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Soil Phosphorus Fractions Change in Winter in a Corn-Soybean Rotation with Tillage and Phosphorus Fertilization

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ABSTRACT

Determining how agricultural management practices affect soil phosphorus (P) over the winter may further our understanding of the soil P cycle under specific environmental conditions in eastern Canada. This study assessed changes over winter for soil P fractions and other selected chemical properties as affected by tillage and P fertilization. In 1992, a long-term corn (*Zea mays* L.) and soybean (*Glycine max* L.) rotational experiment was established in the province of Quebec, Canada. Soil samples (0–15 cm) were collected in fall 2001 and 2007 after a soybean harvest, and in the following spring 2002 and 2008 before corn seeding, in main plots under moldboard plow and no-till managements and selected subplots fertilized with 0, 17.5, or 35 kg P ha^{-1} and 160 kg N ha^{-1}. Soil samples were analyzed for P fractions and other chemical properties to assess changes over winter for 2001–2002 and 2007–2008. Changes over winter of all soil P fractions were significant for the two periods, indicating the occurrence of soil P transformation and movement over winter. The Mehlich-3-extractable Fe, Al, Ca, and Mg decreased during the two studied periods. Tillage had no significant effect on all soil P fractions. The resin-extractable P in 2001–2002 and $NaHCO_3$-extractable inorganic P and NaOH-extractable organic P during the two winters were significantly increased under P fertilization. This study demonstrated that P in cultivated soils changed during winter as a result of changes in labile P fractions possibly due to the solubilization of residual fertilizer P combined with environmental factors.

Key Words: agricultural management practices, environmental factors, inorganic P, labile P, organic P

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Phosphorus (P) is an essential element for plants and its mismanagement can lead to adverse impacts on the environment. Phosphate taken up by crops originates from the soil solution or the solid phase among various inorganic (P_i) and organic (P_o) P fractions (Negassa and Leinweber, 2009). Soil P cycling is controlled by a combination of physical, chemical, and biological reactions (Murrmann and Peech, 1969; McGill and Cole, 1981). These reactions may be affected by crop cultivation, agricultural management, and environmental conditions. Phosphorus fractionation schemes (Hedley *et al.*, 1982) have been widely used to characterize changes in P_i and P_o fractions as affected by cultivation (Hedley *et al.*, 1982), land use and management (Negassa and Leinweber, 2009), and P loss (Wagar *et al.*, 1986; Heilmann *et al.*, 2005).

The effects of tillage and P fertilization on soil P fractions have been studied in different regions and results confirm that no-till (NT) increases labile P fractions, P fertilization increases all Pi fractions (Vu *et al.*, 2008; Zamuner *et al.*, 2008; Ciampitti *et al.*, 2011), and NT combined with P fertilization enhances soil P availability (Shi *et al.*, 2013b). However, seasonal environmental conditions may also affect soil P fractions under different tillage systems and P applications. Seasonal changes in P fractions may provide more complete information on the soil P cycling processes. Perrott *et al.* (1990) found that labile organic P increased during winter and declined in spring for a New Zealand pasture soil. Fabre *et al.* (1996) found that resin-extractable P (resin-P), $NaHCO_3$-extractable P_i ($NaHCO_3$-P_i), $NaHCO_3$-extractable P_o ($NaHCO_3$-P_o), and NaOH-extractable P_i (NaOH-P_i) were higher during winter than spring for soil within a riparian forest in France. All these studies indicate that soil P fractions fluctuate greatly between winter and spring. During winter in cold climates, freezing and thawing cycles and snowmelt may contribute to soil P transformation and movement (Hansen *et al.*, 2000; Henry, 2007; Messiga *et al.*, 2010).

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Previous studies have shown that soil microbial processes are surprisingly active in cold (0 to 5 °C) and even frozen soils (Clein and Schimel, 1995). A significant portion of ecosystem nutrient cycling and loss may occur over winter (Melloh and Crill, 1995; Brooks *et al.*, 1996; Hobbie and Chapin, 1996). The transformation process of soil P over winter may also be a source of P early in the growing season. Therefore, assessing changes in soil P over winter could further our understanding of the soil P cycle (Ziadi *et al.*, 2013). However, few studies have assessed how changes in soil P fractions over winter are affected by agricultural management practices (tillage and P fertilization) for arable soils in cold climatic regions, despite extended periods of cold and snow cover.

