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Effects of long-term and recently imposed tillage on the concentration and composition of amino sugars in a clay loam soil in Ontario, Canada

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ABSTRACT

Tillage disturbance influences soil microorganisms and consequently the production and decomposition of microbial residues such as amino sugars. However, our understanding is still limited with respect to the changes in amino sugars which occur in soil after tillage operations. In this study, changes in amino sugars in a clay loam soil (mesic Typic Argiaquoll) in Ontario, Canada were tracked in long-term (29 years) no-tillage (NT), long-term conventional moldboard plow tillage (MP), and long-term bluegrass (*Poa pratensis* L.) sod (BG) as well as when long-term (13 years) NT was converted to MP, long-term MP was converted to NT, and long-term BG was converted to MP. Our objective was to determine if the quantity of amino sugars in the soil as well as their composition (i.e. whether they originate from bacterial or fungal residues) would respond to changes in tillage practices. We also wanted to evaluate the effects of converting from grassland to arable cropping (corn and soybean) on the amino sugar composition of soils. Soil samples were collected at depths of 0–5, 5–10, and 10–20 cm after 1 (1997), 6 (2002), 11 (2007), and 16 (2012) years following tillage conversion. Concentrations of amino sugars were much greater under long-term BG than under both long-term NT and MP treatments. In the 0–5 cm depth, long-term NT significantly increased total amino sugars and fungal-derived glucosamine (GluN) by 18 and 25%, respectively, compared with long-term MP whereas long-term NT had 26% lower MurA concentrations than long-term CT. Concentrations of total amino sugars in the 0–5 cm depth were reduced significantly within the first year after conversion of long-term NT and BG to MP, due primarily to decreases in the GluN concentrations. On the other hand, concentrations of amino sugars in soil accumulated gradually after conversion of long-term MP to NT. The results confirmed our hypothesis that loss of soil amino sugars is rapid and substantial when MP is initiated after NT and BG, while their recovery is gradual when NT is initiated after MP.

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1. Introduction

No-tillage (NT) is widely recognized as a feasible alternative to moldboard plowing (MP) to improve the soil environment and sustain natural resources. No-tillage has been reported to sequester soil organic carbon (SOC) (West and Post, 2002), reduce soil erosion and surface runoff (Triplett and Dick, 2008), protect soil aggregates and structure (Six et al., 2002), and decrease the labor, time and fuel requirements for land preparation (McLaughlin et al., 2008). However, long-term NT on the fine-textured soils of southwestern Ontario generally results in wetter and cooler soil during spring planting, which in turn negatively affects corn (*Zea mays* L.) emergence and early corn growth (Drury et al., 2003). Some growers are therefore either switching long-term NT to some type of tillage operation ranging from conservation tillage treatments such as zone tillage (Drury et al., 2006, 2012), vertical tillage, or chisel plows or in some cases, back to conventional moldboard plow tillage. Rotation tillage is also used in some soils and regions whereby MP may be used prior to the corn phase of a crop rotation while NT is used before the cereal or legume (e.g. soybean) phase of the rotation (Yang et al., 2008).

The influence of tillage practice on soil biological processes is largely mediated through soil microorganisms (van Groenigen et al., 2010). Soil microorganisms mineralize plant residues on the one hand, but produce microbial residues on the other hand (Kögel-Knabner, 2002). Amino sugars are one of the most important microbial residues in soils, and are derived primarily from microbial cell walls after the microorganisms die (Joergensen and Wichern, 2008). The concentration (quantity) and composition of amino sugars in soils have been used to evaluate the microbial

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contribution to carbon (C) sequestration (Amelung et al., 2008). Several studies have examined the tillage effects on amino sugars in soil (Deng et al., 2011; Guggenberger et al., 1999; Simpson et al., 2004; van Groenigen et al., 2010). It is generally found that the concentrations of total amino sugars are significantly greater under NT relative to MP (Deng et al., 2011; Guggenberger et al., 1999), primarily because of accumulation of amino sugars in microaggregates contained within macroaggregates (Simpson et al., 2004). However, our understanding is still limited with respect to the response of soil amino sugars to tillage conversion, such as replacement of long-term NT by MP or long-term MP by NT.

The most important amino sugars in soils are glucosamine (GluN), galactosamine (GalN), and muramic acid (MurA) (Amelung et al., 2008; Zhang and Amelung, 1996). The chitin of fungal cell walls is the major source of GluN in soil, although bacterial cell walls and the exoskeletons of soil invertebrates can also contribute (Parsons, 1981). Muramic acid is solely derived from the bacterial peptidoglycan cell walls (Amelung, 2001; Parsons, 1981). The microbial origins of GalN remain uncertain even though they account for between 30 and 50% of the total amino sugar pool (He et al., 2011; Joergensen et al., 2010). Galactosamine has been used to indicate bacterial residue (Amelung, 2001; Liang et al., 2007), but could also be produced by fungi (Engelking et al., 2007; Glaser et al., 2004).

The objectives of this study were to: (1) compare the concentration and composition of amino sugars in a clay loam soil under long-term MP, long-term NT, and long-term bluegrass (*Poa pratensis* L.) sod (BG); (2) track the changes in soil amino sugars after conversion of long-term NT to MP, long-term MP to NT, and long-term BG to MP. We hypothesized that: (1) long-term NT could lead to greater concentrations of amino sugars in near-surface soil, especially fungal-derived GluN, than long-term MP; (2) rapid and dramatic decreases in the concentrations of amino sugars occur in near-surface soil when untilled soil is converted to MP; and (3) slow recovery of concentrations of amino sugars occur in near-surface soil upon cessation of MP tillage.

