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Research Paper

Release of phosphorus from crop residue and cover crops over the non-growing season in a cool temperate region

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ABSTRACT

In northern climates, crop residue and cover crops are potential sources of dissolved reactive phosphorus (DRP) to runoff; yet, there are few field studies to quantify this. The objectives of this study were (1) to quantify changes in water extractable phosphorus (WEP) concentrations in the residues of *Triticum aestivum* L. (winter wheat), *Trifolium pretense* L. (red clover) *and Avena sativa* L. (oat) cover crops and surface soil in two agricultural fields (ILD and LON) over the non-growing season (NGS); and (2) to determine if changes in WEP in vegetation residue or soil were reflected in loads of DRP or total P (TP) in surface runoff and/or tile drain effluent. Concentrations of WEP in cover crops were larger than those in wheat residue and soil. Water extractable P concentrations in vegetation increased with plant decomposition and decreased following runoff events indicating that the plant WEP was mobilized in runoff. Differences in WEP concentrations were not observed with topography, with the exception of the period following snowmelt when low-lying areas prone to surface inundation were depleted relative to upland locations. Although WEP appeared to have been mobilized from vegetation and soil pools, loads of DRP (0.165–0.245 kg ha^{-1}) and TP (0.295 kg ha^{-1}–0.360 kg ha^{-1}) leaving the fields were small in comparison to P pools in cover crops (7.70 kg ha^{-1} oat, 1.70 kg ha^{-1} red clover), wheat residues (0.03–0.06 kg ha^{-1}) and soils (1.39–5.87 kg ha^{-1}), suggesting that much of the P released from vegetation was retained within the field. This study provides insight into the timing and magnitude of P release from vegetation throughout the non-growing season in regions with cool temperate climates, and provides an improved understanding of the contribution of cover crops to winter P losses.

1. Introduction

Agricultural best management practices (BMP) for environmental stewardship are designed to reduce soil and nutrient losses from fields. Conservation tillage practices and cover crops are two examples of BMPs that have been employed by some farmers to minimize soil and nutrient losses and improve water quality. However, their effectiveness to provide these benefits during the non-growing season (NGS) remains unclear, largely because surface vegetation may supply dissolved reactive phosphorus (DRP) to runoff as plant residues decay (Gburek and Heald, 1974; Sharpley, 1981) and/or are exposed to freeze-thaw cycles (FTC) (e.g. Bechmann et al., 2005; Elliott, 2013; Miller et al., 1994; Riddle and Bergström, 2013). Consequently, the use of conservation tillage or cover crops as BMPs to mitigate P losses is debatable in areas that experience significant winter periods. Much of the existing knowledge on DRP loss from vegetation following FTC has been obtained under severe frost conditions (either simulated or natural) and less is known about the vulnerability of crop residues and cover crops to DRP loss in more temperate regions such as Southwestern Ontario, that experience frost, but less severe winter conditions. In the Great Lakes region of North America, temperatures are moderated by the Great Lakes and both cover crops and crop residues are often covered by a thick snowpack that insulates them from frigid temperatures. Thus, an improved understanding of the role of surface vegetation in P losses during the NGS in cool temperate climate zones is needed to determine optimal cover crop BMPs suitable for these regions.

Conservation tillage and cover crops have been shown to be effective BMPs for improving water quality. Conservation tillage is broadly defined as any tillage method that maintains at least 30%

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of crop residue on the soil surface (McDowell et al., 2001). This low disturbance BMP reduces the erosiveness of soil, leading to a reduction in the loss of sediment and particulate phosphorus (PP) in runoff (Sharpley and Smith, 1989; Ulén et al., 2010). Furthermore, maintaining crop residue on the soil surface increases infiltration and dissipates rainfall energy, thereby reducing runoff (McDowell et al., 2001) and facilitating the adsorption of DRP and deposition of PP (Sharpley and Smith, 1989). Cover crops may provide similar physical mechanisms as residues to reduce soil erosion and runoff and can also improve the water holding capacity of the soil through increased infiltration (Blanco-Canqui et al., 2015, 2012). In addition, cover crops take up and store nutrients from the soil, particularly nitrogen (Bergström and Jokela, 2001; Blanco-Canqui et al., 2015; Dabney et al., 2001; Liu et al., 2015; Weil and Kremen, 2007). As a result of these combined BMP benefits, managers have recommended that farmers leave at least 30% crop residue on the soil surface (McDowell et al., 2001), and use cover crops to reduce nutrient losses in runoff (Blanco-Canqui et al., 2012) but the impact of these combined practices on P loss represents a significant knowledge gap.

In cold climate regions, snowmelt runoff is an important period for P loss from agricultural systems (Ball-Coelho et al., 2012; Elliott, 2013; Gentry et al., 2007; Hansen et al., 2000; Hansen et al., 2002; Jamieson et al., 2003; Macrae et al., 2007a,b; Rekolainen, 1989; Tiessen et al., 2010; Ulén, 2003) either through surface runoff or tile drainage (Jamieson et al., 2003; Macrae et al., 2007a; Van Esbroeck et al., 2016). The efficiency of crop residues and cover crops to reduce P in runoff during this period is uncertain. Generally, fields under conservation tillage retain more snow, increasing snow water equivalents (Hansen et al., 2000) and therefore runoff (Hansen et al., 2002) than conventional tillage. Consequently, during snowmelt, the volume of water is often too large for crop residues to slow flow, and runoff is not decreased by the presence of surface vegetation (Elliott, 2013; Hansen et al., 2000). Furthermore, most vegetation freezes at the beginning of the winter period, and therefore is less able to protect the soil from water erosion (De Baets et al., 2011). Indeed, Hansen et al. (2000) observed that crop residue did not limit runoff; however, a reduction in the concentration of sediments was observed during their study. Thus, although the role of surface vegetation for reducing PP may be dampened in winter, crop residues and cover crops may provide some protection against surface erosion during this critical period.

