Soil & Tillage Research 178 (2018) 130–138

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Fertilizer placement and tillage effects on phosphorus concentration in leachate from fine-textured soils

Mark R. Williams[a,*], Kevin W. King[b], Emily W. Duncan[b], Lindsay A. Pease[b], Chad J. Penn[a]

[a] USDA Agricultural Research Service, National Soil Erosion Research Laboratory, 275 S. Russell St., West Lafayette, IN 47907, United States
[b] USDA Agricultural Research Service, Soil Drainage Research Unit, 590 Woody Hayes Dr., Columbus, OH 43210, United States

ARTICLE INFO

Keywords:
Tile drainage
Preferential flow
Lysimeter

ABSTRACT

Adoption of no-tillage in agricultural watersheds has resulted in substantial reductions in sediment and particulate phosphorus (P) transport in surface runoff. No-tillage, however, may result in increased losses of dissolved P in tile-drained landscapes due to the accumulation of P in surface soil layers and prevalence of preferential flow pathways. The objective of this study was to examine the effect of fertilizer placement and tillage on P leaching in fine-textured soils following fertilizer application. Rainfall simulations (90 min; 3.8 cm rainfall depth) immediately following application of monoammonium phosphate fertilizer (75 kg P ha^{-1}) were conducted on 9 m^2 plots with pan lysimeters (0.6 m depth) in four agricultural fields located in northwestern Ohio, USA. Three fertilizer placement treatments that covered a range of soil disturbance and soil-fertilizer mixing (broadcasted, injected, and tilled) were replicated on each field. Stable water isotopes were used to separate leachate into preferential and matrix flow components. Results showed that leachate dissolved P concentration was significantly greater when fertilizer was surface broadcast on no-tilled plots (43.7 mg L^{-1}) compared to when the fertilizer was either injected (14.9 mg L^{-1}) or tilled (11.0 mg L^{-1}) into the soil. Event water comprised between 6 and 46% (mean = 22%) of lysimeter leachate and did not vary among treatments. Similar event water contributions among treatments suggest that the disruption of the macropore network was not likely the main mechanism responsible for decreased P concentration in leachate, but rather increased soil-fertilizer contact and decreased interaction between the highly soluble fertilizer and ponded surface water were likely responsible for decreased P concentrations observed for the injected and tilled treatments compared to the broadcasted treatment. Findings indicate that subsurface injection of fertilizer has the potential to limit dissolved P leaching compared to surface broadcast applications and also minimize soil disturbance relative to tillage; thus, it should be considered a promising conservation practice to help meet water quality goals in tile-drained landscapes.

1. Introduction

Excess phosphorus (P) delivery from tile-drained agricultural watersheds has been linked to increases in the magnitude and severity of hypoxic zones and harmful algal blooms in receiving surface waters (Rabalais et al., 2010; Stumpf et al., 2012; Michalak et al., 2013; Kane et al., 2014). In humid regions of the world with poorly drained soils, P transport in subsurface tile drainage is of increasing environmental concern, as tile drains may export P at rates greater than those associated with overland flow (Jamieson et al., 2003; King et al., 2015a; Williams et al., 2016a). Recent studies in the Great Lakes region of North America have shown that tile drains can contribute nearly 50% of watershed discharge and dissolved P fluxes (Macrae et al., 2007; King et al., 2015b). Edge-of-field monitoring in artificially drained landscapes has also indicated that tile drains can account for 47–66% of annual dissolved P losses, but in some instances they may account for up to 95% (Eastman et al., 2010; Van Esbroeck et al., 2016; Williams et al., 2016c). Understanding the dominant processes controlling subsurface P transport and identifying management practices that decrease P loss is therefore critical for attaining water quality goals in these landscapes.