2. Materials and methods

2.1. Site description

This study was conducted on a long-term tillage trial at the Hon. Eugene F. Whelan Experimental Farm, Woodslee, Ontario (42°13′ N, 82°44′ W). The climate is humid continental according to the Köppen climate classification (Peel et al., 2007). The 45-year average annual air temperature and average annual precipitation are 8.9 °C and 831 mm, respectively. The soil is a poorly drained Brookston clay loam and classified as mesic Typic Argiaquoll in the USDA Soil Taxonomy (Soil Survey Staff, 2010) or Orthic Humic Gleysol in the Canadian System of Soil Classification (Bedard-Haughn, 2011). The soil texture in the top 20 cm was 280 g sand kg^{-1}, 350 g silt kg^{-1}, and 370 g clay kg^{-1} (Reynolds et al., 2007).

2.2. Experimental design and soil sampling

The site was tile drained (12.2 m spacing, 0.95 m depth) in 1970 and was in a corn-soybean rotation from 1970 to 1983 prior to the initiation of the tillage treatments in 1983 (Drury et al., 1993). The tillage experiment was established in the fall of 1983 using a randomized complete block design with two replicate blocks. Each plot was 82.2 m long and 12.2 m wide. The treatments included continuous MP, continuous NT, and continuous BG which was harvested annually. The MP treatment involved fall moldboard plowing (to a depth of 17–20 cm) after crop harvest and spring disking (to a depth ~6 cm) plus secondary harrowing prior to planting (McLaughlin et al., 2008). Soil disturbance in the NT treatment was limited to that caused by no-till planting and side-dress application of nitrogen fertilizer. Both the MP and NT plots were cropped to continuous corn. In the fall of 1996, all treatment plots were split into two equal subplots (35 m × 12.2 m each) with a 12.2-m laneway between them. One of the MP subplots was converted to NT treatment, one of the NT subplots was converted to MP, and one of the BG subplots was converted to MP. One of the two subplots for each tillage treatment was left intact so that the 'new' tillage treatment could be compared with the original tillage treatment. A corn-soybean (*Glycine max* L.) rotation was introduced by further dividing the plots into two lengthwise and planting half (35 m × 6.1 m) of the MP and NT subplots into corn and the other half into soybean, and then rotating the two crops annually from 1997 to the present. Hence both crops in the rotation were present every year on both tillage treatments (MP, NT) after 1996. Corn was planted at 77,750 seeds ha^{-1} (76.2-cm row spacing) in mid-May to early June, depending on weather and soil conditions. Corn starter fertilizer (8-32-16) was applied at planting (5 cm below and 5 cm offset from the seed row) to provide an initial 20 kg N ha^{-1}, and nitrogen fertilizer (28% urea-ammonium nitrate) was injected as a side-dress application at the corn six-leaf stage to deliver an additional 150 kg N ha^{-1}. Soybean was planted at 625,000 seeds ha^{-1} (15-cm row spacing) in June with no fertilizer added. Corn was harvested in late October to early November and soybean was harvested in October.

In 1996 before the new tillage treatments were initiated, soils were collected from the 0–10 and 10–20 cm depths and analyzed for total amino sugars, glucosamine, galactosamine and muramic acid contents (Table 1). In the fall of 1997, 2002, 2007 and 2012, five to ten replicate soil cores (3.4 cm in diameter) were collected from the 0–20 cm depth of each plot. The samples from the MP and NT plots were collected during the corn phase of the rotation. Soil

Table 1
The concentration of total amino sugars, glucosamine (GluN), galactosamine (GalN), muramic acid (MurA) and the ratio between the concentrations of glucosamine and muramic acid (GluN/MurA) in a clay loam soil for long-term no-tillage (NT), long-term moldboard plow tillage (MP) and long-term Kentucky bluegrass sod (BG) in 1996 before the new tillage treatments were initiated.

Treatment	Total AS ($mg\,kg^{-1}$)	GluN ($mg\,kg^{-1}$)	GalN ($mg\,kg^{-1}$)	MurA ($mg\,kg^{-1}$)	GluN/MurA
0–10 cm					
CT	1760 (35)† c‡	958 (20) c	638 (13) b	161 (4.7) b	5.9 (0.1) b
NT	1870 (63) b	1080 (30) b	645 (29) b	142 (5.8) c	7.6 (0.2) a
BG	2450 (7) a	1430 (9) a	823 (19) a	203 (3.4) a	7.0 (0.1) a
10–20 cm					
CT	1770 (29) a	1001 (37) a	629 (13) a	133 (2.3) a	7.6 (0.3) b
NT	1660 (22) a	918 (10) b	606 (29) a	133 (8.3) a	7.0 (0.5) b
BG	1702 (49) a	1020 (59) a	592 (11) a	107 (0.1) b	9.5 (0.5) a

† Numbers in brackets are standard errors ($n = 5$).
‡ Means for each depth within a column followed by the same letter are not significantly different from each other ($P = 0.05$).

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