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Research paper

Dissolved organic carbon loading from the field to watershed scale in tile-drained landscapes

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ABSTRACT

Subsurface tile drains influence watershed fluxes of nitrogen, phosphorus, and pesticides, but few studies have examined the role of subsurface tile drains and drainage water management practices on watershed dissolved organic carbon (DOC) export. The objective of this study was therefore to quantify the contribution of subsurface tile drains to watershed DOC export and to evaluate the effect of drainage water management of DOC concentrations and loads in tile-drained fields. Discharge and DOC concentration were measured at the outlet of an agricultural headwater watershed (3.9 km^2) in Ohio, USA and all of the subsurface tile drains (6 total) within the watershed over an 8-year period. Results showed that DOC concentration in both subsurface tile drains and stream water were highly variable (0.1–44.4 mg L^{-1}), with mean DOC concentrations ranging from 5.7 to 8.2 mg L^{-1}. Intra-annual variability in subsurface tile drain and watershed hydrology yielded seasonal differences in DOC loading. Over the study period, 81.7% and 92.4% of watershed and subsurface tile drain DOC loading, respectively, occurred during 20% of the time, typically during winter and spring high flow events. Mean annual DOC loading from the drainage network was 19.6 kg ha^{-1}, while mean annual DOC loading at the watershed outlet was 43.9 kg ha^{-1}. On average, subsurface tile drainage comprised 33% of monthly watershed DOC export (<1–82%). Implementing drainage water management at one of the subsurface tile drains decreased discharge (179 mm; 22%) and DOC loading (6.8 kg ha^{-1}; 26%) compared to an adjacent free draining subsurface tile drain. Findings from this study demonstrate the utility of simultaneously monitoring solute fluxes from both field and watershed scales, and indicate that subsurface tile drains are a significant source of DOC to headwater agricultural streams. Further, results suggest that drainage water management can significantly decrease DOC losses from tile-drained fields.

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1. Introduction

Dissolved organic carbon (DOC) is essential to the functioning of aquatic ecosystems and represents a large flux of organic matter from watersheds (e.g., Mulholland, 1997). DOC serves as an energy source for heterotrophs, regulates the cycling of inorganic nutrients, and influences light and temperature regimes (Stanley et al., 2012). It also affects the transport and bioavailability of organic pollutants and heavy metals, which pose a risk to downstream drinking water quality (Ledesma et al., 2012). While the dynamics and biogeochemistry of DOC have been widely studied in upland forested watersheds, few studies have examined DOC fluxes in artificially drained agricultural watersheds commonly found across the Midwestern U.S., eastern Canada, and northern Europe. Subsurface tile drainage alters the dominant hydrologic flow pathways in these watersheds (e.g., King et al., 2014), which has been shown to influence fluxes of nitrogen (Tomer et al., 2003; Kennedy et al., 2012; Williams et al., 2015), phosphorus (Macrae et al., 2007; King et al., 2015), and pesticides (Kladivko et al., 2001; Stone and Wilson, 2006). As such, subsurface tile drainage likely also represents an important contributor to the overall DOC flux from agricultural watersheds (Royer and David, 2005; Dalzell et al., 2007; Ruark et al., 2009; Warrner et al., 2009).

Research at both field and watershed scales has shown the potential importance of subsurface tile drains on stream DOC export. Field studies examining the effect of specific factors such as vegetation type (Aitkenhead and McDowell, 2000) and drainage intensity (Dalzell et al., 2011) on DOC fluxes have suggested that single tile drain outlets can contribute up to 48 kg ha^{-1} of DOC to receiving streams and agricultural drainage ditches (e.g., Ruark

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et al., 2009). At the watershed scale, studies have indicated that subsurface tile drainage results in substantial intra-annual variation in stream water DOC concentration compared to undrained watersheds where wetlands persist (Hinton et al., 1997; Dalzell et al., 2007). The magnitude, timing, and composition of DOC in artificially drained watersheds has also been shown to reflect the quick transfer of DOC via subsurface drainage networks to the stream channel (Vidon et al., 2008).

Separating watershed DOC load between subsurface tile drains and other potential sources (i.e., surface runoff, in-stream processes) has been a limitation in previous studies of DOC export often due to the number of tile drain outlets within these watersheds. Indeed, DOC fluxes in tile-drained watersheds ranging from 22 to 480 km^2 have been examined, but these watersheds likely contain tens to hundreds of tile drain outlets which requires extrapolation of field-scale DOC loads to the watershed scale (e.g., Royer and David, 2005; Warrner et al., 2009). Measuring nutrient export in small headwater watersheds (<5 km^2) with fewer tile drain outlets, however, has been a useful approach for understanding the relationship between subsurface drainage and watershed nutrient fluxes (e.g., Macrae et al., 2007; King et al., 2015; Williams et al., 2015). Understanding nutrient and carbon transport in small headwater watersheds also has broad implications for biogeochemical cycling in downstream (higher order) systems (e.g., Peterson et al., 2001; Dalzell et al., 2011). Thus, in this study, we simultaneously measure DOC export at the outlet of a small agricultural headwater watershed and all of the subsurface tile drains (6 total) in the watershed to assess the integrated effects of subsurface tile drainage on the magnitude and timing of watershed DOC transport.

