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Soil phosphorus loss in tile drainage water from long-term conventional- and non-tillage soils of Ontario with and without compost addition

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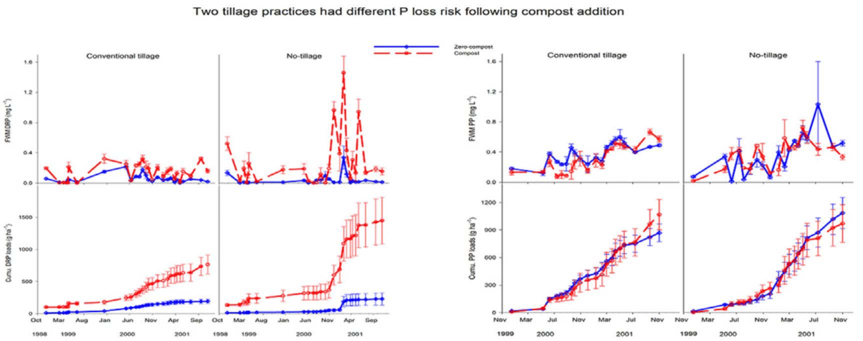
HIGHLIGHTS

- Quantification of agricultural practices on P loss is needed to reduce P loss risk.
- Compost addition increased DRP loss at a rate 113% higher under NT than under CT.
- DRP loss with NT was solely driven by DRP concentration in tile drainage water.
- DRP loss with CT was collectively driven by DRP concentration and flow volume.
- Compost addition did not affect PP loss, regardless of tillage practices.

GRAPHICAL ABSTRACT



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ABSTRACT

Recent ascertainment of tile drainage a predominant pathway of soil phosphorus (P) loss, along with the rise in concentration of soluble P in the Lake Erie, has led to a need to re-examine the impacts of agricultural practices. A three-year on-farm study was conducted to assess P loss in tile drainage water under long-term conventional- (CT) and non-tillage (NT) as influenced by yard waste leaf compost (LC) application in a Brookston clay loam soil. The effects of LC addition on soil P loss in tile drainage water varied depending on P forms and tillage systems. Under CT, dissolved reactive P (DRP) loss with LC addition over the study period was 765 g P ha^{-1}, 2.9 times higher than CT without LC application, due to both a 50% increase in tile drainage flow volume and a 165% increase in DRP concentration. Under NT, DRP loss in tile drainage water with LC addition was 1447 g P ha^{-1}, 5.3 times greater than that for NT without LC application; this was solely caused by a 564% increase in DRP concentration. However, particulate P loads in tile drainage water with LC application remained unchanged, relative to non-LC application, regardless of tillage systems. Consequently, LC addition led to an increase in total P loads in tile drainage water by 57 and 69% under CT and NT, respectively. The results indicate that LC application may become an environmental concern due to increased DRP loss, particularly under NT.

1. Introduction

In the past few decades, mitigation of agricultural phosphorus (P) loss was mainly addressed by implementing practices (e.g. conservation tillage) that are expected to reduce soil erosion and sediment-bound P loss (Kleinman et al., 2009). In the Great Lakes watersheds, not surprisingly, agricultural total P (TP) loads have often been found decreased mainly due to the reductions of particulate P (PP) losses (Richards et al., 2009; Daloğlu et al., 2012). However, the loads of dissolved reactive P (DRP), a form of P that is readily available to the aquatic biota, declined through the early 1990s, but then

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increased since the mid-1990s, as has the incidence of algal blooms (Daloğlu et al., 2012). Such increases in DRP loads and surface water deterioration may have been partly driven by the changes of agricultural management practices occurring in the last few decades (Michalak et al., 2013; Daloğlu et al., 2012). For example, increases of autumn fertilizer application, surface broadcast fertilizer application, and conservation tillage in the Maumee River region over the past ten years have been found to contribute to the observed 218% increase in DRP loadings into the river between 1995 and 2011 (Michalak et al., 2013). Therefore, re-emerging surface water quality degradation has raised a need to re-examine the impacts of agricultural management practices on agricultural P, particularly DRP, losses.

Compared to conventional tillage (CT), non-tillage (NT) reduces soil erosion rates (mm yr^{-1}) by 2.5 to >1000 times, with median and mean values of 20 and 488 times, respectively, according to 39 independent studies involving direct comparisons of soil erosion between CT and NT (Montgomery, 2007). Accordingly, PP loss from agricultural soils are also generally decreased, when NT is adopted (Ulén et al., 2010). In addition, NT practice is effective in controlling soil evaporation, improving soil structure, and reducing energy needs (Lai et al., 2007). With all these benefits, NT practice has been promoted rapidly around the world. In Canada, for instance, the percentage of NT land acreage in the total farm land prepared for seeding have increased to 56% in 2011 from 16% in 1996 (Census of Canadian Agriculture, 1996 and 2011). Meanwhile, it has become apparent that long-term NT practice tends to accumulate P in the upper few centimeters of soils, which may lead to an increase of DRP loss into surface water (Cade-Menun et al., 2010). On a poorly drained Brookston clay loam soil, for example, NT practice led to significantly higher DRP concentration in surface runoff (0.16–0.36 mg L^{-1} under CT vs. 0.41–1.88 mg L^{-1} under NT) and tile drainage water (0.20–0.30 mg L^{-1} under CT vs. 0.41–0.61 mg L^{-1} under NT) than CT (Gaynor and Findlay, 1995).