In fine-textured soils, preferential flow through soil macropores (e.g., root channels, earthworm burrows, and desiccation cracks) has been hypothesized to be an important process controlling subsurface P transport (Sims et al., 1998; King et al., 2015a). Preferential flow pathways can provide a direct connection between the soil surface and tile drains (Akay and Fox, 2007), which has been evidenced by the rapid response of drainflow to tracer applications at the soil surface

* Corresponding author.
E-mail addresses: mark.williams2@ars.usda.gov (M.R. Williams), kevin.king@ars.usda.gov (K.W. King), emily.duncan@ars.usda.gov (E.W. Duncan), lindsay.pease@ars.usda.gov (L.A. Pease), chad.penn@ars.usda.gov (C.J. Penn).

https://doi.org/10.1016/j.still.2017.12.010
Received 28 July 2017; Received in revised form 8 December 2017; Accepted 11 December 2017
0167-1987/ Published by Elsevier B.V.

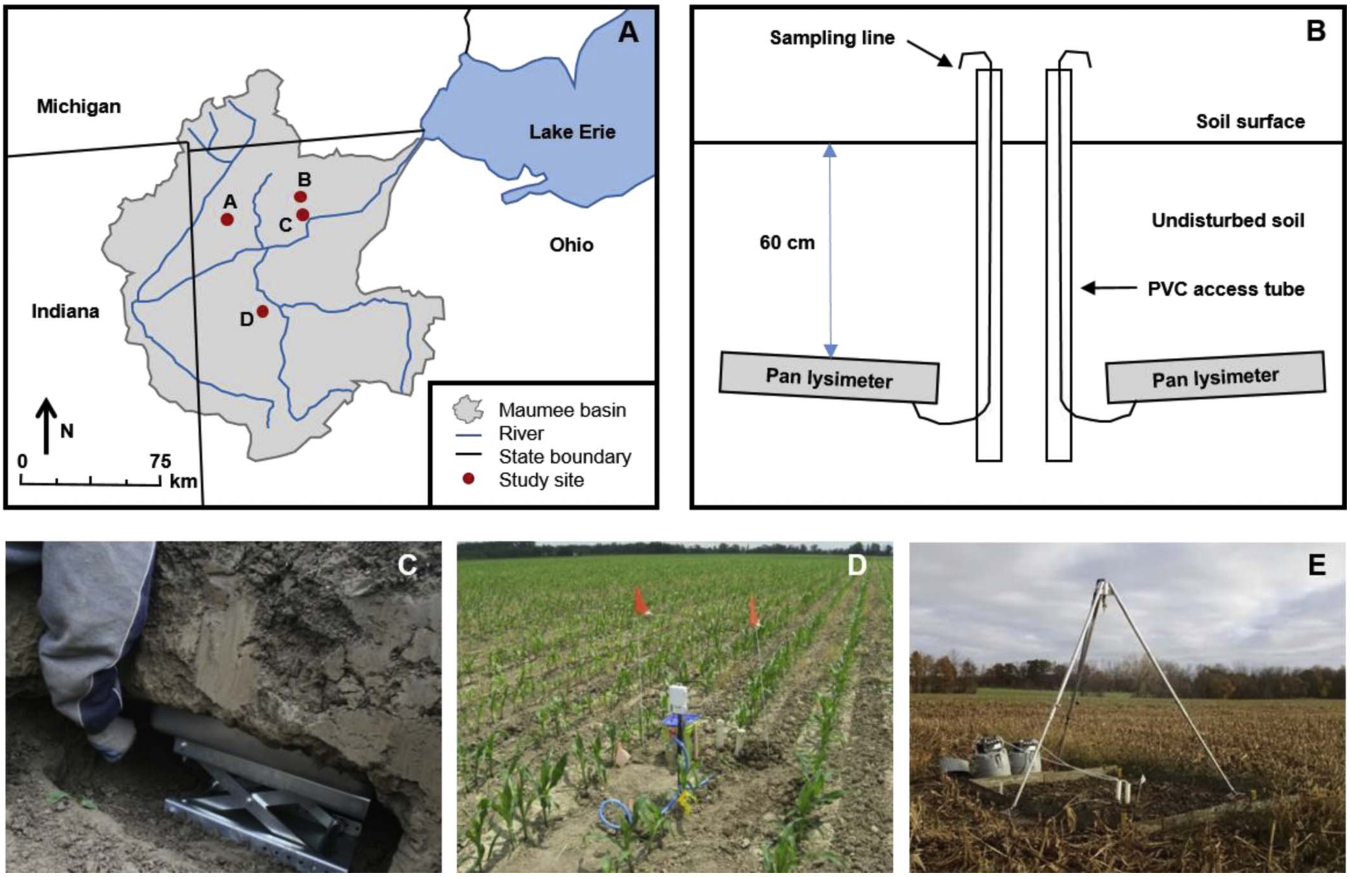

Fig. 1. Regional map showing the Maumee basin and four study fields relative to Lake Erie (A) and schematic of pan lysimeter installation (B). Field and soil characteristics are shown in Table 1. Pictures of a pan lysimeter being installed (C), field after pan lysimeter installation (D), and rainfall simulation (E).

