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Drainage water management combined with cover crop enhances reduction of soil phosphorus loss

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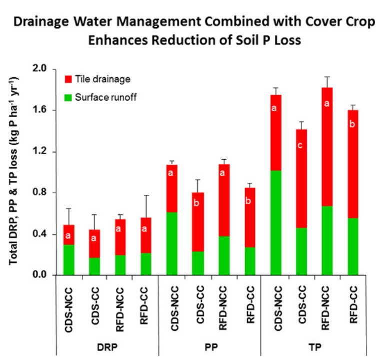
HIGHLIGHTS

- Surface runoff and tile drainage flow volumes were reversely affected by CC and DWM.
- Total volumes of field water discharge were similar, regardless of DWM-CC treatments.
- CDS reduced DRP loss in drainage water, which however became less effective with CC.
- CDS combined with CC enhanced reduction in soil PP and TP losses.

GRAPHICAL ABSTRACT



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ABSTRACT

Integrating multiple practices for mitigation of phosphorus (P) loss from soils may enhance the reduction efficiency, but this has not been studied as much as individual ones. A four-year study was conducted to determine the effects of cover crop (CC) (CC vs. no CC, NCC) and drainage water management (DWM) (controlled drainage with sub-irrigation, CDS, vs. regular free tile drainage, RFD) and their interaction on P loss through both surface runoff (SR) and tile drainage (TD) water in a clay loam soil of the Lake Erie region. Cover crop reduced SR flow volume by 32% relative to NCC, regardless of DWM treatment. In contrast, CC increased TD flow volume by 57 and 9.4% with CDS and RFD, respectively, compared to the corresponding DWM treatment with NCC. The total (SR + TD) field water discharge volumes were comparable amongst all the treatments. Cover crop reduced flow-weighted mean (FWM) concentrations of particulate P (PP) by 26% and total P (TP) by 12% in SR, while it didn't affect the FWM dissolved reactive P (DRP) concentration, regardless of DWM treatments. Compared with RFD, CDS reduced FWM DRP concentration in TD water by 19%, while CC reduced FWM PP and TP concentrations in TD by 21 and 17%, respectively. Total (SR + TD) soil TP loss was the least with CDS-CC followed by RFD-CC, CDS-NCC, and RFD-NCC. Compared with RFD-NCC, currently popular practice in the region, total TP loss was reduced by 23% with CDS-CC. The CDS-CC system can be an effective practice to ultimately mitigate soil P loading to water resource.

1. Introduction

Increased phosphorus (P) use to meet ever-increasing demands for food, feed, fibre, and fuel has concomitantly increased P export from agricultural fields, which constitutes a critical non-point source of P

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eutrophication in streams and lakes (Sims et al., 1998). To address this environmental concern, development of soil-test and crop-demand based nutrient management plans are necessary to ensure fertilizer P being utilized in a way that is both economically and environmentally responsible (Sharpley et al., 2003). Some other complementary strategies, such as water management systems that restrict nutrient loss (Tan et al., 2007) and cover crops that biologically remove soil legacy nutrients susceptible to loss (Dabney et al., 2001), have also received increasing attention.

Water management systems, such as tile drainage, allow removal of excessive soil water, resulting in improved soil physical quality and crop yields (Tan et al., 2007). However, traditional tile drainage may lead to increased nutrient loss (Tan and Zhang, 2011). To mitigate nutrient loss while increasing crop yields, the regular free tile drainage has been advanced with an option of installing a "riser" on the tile outlet to implement water table control and sub-irrigate crops, namely "controlled drainage with sub-irrigation (CDS)" (Tan et al., 1993). The outlet riser serves a dual function of controlling drainage outflow during the period of excess water and returning the water back into the tile lines to sub-irrigate crops under drought conditions. Recent field studies have shown that incorporation of CDS system with field crop production can relieve the negative impacts of drought stress on crops during the growing season and the environmental degradation associated with off-field movement of nutrients (King et al., 2014).

Overwinter cover crops have been demonstrated to be effective in reducing surface runoff flow, enhancing evapotranspiration of soil water, and extracting residual nutrients (Dabney et al., 2001). Studies have reported that cover crops dramatically reduced NO_3-N loss up to 84% in surface runoff (Sharpley and Smith, 1991) and up to 62% in tile drainage (Constantin et al., 2010). However, the benefits of cover crops to P transport are generally less clear than erosion and NO_3-N leaching.

The effects of cover crops on dissolved P loss have been inconsistent, with some studies even indicating increased dissolved P losses in runoff (Riddle and Bergstrom, 2013), while they are effective in reducing particulate P (PP) and total P (TP) losses in surface runoff (Sharpley and Smith, 1991). Having summarized the effects of cover crops on surface runoff P loss from two watersheds under clean-tilled peanuts, Sharpley and Smith (1991) found that cover crops dramatically reduced PP and TP losses, compared to bare soil. However, soluble P loss in runoff was greater in the presence of cover crops than fallow. This indicates the successful control of one form of P loss by cover crops may unintentionally exacerbate the loss of the other, and thus complicates their effects on P loss. The effects of cover crops on P loss in both surface runoff and tile drainage water, as well as the synergistic effects of drainage water management systems and cover crop, must be investigated, if truly beneficial management practices are to be developed. The objective of this study, therefore, was to determine both the individual and the combined effects of drainage water management and a winter wheat cover crop on field water discharge flow volume and P losses in both surface runoff and tile drainage on a fine-textured soil of the Lake Erie basin.