One challenge facing crop production on many fine-textured soils is that average field-crop yields tend to plateau and perhaps even decline in some areas (Wallace and Terry, 1998). It is widely believed that intrinsically poor physical quality of fine-textured soils is one of the key factors leading to yield plateaus or decreases (Reynolds et al., 2003). If optimal soil physical quality could be achieved and maintained, average field-crop production could be increased by as much as 25–50% (Wallace and Terry, 1998). Recently, organic wastes (e.g., livestock manure and yard waste) have received renewed attention for their roles in improving soil physical quality of fine textured soils (Reynolds et al., 2003). For example, Reynolds et al. (2003) reported that yard waste compost improved organic C, bulk density, and plant-available water holding capacity of a Brookston clay loam soil. When organic wastes are used as soil conditioners to improve soil physical quality, amounts of P contained in the material are rarely balanced with regard to crop needs, and may exceed the requirement of crops, leading to increased P loss risk. However, limited information on effects of organic soil conditioner application on P loss is available under field conditions.

Fine-textured soils generally have high potential for downward moving P loss due to greater likelihood of cracking and the subsequent preferential flow (Toor and Sims, 2015; van Es et al., 2004). In Ontario, over 70% of agricultural soils are tile drained, which would increase the risk of downward movement of P leaving farm fields. Subsurface drainage discharge contributed to 55–68% of total DRP loss from a Brookston clay soil during a three-year period under corn production (Gaynor and Findlay, 1995). Our recent study with a Perth clay soil also indicated that, under a corn-soybean rotation, tile drainage contributed to 95% of total DRP loads and 29–64% of PP loads (Tan and Zhang, 2011). Zhang et al. (2015) observed that P loss in tile drains from clay loam soils varied with cropping systems, but for any of which long-term continuous fertilizer P addition notably increased DRP and TP loss primarily caused by the increases in concentration of P. They further pointed out that P downward movement loss in tile drains must be taken into consideration from a water quality point of view.

Generally, NT practice along with application of organic amendment tends to improve water infiltration and further promote P transport deeper into soil profile (Stone and Schlegel, 2010; Hangen et al., 2002; Miller et al., 2002). Therefore, the knowledge of tillage practice and organic waste application on tile drainage P loss has particular significances on risk assessment of soil P loss from fine-textured soils. Also, it is essential to develop beneficial management practices that minimize P loss while maximizing crop production. For potential use of yard waste compost as a soil conditioner, researchers in Ontario, Canada, have had growing interest clarifying effects of yard waste compost application on soil health and P loss risk potential. Reynolds et al. (2003) reported that yard waste compost application improved soil physical conditions. The current study was conducted to further investigate effects of organic soil conditioner application on P loss in tile drainage water from a Brookston clay loam soil under long-term NT and CT practices. In our view, the results with yard waste compost may also provide indications for those with animal manure due to similarities between the both, which will be discussed in this paper.

2. Materials and methods

2.1. Experimental site and design

The on-farm experiment was conducted at two farm fields, including Farm A (42° 12′ 15″ N, 82° 44′ 50″ W) and Farm B (42° 12′ 15″ N, 82° 45′ 58″W), from 15 Sept. 1998 to 14 Nov. 2001. The two farms located within 0.5 km of each other on a Brookston clay loam soil (Orthic Humic Gleysol). Brookston clay and clay loam soils are major agricultural soils in southwestern Ontario, occupying approximately 66% of the region's agricultural lands. The 45-year average (1961–2005) of annual precipitation was 831 mm in the experimental area. Farm A had been continued with NT practice since 1989, while farm B had been consistently under CT practice since 1991. Both farm fields were overall flat and had been applied with commercial fertilizer P at the rates locally recommended, as well as with sufficient N and K added to meet crop needs for essential nutrients. Other field and crop managements followed the local practices. Soil conditions would have been well established under each of the respective tillage systems, and would be spatially homogeneous in each individual farm field after approximate ten years of preparation prior to the formal treatments implemented. In addition, soil conditions associated with P loss risk seemed generally similar between the CT and NT farm fields, because P concentrations in tile drainage water were largely similar between CT and NT without LC compost application, which will be further discussed below. As such, the two farm fields provided an ideal and unique opportunity for this study to determine the effects of LC addition on soil P loss between soils under CT and NT. Each farm was divided into two portions (i.e. two plots) in the fall of 1998 shortly after crop harvesting, with one receiving LC and the other as control (i.e. zero-LC application). The portion areas for farm A under NT were 2.0 ha for LC and 2.4 ha for zero-LC, while for farm B under CT they were 2.4 and 2.2 ha for LC and zero-LC, respectively.

Each plot on both NT and CT farms contained five subsurface tile drains (10.4-cm i.d.) spaced at 8.7 m, with an average depth of 0.6 m below the soil surface. The length of tiles was 538 m and 450 m at the NT and CT sites, respectively.

2.2. Crop management and compost application

Cropping system on both field sites was a corn-soybean rotation, with soybean grown in 1999 and 2001 and corn grown in 2000. On May 7 and 12, 1999, soybeans were seeded at the rate of 566,500 seed ha^{-1} on the CT site and at the rate of 579,040 seed ha^{-1} on the NT site, both with a row space of 38 cm. Between early May and early June in 2000, field corn was seeded (72,000 seed ha^{-1}) in 76.2 cm wide rows at both CT and NT sites. On May 4 and 12, 2001, soybeans