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Controlling tile drainage during the growing season in Eastern Canada to reduce nitrogen, phosphorus, and bacteria loading to surface water

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ABSTRACT

Drainage water management such as controlled tile drainage (CTD) is one means to help meet pollution mitigation targets and boost crop yields. In this study, CTD was retrofit to existing tile drained fields in eastern Ontario, Canada (humid continental climate) to study water quality benefits. A suite of paired field systems were used to compare CTD tile drainage quality with conventional tile drainage quality for nine growing seasons (2005–2013), translating to 35 field-crop years. Field crops were corn, soybean and forage. For CTD fields, controlled tile drainage was employed only during the growing season (time period when comparisons were made) due to surface runoff/erosion and growing season length concerns associated with non-growing season flow control. Water quality targets in tile effluent included: nitrate, ammonium, total phosphorus, dissolved reactive phosphorus, and fecal indicator bacteria such as *E. coli*, and *Enterococci*. Respectively, there were 60, 51, 58, 66, 66, 76, and 25% reductions in above noted drainage water fluxes and water quality targets as a result of CTD (for all 35 field-crop years combined). Concurrent environmental and potential public health benefits of managing tile drainage during the growing season were demonstrated; moreover, over the course of the study, corn and soybean yields were significantly boosted by CTD.

1. Introduction

In North America, controlled tile drainage (CTD) is currently employed as an agricultural beneficial management practice (BMP) on a relatively small land base relative to the total area upon which CTD could be utilized. Because the environmental and agronomical benefits associated with CTD such as yield boosts and reduced tile drainage pollution to the environment are now so well documented (Drury et al., 1996; Mejia et al., 2000; Ghane et al., 2012; Skaggs et al., 2012; Sunohara et al., 2014; Nash et al., 2015), impetus for increased adoption is required.

Recent environmental regulatory directives on water quality in important surface waters such as the Great Lakes and Gulf of Mexico (e.g. Rabalais et al., 2002a, 2002b; Scavia et al., 2014) will potentially increase the immediate interest in CTD on account of requirements to meet water quality targets or objectives in relatively short periods of time. (Annex 4 Objectives and Targets Task Team, 2015). For the Great Lakes, the Ohio Lake Erie Phosphorus Task Force recommended a 40% reduction in phosphorus loadings from the Maumee River to Lake Erie to reduce or eliminate harmful algal blooms (Ohio EPA, 2010). For the Gulf of Mexico, 30% nitrogen load reductions are required to reduce the areal extent of hypoxia to less than 5000 km^2 (Rabalais et al., 2002a). Managing tile drainage is an attractive BMP to help meet these targets in that it offers an almost immediate environmental net benefit (through reduced tile drain discharge and associated nutrient loads) relative to other BMPs, such as vegetated buffer zones and wetlands that need time to mature and develop. The temporal efficacy of CTD was demonstrated at the watershed-scale by Sunohara et al. (2015) who showed in a paired watershed study that abrupt and prolific adoption of CTD immediately and significantly reduced growing season loads of NO_3^-–N, NH_4^+–N, dissolved reactive P, and total P at watershed outlets.

In agricultural regions with intensive livestock production, manure application is a common practice, and manure derived

Abbreviations: ANTP, above normal total precipitation; BMP, beneficial management practices; BNTP, below normal total precipitation; CTD, controlled tile drainage; DRP, dissolved reactive phosphorus; MPN, most probable number; UCTD, uncontrolled tile drainage.

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nutrients are often cited for their deleterious environmental impact (Sims et al., 1998; Wilkes et al., 2009; Frey et al., 2015). Furthermore, land application of both animal and human waste can potentially increase public health risks associated with waterborne pathogens (Guan and Holley, 2003; Gerba and Smith, 2005). When assessing the transport pathways that facilitate the off-field movement of contaminants derived from such waste products, it is well documented that tile drains can be efficient pollutant conduits (Joy et al., 1998; Lapen et al., 2008; Pappas et al., 2008); and accordingly, CTD could be a means to reduce disease infection risks. In a field-scale experiment designed to track the movement of a broad suite of liquid swine manure constituents, Frey et al. (2014, 2015) found that CTD employed on macroporous field plots significantly reduced loads of fecal indicator bacteria, the pathogen *Campylobacter* spp., and antimicrobial resistance genes (ARG) in tile drainage as compared to uncontrolled tile drainage (UCTD). At the same paired watershed experimental site used by Sunohara et al. (2015), Wilkes et al. (2014) observed significant reductions in ruminant fecal pollution markers and several waterborne pathogens in the stream discharge from the watershed with CTD extensively employed during the growing season, as compared to the watershed with UCTD only. Hence, from multiple experiments conducted across a range of spatial scales there is strong evidence that suggests CTD can concurrently reduce exposure risks associated with field-derived pathogens and ARG.