2. Materials and methods

2.1. Experimental site and design and agronomic management

The four-year study with a corn (*Zea mays* L.)-soybean (*Glycine max.* (L) Merr.) rotation was established in late 1999 and continued until 2003 in a Brookston clay loam soil (fine-loamy, mixed, mesic Typic Argiaquoll) on the Eugene F. Whalen Experimental Farm, Agriculture and Agri-Food Canada, in Southwestern Ontario, Canada (42°13′N, 82°44′W). The 43-year means of annual air temperature and precipitation at the field site were 8.9 °C and 830 mm, respectively. Weather data were collected using a weather station located within 0.5 km of the site (Table S1). Annual precipitation data were presented based on the cropping year (i.e. from Nov 1st when the soil was started for preparation of cropping the next year with fall tillage until Oct 31st the following year when crop was harvested). The soil contained 280 g kg^{-1} sand, 350 g kg^{-1} silt, 370 g kg^{-1} clay, 21.4 g kg^{-1} organic C, 2.5 g kg^{-1} total N, 14.1 mg kg^{-1} NO_3-N, 4.91 mg kg^{-1} NH_4-N, 11.3 mg kg^{-1} water extractable P, 7.49% degree of P saturation determined using the Melich-3 procedure (Wang et al., 2010) and 191 mg kg^{-1} Mehlich-3 extractable K, with a pH of 7.5, prior to the initiation of the study.

The experimental design of the field site consisted of eight treatment combinations of two drainage water managements (DWM) (i.e., regular free drainage, RFD, vs. controlled drainage with sub-irrigation, CDS) with two compost amendments (i.e., yard waste leaf compost and liquid pig manure compost) or two soil crop covers (i.e., no cover crop, NCC, vs. winter wheat as cover crop, CC). The treatments were arranged in a completely randomized block design with two replicates. The plot size was 15 m wide by 67 m long. However, only the four combinations of DWM with soil crop covers were selected for this study to determine the effects of cover crop along with DWM on soil P loss. Two tiles spaced out 7.5 m were located in each plot at 0.6 to 0.7 m depth. The tiles ran parallel to the length of each plot. In the CDS plots, a riser was installed for each plot to effectively "raise" the average water table from the drain depth to 0.3 m below soil surface. The risers were continuously in place except for brief periods during planting and harvesting when they were released to prevent soil structure damage from field operation or wheel traffic compaction associated with excessively wet soil. Sub-irrigation in the CDS plots was initiated during the growing season once the water level behind the risers dropped below the one set for 0.3 m from soil surface. This was accomplished by pumping water from an irrigation pond filled with municipal water to the risers via an underground 50-mm diameter polyethylene pipe. Water meters (Neptune T-10; Neptune Equipment Co., Cincinnati, OH) located at the control structures recorded the total volume of irrigation water delivered to each plot. Both N and P loadings in sub-irrigation water were insignificant due to their low concentrations (Table S2). In addition, while the plots of CDS treatments were on water table controlled mode in both 2000 and 2003, no sub-irrigation was conducted due to sufficient natural rainfall during the growing season.

Winter wheat (cultivar AC Ron in 1999; AC Essex in other years) was seeded as a cover crop in the designated plots shortly after corn or soybean harvest in late Oct. or early Nov. using a no-till drill at 105 kg ha^{-1} in the first 3 years (1999–2001) and at 112 kg ha^{-1} in 2002. The cover crop was killed using glyphosphate [either Roundup (Monsanto) at 0.84 kg ha^{-1} or Vantage (Dow Agrosciences) at 1.4 kg ha^{-1}] in May or early June of each spring.

Corn (variety N58D1) was planted on 17 May 2000 and 22 May 2002 at 79,700 seeds ha^{-1} in 76 cm wide rows using a Kinze four row planter. Soybean was planted on 8 June 2001 (variety A2553) and 17 June 2003 (variety S20Z5) at 112 kg seeds ha^{-1} in 20.3 cm wide rows using a John Deer 1590 no-till drill. Starter fertilizer (18-46-0 at 142 kg ha^{-1}) was applied at planting and a side-dress of 28% UAN (urea ammonium nitrate) solution (150 kg N ha^{-1}) injected into the soil ~15 cm from each corn row at ~10 cm depth in June when corn was at six-leaf stage. No potassium (K) was applied to corn production due to the high native soil K at the site. No fertilizers were applied for soybean production. Weed control was achieved by pre-emergent broadcasting atrazine (1-chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine at 1.1 kg a.i. ha^{-1}), metribuzin (0.56 kg a.i. ha^{-1}) and dual magnum (1.05 kg a.i. ha^{-1}) for corn and dual magnum (1.2 kg a.i. ha^{-1}), metribuzin (0.42 kg a.i. ha^{-1}) and pursuit (0.08 kg a.i. ha^{-1}) for soybean. Fall cultivation included annual fall disking operation (~7.5 cm deep) to incorporate corn and soybean stubble before planting winter wheat. Spring tillage with two passes of an S-tine cultivator and packer was conducted prior to planting either corn or soybean.

2.2. Surface runoff and tile drainage water discharge monitoring, sampling and phosphorus determination

There was a 30 cm high berm, as well as a 1.2 m deep plastic barrier installed, on three sides (excluding the lower end with the catch basin)