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Phospholipid fatty acid biomarkers show positive soil microbial community responses to conservation soil management of irrigated crop rotations

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ABSTRACT

The increasing acreages of crops like potato and sugar beet, which return little C to the soil, and whose harvesting methods cause soil disturbance, led to the establishment of a 12-yr study to evaluate soil conservation (CONS) management systems in southern Alberta. The CONS management systems, applied to 3- to 6-yr crop rotations, were compared with conventional (CONV) management systems that included wheat monoculture. The CONS management was a suite of practices that included addition of cattle manure compost, reduced tillage, diverse crop rotations and use of cover crops that CONV management did not have. In the last two years of the study (2010 and 2011), soil microbial biomass was measured in bulk soil and wheat rhizosphere using the substrate-induced respiration method and phospholipid fatty acid (PLFA) biomarkers. β-glucosidase enzyme activity was measured to evaluate soil functioning (C cycling). Total soil microbial biomass, and that of its components (fungi and bacteria), was significantly greater under CONS management than under CONV management. The total PLFA contents of 3- and 4-yr CONS rotations (15.24–34.69 nmol g^{-1} soil) were 84–193% greater than those in CONV management (33.45–63.66 nmol g^{-1} soil) when differences were significant, and fungal PLFA was up to 382% greater. β-glucosidase activity was 50% greater under CONS management than CONV management. Principal component analysis confirmed that the soil microbial community structures in the different rotations were shaped by management practices. These positive responses of soil microbial communities to conservation management will enhance biological processes including nutrient cycling and biological pest control.

1. Introduction

The area planted to potato (*Solanum tuberosum* L.), sugar beet (*Beta vulgaris* L.) and dry bean (*Phaseolus vulgaris* L.) in southern Alberta has increased 2- to 3-fold recently due to value-added food processing (Alberta Agriculture and Forestry, 2015). However, these crops produce less biomass than the cereal or forage crops that they replace in irrigated crop rotations (Li et al., 2015), and the reduced C returns to the soil may lead to reductions in soil organic C. In addition, potato is usually grown on raised beds (hills) which require extra tillage passes and the harvesting methods of both potato and sugar beet necessitate heavy soil disturbance, making the soil susceptible to wind and water erosion (Chow et al., 1990; Carter and Sanderson, 2001). Annual soil losses by water erosion from continuous potato plots on 8 and 11% slopes have been estimated at 17 and 24 Mg ha^{-1} yr^{-1}, respectively, in New Brunswick, Canada (Chow et al., 1990). Eroded soils lose some of their organic C and nutrients, and soil tillage further reduces organic C by accelerating its decomposition (Lupwayi et al., 2004). Therefore, growing these crops results in soil degradation.

To address the soil degradation issues of these soils, a study was conducted from 2000 to 2011 to determine if soil conservation practices could be applied to southern Alberta irrigated cropping systems. These practices included addition of cattle manure compost, reduced tillage, and use of cover crops and solid-seeded narrow-row dry bean, applied as a package. Yields of the crops in the study have been published, and they show increases of potato,

Abbreviations: ANOVA, Analysis of variance; CONS, Conservation management; CONV, Conventional management; GN, Gram negative; GP, Gram positive; PLFA, Phospholipid fatty acid; PCA, Principal component analysis.

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sugar beet and dry bean yields under conservation management relative to conventional management (Larney et al., 2015, 2016a,b). Some of the soil properties that have been studied in the trial are organic C fractions and aggregate stability (Li et al., 2015). Results indicated that by the conclusion of the 12-yr study, particulate, fine and total organic C had increased by >145, 20 and 45%, respectively, under CONS management. The stability of soil aggregates also improved significantly under CONS management relative to CONV management that did not have soil conservation practices (Li et al., 2015). Here we report on the soil microbial responses to these soil conservation practices because the soil microbial community mediates many important biological processes for sustainable agriculture. These processes include biological nitrogen fixation (Jensen and Hauggaard-Nielsen, 2003; Gaby and Buckley, 2011), biomass decomposition and nutrient cycling (Schneider et al., 2012; Lupwayi and Soon, 2015), formation and maintenance of soil aggregates (Six et al., 2004; Blaud et al., 2012), biological disease and pest control (Janvier et al., 2007; Mendes et al., 2011), detoxification of agro-chemicals (Shelton and Doherty, 1997; Itoh, 2014) and regulation of climate through C and N cycles (Baldock et al., 2012; Gregorich et al., 2015). In addition to the importance of these biological processes for sustainable agriculture, soil microbial properties (e.g., biomass, diversity and activity) are sensitive indicators of soil quality (Doran et al., 1996; van Bruggen and Semenov, 2000) because they respond quickly to changes in soil management. Some new microbial indicators of soil quality or functionality include functional genes by molecular biological methods (Stone et al., 2016) and the 1-day CO_2 test (Muñoz-Rojas et al., 2016), but evaluation many indicators in field trials from diverse agro-ecosystems showed that the CO_2 test was one of the highly variable ones (Morrow et al., 2016).