Numerous studies have reported that dissolved nutrient transport can be greater in surface runoff or ground water from conservation till or no-till systems than from conventional tillage systems (e.g., Baker and Laflen, 1982; Bundy et al., 2001; Daverede et al., 2004; Langdale et al., 1985; McDowell and McGregor, 1984; Sharpley and Smith, 1994; Zhao et al., 2001). Such increased losses have previously been attributed to the stratification of nutrients at the soil surface caused by reduced mixing of fertilizers or manures in conservation tillage or no-till systems in comparison to conventional systems. However, the literature also suggests that the release of nutrients from plant residue that remains on the soil surface after harvest can also amplify P loss (McDowell and McGregor, 1984; Sharpley, 1981; Sharpley and Smith, 1989; Schreiber and McDowell, 1985; Wendt and Corey, 1980). Bechmann et al. (2005) and Sharpley (1981) reported greater P loss from plots containing cover crops and crops compared to plots with bare soil and soil applied with manure. This suggests that surface vegetation has the potential to be a significant DRP source to runoff. These findings have been observed in both laboratory (Miller et al., 1994; Schreiber, 1985; Schreiber and McDowell, 1985) and field settings (Sharpley, 1981; Sharpley and Smith, 1989; Wendt and Corey, 1980).

Freeze-thaw cycles during the winter period may amplify the potential for DRP loss from crop residues and cover crops. Indeed, DRP losses can be substantial during snowmelt (Ginting et al., 1998; Little et al., 2007), likely for several reasons. First, higher DRP losses have been reported from vegetation following exposure to freezing or FTC (Bechmann et al., 2005; Elliott, 2013; Liu et al., 2013a; Miller et al., 1994; Riddle and Bergström, 2013; Roberson et al., 2007; White, 1973). During freezing, the disruption of plant cells causes the release of inter/intra cellular P due to the formation of ice crystals (Bechmann et al., 2005; Jones, 1992; Liu et al., 2014). Second, snowmelt runoff often extends over longer time periods than rainfall-induced runoff events, providing ample time for increased reactions between soil, water and vegetation (Tiessen et al., 2010). However, such interactions may be restricted to areas within fields that experience surface inundation rather than areas that are higher topographically that do not experience significant contact with surface runoff. Given the significance of DRP as a highly bioavailable form of P, leaving crop residues and cover crops on fields (or low-lying sections of fields) throughout the winter may therefore not be a BMP for mitigating P losses.

Much of the existing knowledge on the role of crop residues and cover crops in P loss in regions subjected to freezing has been derived from controlled laboratory studies or has been conducted in regions that have much colder winters than is experienced in the Great Lakes Region of North America such as western Canada (Elliott, 2013), the Upper Midwestern United States (Roberson et al., 2007; Timmons et al., 1970) and various Scandinavian countries (Liu et al., 2014; Liu et al., 2013a; Øgaard, 2015; Riddle and Bergström, 2013; Sturite et al., 2007). Although air temperatures can reach lows in the range of −25 °C in the Great Lakes region, temperatures beneath the thick snowpack are more moderate (often fluctuating between −4 to 0 °C, Macrae, unpublished data). Moreover, cool, temperate regions may experience numerous FTC throughout the NGS (beginning late in the autumn), prior to the onset of the spring freshet when most surface runoff typically occurs (Van Esbroeck et al., 2016). It is unclear when the majority of the vegetation P pool is released over the NGS. It is possible that the pool of P in the crop residues and cover crops may be released vertically to soils following autumn FTC rather than mobilized during the snowmelt period.

Little field data exists that examines the role of crop residues and cover crops in runoff P during the NGS, and, it is unclear how P losses from vegetation compare to those from soils. Moreover, the contribution of vegetation to runoff has been examined in surface runoff but not subsurface (tile) drainage. At more southern locations within the Great Lakes region, tile drains often remain active during the winter period (Lam et al., 2016; Macrae et al., 2007a,b; Van Esbroeck et al., 2016). Therefore, P release from vegetation may contribute to both surface runoff and tile P losses, particularly where significant connectivity between the surface and tile drains through preferential pathways exists. However, the loss of DRP from the crop canopy, as well as senescent plant material must be considered along with the release and sorption of P by surface soil (Sharpley, 1981). In this research, potential losses of P from winter wheat residue, cover crops and surface soil were examined in two commercial agricultural fields and coupled with observations of P loss in surface and subsurface (tile) drainage to address the following objectives:

(1) To quantify water extractable P (WEP) concentrations in surface soil, winter wheat residue (WR) and cover crops (oat (O), red clover (RC)) throughout one NGS (August–April inclusive), and relate temporal differences to hydroclimatic conditions over the study period.
(2) To determine if WEP concentrations in soil and vegetation (WR, O and RC) throughout the NGS differ topographically within a