However, like other BMPs, the effectiveness of CTD will be influenced by climate, soil, and field management practices (Christianson and Harmel, 2015a,b). For example, in many of the humid continental regions of Canada, controlling or restricting tile drainage during the non-growing season could augment sediment and phosphorus loads in tile and overland flow (Tan and Zhang, 2010; Ball Coelho et al., 2012). Furthermore, it is well documented that soluble forms of phosphorus can be mobilized in water saturated soils (i.e. lower soil redox potential) (Sallade and Sims, 1997), which can be imposed by water table management (Sanchez Valero et al., 2007; Ballantine and Tanner, 2013). Potential drawbacks of CTD were also noted by Frey et al. (2014, 2015), who found that while aggressive tile drainage control prior to, and following liquid swine manure application could significantly reduce bacteria fluxes in tile, it did not significantly reduce the fluxes of veterinary antibiotics, non-conservative water tracers, nitrogen, and phosphorus in drainage effluent during the non-growing season in fall.

It is the objective of this study to further elucidate the long term effectiveness of CTD for mitigating nutrient and bacteria fluxes in tile effluent during the growing season. The data includes nine years of tile discharge, nitrogen, phosphorus, and fecal indicator bacteria fluxes from corn, soybean, and forage crops grown on a suite of paired-fields under CTD and UCTD in eastern Ontario, Canada. While many studies have documented the implications of CTD on nitrogen fluxes alone (Skaggs et al., 2012), and nitrogen and phosphorus fluxes together (e.g. Wesström and Messing, 2007; Feset et al., 2010), there is limited, longer term field data from paired-field experimental configurations on nitrogen, phosphorus, and fecal indicator bacteria together. Moreover, the monitoring length of this study facilitates rigorous statistical assessment of CTD performance under a wide range of environmental/cropping conditions.

2. Materials and methods

2.1. Study area

The study is comprised of 9 years (2005–2013) of growing season (defined here as ~May to ~October) data on fields located in an experimental watershed (Sunohara et al., 2015) in eastern Ontario, Canada (Fig. 1). Here, 30−year normal annual precipitation (1981–2010) is 981 mm, and average daily air temperature is 6.5 °C (Environment Canada, 2015). Average 30−year precipitation and mean 30−year air temperatures during the growing season are 536 mm and 16 °C, respectively (Environment Canada, 2015). Land use in the watershed is predominantly agriculture (e.g., dairy-related corn (*Zea mays*), soybean (*Glycine max*), and mixed forage crop rotations and to a lesser extent corn-soybean

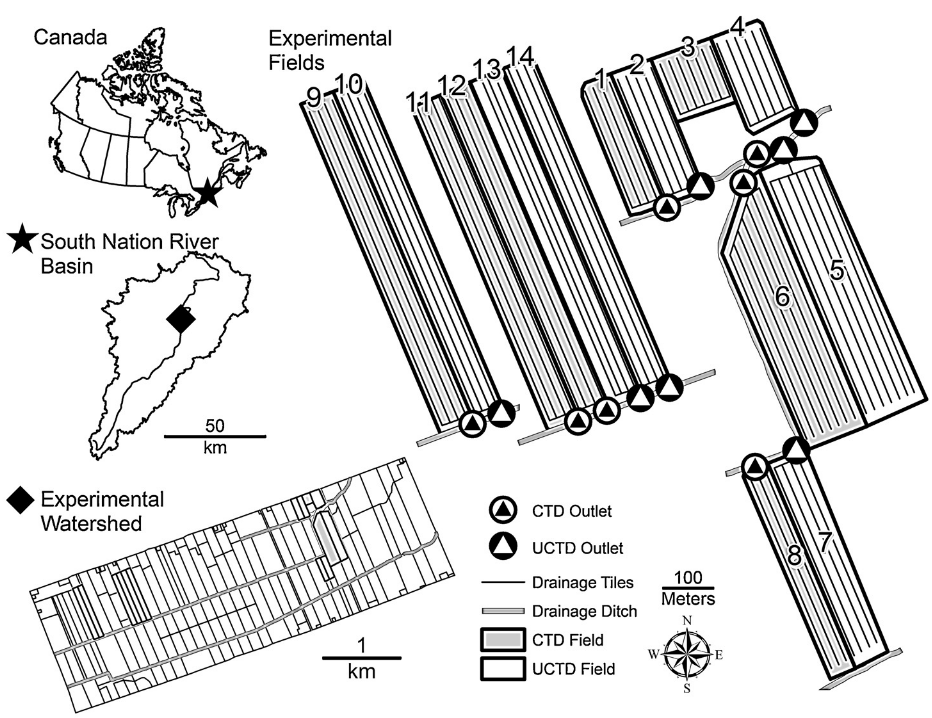

Fig. 1. Experimental watershed and paired uncontrolled (UCTD) and controlled tile drainage (CTD) fields, within eastern Ontario, Canada. The seven field pairs include: fields 1&2, 3&4, 5&6, 7&8, 9&10, 11&14, 12&13.