(Kung et al., 2000) and the visible linkage between macropores and tile drains (Shipitalo and Gibbs, 2000). Phosphorus levels in agricultural soils are typically greater in surface soil horizons due to contemporary or historic applications of either manures or commercial fertilizers (Baker et al., 2017). Thus, preferential flow pathways may facilitate the transport of P-laden water to tile drains by bypassing the normally high P adsorption capacity of the soil matrix (Djodjic et al., 1999; Simard et al., 2000; Geohring et al., 2001; Vidon and Caudra, 2011; Klaus et al., 2013; Williams et al., 2016a).

Recent reviews of P transport in tile-drained landscapes have noted that no-tilled fields may be more susceptible to elevated dissolved P concentrations in drainage water compared to tilled fields due to the greater potential for vertical stratification of P in the soil profile and formation of preferential flow pathways (King et al., 2015a; Christianson et al., 2016). Conceptually, tillage practices disrupt the continuity of the macropore network resulting in more torturous flow pathways for solute transport compared to no-tillage (Djodjic et al., 2002; Cullum, 2009). For example, Andreini and Steenhuis (1990) measured solute transport in soil columns that were either tilled or no-tilled. The authors found that in the no-tilled columns preferential flow resulted in the short-circuiting of the solute tracer, contrasting with predominantly matrix flow observed in the tilled columns. Tillage also results in the mixing of surface soils with subsoils, which has implications for soil P sorption capacity. Sharpley (2003) found that this mixing minimized dissolved P loss due to the combined effects of dilution of high P surface soils and an increased soil P sorption capacity. Similarly, tillage immediately following fertilizer application can increase soil-fertilizer contact compared to surface broadcast fertilizer application and result in decreased dissolved P losses (Addiscott and Thomas, 2000).

Over the past four decades, considerable financial and personnel resources have been dedicated to the adoption of no-tillage in agricultural watersheds. These efforts have resulted in significant reductions in sediment and particulate-bound P delivery to surface waters (e.g., Richards and Baker, 1998, 2002). Concerns of increased dissolved P transport in tile drains from no-tilled fields, however, has sparked scientific and public debate on the water quality trade-offs associated with tillage practices (Smith et al., 2015). The injection of P fertilizers into the subsurface has been suggested as a compromise, as it may retain the benefits of both no-tillage (e.g., improved residue cover, decreased erosion, reduced particulate P losses) and tillage (e.g., increased soil-fertilizer contact, increased flow path tortuosity, decreased vertical stratification of P, decreased dissolved P losses). Several watershed modeling studies have shown that subsurface fertilizer placement can effectively produce desired water quality outcomes (Gildow et al., 2016; Kalcic et al., 2016). In contrast, field observations indicate that subsurface fertilizer placement may not yield adequate reductions in dissolved P leaching (Ball-Coelho et al., 2007; Feyereisen et al., 2010).

The objective of this study was to examine the effect of preferential flow through soil macropores on P leaching in agricultural fields with different tillage and fertilizer application practices. Specifically, we investigated preferential flow and P concentrations in leachate from three treatments representing a range of soil disturbance (no-tilled vs. tilled) and soil-fertilizer mixing (broadcasted vs. injected vs. tilled). Rainfall simulations on field plots with pan lysimeters were conducted following fertilizer application and stable water isotopes were used to separate leachate into preferential and matrix flow components and quantify the relationship between preferential flow and subsurface P transport. We hypothesized that tillage following fertilizer application would result in less dissolved P leaching compared to either no-tillage with surface broadcast fertilizer application or fertilizer injection into