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Subsurface drainage volume reduction with drainage water management: Case studies in Ohio, USA

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ABSTRACT

Drainage water management (DWM) is promoted as an agricultural best management practice that reduces subsurface drainage volume and thereby the transport of soluble nutrients to streams. This study was conducted on private crop fields to quantify the effect of managed subsurface drainage on daily subsurface drainage volume, in poorly drained and somewhat poorly drained soils of northwest Ohio. A paired zone approach was used where a part of each field was conventional free draining and the other part was under drainage water management. At each site, comparison of median daily subsurface drainage volume from the two zones indicated that drainage water management was effective at reducing daily subsurface drainage volume. A linear mixed model procedure was applied to determine the percent reduction in daily subsurface drainage volume as a result of drainage water management. Using the paired dataset at each site, the model predicted the total daily subsurface drainage volume from the managed zone as a function of the observed total daily subsurface drainage volume from the conventional zone. The percent reduction of daily subsurface drainage volume varied from 40% to 100% depending on site. While the magnitude of the reduction of the daily subsurface drainage volume is site specific, the general expectation is that if DWM is instituted broadly and appropriately in northwest Ohio, mean daily subsurface drainage volume would lessen on an annual basis. Such reduction may eventually translate into a reduction in nutrient loads exported from farm fields.

1. Introduction

Excess water on the surface and/or in the profile of agricultural soils negatively affects timeliness of field operations (tillage, planting, harvesting, etc.) and soil aeration, and contributes to soil erosion. Delayed field operations as well as inadequate soil aeration are potential causes of crop yield reduction (Brown and Ward, 1997). The economic costs associated with wet or waterlogged agricultural soils are problematic for the farmers, and especially in the midwestern United States. Subsurface drainage facilitates the removal of excess water from the soil profile and helps lower the seasonal water table. Ohio, like much of the midwest, is drained extensively with subsurface drains to facilitate crop production (Fausey et al., 1995).

Although drainage is known to provide crop production benefits, some adverse environmental effects have been identified, in particular the export of soluble nutrients to surface water bodies (Fausey et al., 1995). In response to hypoxic conditions in surface water bodies, especially in the Gulf of Mexico (Mitsch et al., 2001; Rabalais et al., 1996, 2001) and Lake Erie (Boyce et al., 1987), attention has been drawn to abundant evidence that soluble nutrients move into streams from croplands that are subsurface drained. Suggested approaches for reducing nutrient delivery to streams through subsurface drainage systems include non-structural improvements in nutrient use efficiency through the alteration of the rate, placement, timing and formulation of fertilizers (USDA-NRCS, 2012b). Structural approaches include: immobilization and recycling of soluble nutrients using cover crops (Hoorman, 2009; Jones and Jacobsen, 2009); drainage discharge reduction through the use of control structures on existing and new subsurface drainage systems (Zucker and Brown, 1998); and the use vegetated drainage ditches, wetlands, and reactive barriers to increase capture and transformation of soluble nutrients (Strock et al., 2010).

Controlled drainage is a best management practice used to reduce drainage water volumes and nutrient loads to receiving

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streams, and is generally addressed as drainage water management. In this paper, the term "drainage water management (DWM)" (Frankenberger et al., 2007) will describe the use of an in-line water level control structure to adjust the outlet elevation at different times during the year according to crop stage and field trafficability needs. The outlet elevation is adjusted by adding or removing stop logs in the control structure, which determines the level of the water table (subject to precipitation) in the field at which drainage can occur.

Studies conducted to evaluate the effectiveness of DWM on crop and forest lands with moderately and poorly drained sandy loam soils in the Eastern Coastal Plains of the U.S. reported an overall reduction of drainage volume (Amatya et al., 1998; Gilliam et al., 1979). DWM was associated with annual subsurface drainage and nitrate export load reduction in a field experiment on poorly drained soils in Illinois (Cooke and Verma, 2012). The effectiveness of this practice was demonstrated in on-farm experiments in Indiana on loam soil (Adeuya et al., 2012), in Ontario (Canada) on a predominantly loam soil (Lalonde et al., 1996), and in Lithuania on a sandy loam soil (Ramoska et al., 2011). Other studies demonstrated DWM effectiveness at reducing subsurface drainage volume using field plot experiments in Sweden on a loamy sand soil (Wesstrom and Messing, 2007), in Ontario on a clay loam soil (Drury et al., 2009), and in Iowa on silty clay loam and clay loam soils (Helmers et al., 2012; Jaynes, 2012). Research on Hoytville silty clay soil in Ohio (Fausey, 2005) showed DWM on field plots with a corn-soybean rotation resulted in a 40% reduction in subsurface drainage volume compared to conventional subsurface drainage.