Managing carbon in agricultural landscapes has become of greater interest in recent years (Stanley et al., 2012), as national and global initiatives are promoting soil health, which includes increasing soil organic matter (NRCS, 2003) and carbon sequestration in agricultural soils. Reduced tillage practices, planting cover crops, and using animal manures have been shown to increase soil organic carbon in agricultural fields (e.g., Lal, 2004), but these increases may be offset in tile-drained fields due to increased DOC losses through the subsurface drainage network. In areas of northern Europe where peatlands have been historically surface-drained to increase the area of land suitable for agriculture or to allow peat-cutting for fuel, drain blocking (i.e., creating dams at intervals along the length of the surface drain) has been used to decrease DOC fluxes (Wallage et al., 2006; Armstrong et al., 2010). This suggests that drainage water management, the practice of seasonally adjusting the outlet elevation of the subsurface drainage system through installation of a water control structure (Skaggs et al., 2012), may be an effective practice in tile-drained landscapes to reduce DOC delivery from tile drains to streams.

In this study, we measure discharge and DOC concentration at the outlet of an agricultural headwater watershed in central Ohio, USA and all of the subsurface tile drains within the watershed over an 8 year period (2005–2012) to better understand the relationship between field and watershed scale DOC export. Our objectives were to (1) determine the proportion of watershed DOC export that is derived from subsurface tile drainage in an agricultural headwater watershed; and (2) quantify the effect of drainage water management on DOC concentrations and loads in tile-drained fields. Since subsurface tile drainage can have a large influence on hydrologic flow paths in headwater watersheds, we hypothesized that DOC loading from subsurface tile drainage would be a significant contributor to the overall watershed DOC flux. We also hypothesized that implementation of drainage water management would decrease DOC loading from tile-drained fields compared to conventional free drainage.

Table 1

Crop production management including tillage, crop, nutrient source, and nutrient rate, for fields B2 and B4. Management in B2 and B4 is representative of the prevailing practices that were found throughout Watershed *B* during the study period.

Year	Date	Operation[a]
2004	May 11	Tillage
	May 13	Corn planting Fertilizer application; 12-15-20 (26.9 kg N ha^{-1}; 14.7 kg P ha^{-1})
	June 13	Fertilizer application; 28-0-0 (167.3 kg N ha^{-1})
	November 13	Harvest
2005	May 7	Soybean planting
	October 5	Harvest
2006	April 30	Tillage
	May 1	Corn planting Fertilizer application; 10-34-0 (82.1 kg N ha^{-1}; 48.7 kg P ha^{-1})
	June 20	Fertilizer application; 28-0-0 (167.3 kg N ha^{-1})
	October 27	Harvest
2007	May 9	Soybean planting
	October 10	Harvest
	October 16	Fertilizer application; Chicken litter (456 kg N ha^{-1}; 117.4 kg P ha^{-1})
	October 17	Tillage
2008	May 7	Soybean planting
	October 2	Harvest

Adapted from King et al. (2016).

[a] Fertilizer listed as nitrogen-phosphorus-potassium (N-P-K).

2. Materials and methods

2.1. Experimental watershed

Our study took place in Watershed *B* (3.9 km^2), which is located in central Ohio, USA (40°12′41.83″ N, 82°49′31.48″ W) and is a subwatershed of the Upper Big Walnut Creek (492 km^2) (Fig. 1). The Upper Big Walnut Creek watershed is an USDA Agricultural Research Service benchmark watershed and has been studied as part of the Conservation Effects Assessment Project (CEAP) since 2004 (Mausbach and Dedrick, 2004). The majority of headwater streams in the Upper Big Walnut Creek watershed have been classified as impaired due to nutrient enrichment, pathogens, and habitat degradation stemming from agricultural practices (Ohio EPA, 2004). Crop production agriculture consisting primarily of corn (*Zea mays* L.)-soybean [*Glycine max* (L.) Merr.] crop rotations comprises 73% of the land use in Watershed *B*, with the remainder of the watershed consisting of urban/farmstead (21%) and woodland (6%) land uses. Typical crop production management for agricultural fields in Watershed *B* is shown in Table 1.

The topography of Watershed *B* is relatively flat, with slopes less than 1%. Soils throughout the watershed consist of a somewhat poorly drained Bennington silt loam (Fine, illitic, mesic Aeric Epiaqualfs) and a very poorly drained Pewamo clay loam (Fine, mixed, active, mesic Typic Argiaquolls) (Table 2). These soils typically contain 3–4% organic matter in surface horizons, with organic matter content decreasing with depth (USDA SSURGO, 2017). Soil saturated hydraulic conductivity ranges between 33 mm h^{-1} at the surface and 3–10 mm h^{-1} at a depth of 1.0 m (USDA SSURGO, 2017). Based on existing subsurface drainage maps for the watershed and conversations with land owners, it is estimated that 80% of Watershed *B* is systematically tile-drained (Fig. 1). Subsurface tile laterals are clay or perforated plastic, generally spaced 15 m apart, and buried at a depth of 0.9–1.0 m. The estimated average age of the subsurface drainage network is >50 yr. Surface inlets, one located in a grassed waterway and one in a roadside ditch, are connected to