass nitrogen; MVSP, multi-variate statistical package; NT, no-till; RCBD, randomized complete block design.

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economically and environmentally sustainable than practices that do not. However, correlations between soil microbial properties and crop productivity can be difficult to demonstrate. One reason for this difficulty is that crop yield integrates many factors related to genetic yield potential, crop nutrition (soil chemical, biological and physical properties) and crop health (pathogen and pest levels), and some of these factors further depend on environmental conditions. Another reason is limited data variability if data are collected from only one or two trials at one or two sites in one or two seasons, especially if the trial itself has a limited range of treatments.

In a study of four 10- to 25-year field experiments with different soil and crop management systems in southern Brazil, Silva et al. (2010) reported that microbial biomass C (MBC) and microbial biomass N (MBN) were consistently higher under no-till (NT) than conventional tillage (CT) and were associated with higher corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) grain yields. In another study of three long-term P fertilizer experiments in corn and soybean in the Cerrado region of Brazil, regression analysis revealed critical levels (equivalent to 80% of the highest crop yields) for MBC, basal respiration, cellulase, β-glucosidase, acid phosphatase, and arylsulfatase (Lopes et al., 2013). No such correlation/regression studies using long-term experiments or regional trials have been conducted on the Canadian prairies. At one of two sites in a three-year experiment on application of cattle manure in north-western Alberta, Lupwayi et al. (2005) reported positive correlations between soil MBC and K uptake by wheat (*Triticum aestivum* L.). However, correlations with crop yields were not significant. In another one-site, four-year cattle manure study in barley (*Hordeum vulgare* L.) and canola (*Brassica rapa* L.) grown in rotation, all significant correlations between soil microbial properties (MBC, functional diversity and CO_2 evolution) and soil nutrient contents as well as crop nutrient uptake were positive, with the exception of negative correlations with soil Mn content and with exchangeable Na (Lupwayi et al., 2014). The positive correlations sometimes translated into positive correlations with crop yields. Such correlations are probably expected in crop experiments with organic soil amendments including cattle manure because the manures supply organic C to soil microbiota, which in turn supply nutrients to crops through mineralization of organic nutrients that the manures contain. Correlating soil microbial properties with crop productivity in many types of agronomic trials is important to show that soil microorganisms drive many biological processes that are critical for sustainable agriculture.

There is increasing demand for edible oil and biodiesel feedstock from canola and other crops in Canada (Smith et al., 2007). Meeting this demand from canola will require the crop to: (a) be grown on a greater landbase, (b) be grown at higher frequencies in crop rotations, or (c) yield more per unit area. The last option is probably the best one because unoccupied land is not always available, and short crop rotations increase disease pressure (Kutcher et al., 2013). However, increasing crop yield per unit area will require increasing input levels, in addition to using improved crop varieties. An agronomy field trial was conducted at seven locations on the Canadian prairies to compare higher-than-average seeding and N rates with currently recommended rates for increasing canola seed and oil yields (Harker et al., 2012). The objective of this work was to examine the effect of these agricultural practices focused on increasing canola yields on several soil biological properties, and how these biological properties are related to canola yield. To this end, we used a field trial to (a) examine the effects of increasing seeding and N rates, and different N form–fungicide treatments, on soil microbial biomass, activity and functional diversity, and (b) relate the soil microbial properties to canola grain yields in a large dataset that covered many soil types and climatic conditions. We hypothesized that canola yield would correlate with soil microbial properties in a large diverse dataset encompassing the Canadian prairies.

Table 1
List of treatments.

Treatment	Seeding rate (seeds m^{-2})	N rate (×recommended rate)	N form
1	75	1	Uncoated
2	75	1	Uncoated + fungicide[a]
3	75	1	Coated + fungicide
4	75	1.5	Uncoated
5	75	1.5	Uncoated + fungicide
6	75	1.5	Coated + fungicide
7	150	1	Uncoated
8	150	1	Uncoated + fungicide
9	150	1	Coated + fungicide
10	150	1.5	Uncoated
11	150	1.5	Uncoated + fungicide
12	150	1.5	Coated + fungicide

[a] Prothioconazole.

2. Materials and methods

2.1. Sites, treatments and experimental design

Direct-seeded (no-till) experiments were conducted in western Canada from 2008 to 2010 at Beaverlodge, Alberta (55.28° N, 119.48° W); Brandon, Manitoba (50.08° N, 99.98° W); Edmonton, Alberta (53.78° N, 113.68° W); Indian Head, Saskatchewan (50.58° N, 103.78° W); Lacombe, Alberta (52.58° N, 113.78° W); Lethbridge, Alberta (49.78° N, 112.88° W) and Swift Current, Saskatchewan (50.38° N, 107.78° W). All plots were established on no-till fields previously sown to wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.). Prior to seeding, a single pre-seeding glyphosate application (450–900 g a.e. ha^{-1}) was applied to the entire plot area to control emerged weeds. Twelve factorial treatments were arranged in a randomized complete block design with four replications (Table 1). The 2 × 2 × 3 factorial arrangement consisted of two canola seeding rates (75 or 150 seeds m^{-2}, i.e., 750,000 and 1,500,000 seeds ha^{-1}), two nitrogen rates (1× and 1.5× soil test recommendation) and three nitrogen form–fungicide (prothioconazole, Proline 480® SC, Bayer CropScience Inc., Calgary, Alberta, Canada) combinations (uncoated urea, no fungicide; uncoated urea + fungicide; and 50% polymer-coated urea + fungicide). Proline 480® SC (480 g prothioconazole per liter, formulated as a suspension concentrate) was applied at 20–50% bloom stage of canola at 363 mL ha^{-1} with a water volume of 100 L ha^{-1}. Soil cores for soil test recommendations were taken from 10 bulked samples (0-cm to 30-cm depth) across experimental areas prior to the first year of the experiment, and some of the results from the initial soil testing are presented in Table 2. A canola–wheat–canola rotation (2008–2009–2010) was followed. The wheat in 2009 was just a rotation crop, i.e., it was not subjected to the different seeding rate, N rate, N form or fungicide treatments. The canola variety used in 2008 was glufosinate-resistant InVigor 5440, and in 2010 it was glyphosate-resistant 72-55RR. We changed the varieties in order to rotate herbicide-resistant canola systems as a way to limit herbicide resistance in weeds. The management of the crops is described by Harker et al. (2012). All the fertilizers were side-banded at the time of seeding. The three most dominant weed species in each plot were recorded and weed cover proportions were visually estimated for each species from two 0.5-m^2 quadrats at pre-spray and post-spray (3–4 weeks after final herbicide application) intervals. Canola was harvested with plot combines and yield was corrected to 8.5% moisture content. Immediately after harvest, 30 random canola stem-root samples were collected from each plot and assessed for root maggot (Diptera: Anthomyiidae: *Delia* spp.) damage (categorically scored 0–5, where 0 = no visible damage and 5 = severe damage).