The objectives of this study were to examine how CONS management affected soil microbial biomass, functioning and community structure in the last two years of the 12-yr study. The results will complement previously-published results on soil C and aggregate stability (Li et al., 2015), weed populations (Blackshaw et al., 2015), nematode populations (Forge et al., 2015) and dry bean (Larney et al., 2015), potato (Larney et al., 2016b) and sugar beet (Larney et al., 2016a) yields.

2. Materials and methods

2.1. Study location, experimental treatments and management

A 12-yr (2000–2011) irrigated field study was conducted at Vauxhall, Alberta (50° 03′ N, 112° 09′ W, elev. 781 m). The soil was a Dark Brown Chernozem (Typic Borroll in Soil Taxonomy; Haplic Kastanozem in World Reference Base) with 520 g kg^{-1} sand, 340 g kg^{-1} silt, 140 g kg^{-1} clay, and 12.9 g organic C kg^{-1} soil and pH 6.9 (0–15 cm depth). The 30 year (1981–2010) mean annual precipitation is 352 mm with a mean annual air temperature of 5.8 °C. The weather conditions during the 2010 and 2011 growing seasons, when soil samples were collected for the part of the study reported here, are presented in Fig. 1. These records were collected from an automated weather station located about 300 m from the plots.

The entire plot area was planted to barley (*Hordeum vulgare* L.) in 1999 and treatments were established in the spring of 2000. There were seven rotation treatments: continuous (monoculture) wheat (*Triticum aestivum* L.), two 3-yr rotations, two 4-yr rotations, one 5-yr rotation (but with two wheat phases that were each sampled for this study), and one 6-yr rotation (Table 1). These rotations were managed utilizing CONV or CONS management practices (described below). All crop phases of a rotation were grown each year to account for varying environmental conditions over years. This resulted in 26 rotation phases organized in a randomized complete block design (RCBD) with four replicates. The individual plot sizes were 10.1 by 18.3 m with 2.1 m buffer zones between plots.

For the CONS rotations (Table 1), a package of the following four practices was applied (for details, see Larney et al., 2015, 2016a,b):-

1. Direct seeding and/or reduced tillage where possible in the rotation: one pass of a chisel plough and packers or disc harrow.
2. Fall-seeded cover crops: oat (*Avena sativa* L.) and fall rye (*Secale cereale* L.) with entry points indicated in Table 1. However, fall establishment of oat was sub-optimal and was replaced with fall rye from fall 2003 onward.
3. Composted cattle manure: straw-bedded beef cattle feedlot manure compost (182, 15.4, and 5.4 g kg^{-1} dry wt. of total C, N,

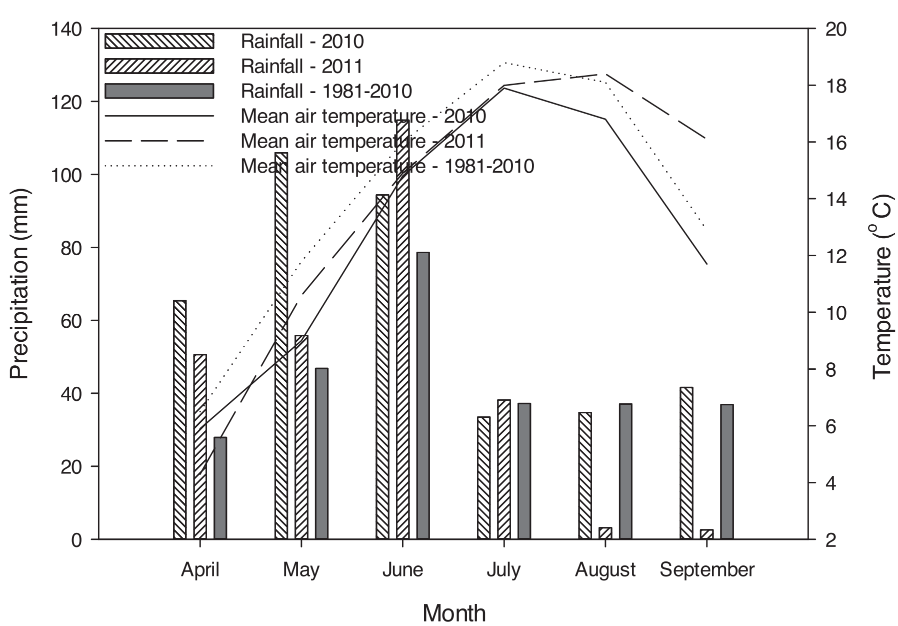

Fig 1. Total monthly precipitation and mean air temperatures during the study period, and 30-yr averages.