In 1992, a study was initiated at the experimental farm of Agriculture and Agri-Food Canada near Montreal to evaluate the effects of tillage management practices and mineral fertilization on soil ecosystem processes and nutrient dynamics under a corn-soybean rotation, the dominant components of legume-cereal associations in North America. Studies conducted at this experimental site assessed the effects of tillage and P fertilization on soil P availability (Messiga *et al.*, 2010, 2012), soil P fractions over 10- and 16-year periods of cultivation (Shi *et al.*, 2013b), and associated soil microbial status (Shi *et al.*, 2012, 2013a). Messiga *et al.* (2010) showed that under laboratory conditions water-extractable P and Mehlich-3-extractable P (P_{M3}) in the uppermost layer of NT soils enriched with crop residues increase as the number of freezing and thawing cycles increases. Therefore, biogeochemical P cycling might be affected by soil processes taking place at subzero winter temperatures. These soil processes may be affected by tillage management and P fertilization during winter. The objectives of this study were: i) to determine changes in soil total P and associated P fractions and selected soil chemical properties over winter (from fall to spring) during two periods (2001–2002 and 2007–2008) and ii) to determine the effects of tillage management practices and P fertilization on these changes. We hypothesized that all soil P fractions and selected soil chemical properties significantly changed over winter and these changes were largely affected by tillage and P fertilization practices.

MATERIALS AND METHODS

Experimental site

The study site was established in 1992 on a clay loam soil (Dystric Gleysol, IUSS Working Group WRB, 2014) at the L'Acadie Experimental Farm of Agriculture and Agri-Food Canada in the province of Quebec, Canada (45°18′ N, 73°21′ W). In the Ap horizon of the soil, the clay content was 364 g kg^{-1} and the sand content was 204 g kg^{-1}. The soil was tile-drained with less than 1% slope and was originally cropped with alfalfa (*Medicago sativa* L.) before 1992. Average across the plot area, the chemical properties of the topsoil at establishment were as follows: organic matter, 38 g kg^{-1}; P_{M3}, 60 mg kg^{-1}; P saturation index (P_{M3}/Mehlich-3-extractable Al), 4.3%; pH, 6.3 (1:2 soil/water) (Légère *et al.*, 2008).

This long-term experimental site consisted of a completely randomized split-plot factorial design with two tillage practices, moldboard plow (MP) and NT, as main plots and mineral N (0, 80, and 160 kg N ha^{-1}) and P (0, 17.5, and 35 kg P ha^{-1}) fertilizer rates as subplots. The treatments were replicated 4 times for a total of 72 subplots, each measuring 25 m × 4.6 m. All crop residues were left on the soil surface after harvest and chopped in the case of corn. Details on treatment management practices are described in Shi *et al.* (2012). Corn was sown at 74 × 10^3 plants ha^{-1} and soybean at 45 × 10^4 plants ha^{-1}. Each plot comprised six rows with 0.76 m between rows. All the fertilizers were applied to only the corn phase of the rotation using a disk opener (3–4-cm deep) following local recommendations (CRAAQ, 2010). Nitrogen, as urea, was first band-applied (5 cm from the seeding row) at planting at rates of 0, 48, and 48 kg N ha^{-1}, and then side-dressed at rates of 0, 32, and 112 kg N ha^{-1}. Phosphorus, as triple super-phosphate, was band-applied as a single application at planting. All plots received 41.5 kg K ha^{-1} as 0-0-60 muriate of potash band-applied at planting in 1992 and 2007. Herbicides for each crop were applied based on provincial recommendations. Air temperature was obtained from the L'Acadie meteorological station less than 1 km from the experimental site; snowfall, rainfall, and precipitation data were obtained from the Iberville meteorological station less than 10 km from the experimental site (Environment Canada, 2014).

Soil sampling and analysis

To focus on P fertilization effect, subplots receiving 0 (P0), 17.5 (P17.5), and 35 (P35) kg P ha^{-1} and 160 kg N ha^{-1} were selected within the experimental setup. In each plot, four soil cores were randomly collected from the 0–15-cm depth using an auger (2-cm diameter). Samples were collected in fall 2001 (October 17) and 2007 (October 16) after a soybean harvest, and