Amenumey et al. (2009) conducted a meta-analysis of reported subsurface drainage volume reduction data, and identified different factors affecting drainage discharge under DWM. Their analysis indicated that DWM helped reduce subsurface drainage volume by an average of 47% compared to conventional subsurface drainage. The authors also found that greater subsurface drainage volume reduction – up to 75% – is likely to occur in loamy sand soils, compared to 37% in clay loam soils. Crops and climate were also found to affect subsurface drainage volume reduction, but not as strongly as soil type. Other reviews (Skaggs et al., 2010, 2012) reported subsurface drainage volume reductions of 17 to 80%, with DWM. These authors concluded that the effectiveness of the practice depends on soils, climatic conditions, and on drainage system design and management.

Overall, DWM research indicates that subsurface drainage volume reduction is the main driver of the reduction of soluble nutrient loads exported from cropland through subsurface drainage systems, and in most cases there is minimal change in nutrient concentration (Adeuya et al., 2012; Drury et al., 2009; Fausey, 2005; Gilliam et al., 1979; Lalonde et al., 1996; Skaggs et al., 2005, 2010; Smith and Kellman, 2011). Studies conducting both field experiments and model simulations of managed vs. conventional subsurface drainage also indicated reductions in subsurface drainage volume, and showed that reduced nitrate loss was associated with managed subsurface drainage (Ale et al., 2012; Fang et al., 2012; Jaynes, 2012; Luo et al., 2010). Consequently there is sufficient evidence that subsurface drainage volume reduction results in the reduction of soluble nutrients loads.

DWM is not a novel concept, but its adoption and use has not been widely implemented except in north Carolina (Skaggs et al., 2012). The USDA Natural Resources Conservation Service (USDA NRCS) has begun to promote the adoption of DWM as a nutrient reduction strategy for the Gulf of Mexico, Lake Erie, and Chesapeake Bay, and established a standard for DWM (USDA-NRCS, 2012a). However, the implementation, management and effectiveness of the practice need to be further demonstrated. An USDA–NRCS Conservation Innovation Grant (CIG) project was initiated in 2006 to address this need, and involved the implementation of DWM on privately owned farms in five Midwest U.S. states. This manuscript reports the flow reduction results on six demonstration farms in Ohio. The overall objective of this paper was to quantify the reduction in mean daily subsurface drainage volume associated with DWM across a range of soils in Ohio where subsurface drainage is required for economical crop production.

2. Materials and methods

2.1. Experimental design, site descriptions and data collection

Subsurface drained agricultural fields located on six private farms in northwest Ohio (Fig. 1) were used for this study. Basic characteristics of the sites are described in Table 1. The sites have fine textured, slowly permeable soils, and require subsurface drainage for economically viable crop production. They are relatively flat, with average slopes ranging from 0.2% to 1.6%, which make these sites suitable for DWM. Thirty-year annual precipitation normals (1981–2010) varied between 800 mm (Defiance) and 993 mm (Crawford).

Each site contained 2 adjacent zones independent of each other. Each zone had a subsurface drainage network outlet that discharged through an in-line water level control structure (Agri-Drain Corporation, Adair, IA), independently of the other zone (Fig. 1). There was no physical barrier between the zones at each site. In general, the drain laterals were 10-cm diameter at a depth of 0.8 to 1.2 m.

The paired zones at each site were farmed as a single field and had identical management in terms of cropping, tillage and fertilization, before as well as during the study (Table 2). Each in-line water level control structure contained PVC stoplogs that could be stacked for flow management, i.e., artificially change the outlet elevation. The topmost stoplog included a 10-cm deep V-notch weir used to help quantify flow through the structure. At each site, one of the zones, denoted as managed zone, was randomly chosen for implementation of a DWM plan. The outlet elevation of the managed zone was raised or lowered by inserting or removing stoplogs in the in-line control structure at recommended times during the year.

The recommended management plan for the managed zones was to set the outlet elevation at 30 cm below the ground surface during December through March each year (non-growing season) to reduce drain flow. During mid-June through September (growing season), the managed zones outlet elevation was set at 45 to 50 cm below the ground surface to both reduce drain flow and retain any available water for crop use. The managed zones outlet elevation was set to the lowest level in the control structure allowing free drainage during April through mid-June each year to facilitate planting and crop establishment, and again during October and November to facilitate harvest and any autumn field operations.

Although the drainage management of the managed zones was generally based on the recommended plan, the actual dates the outlet elevation was adjusted varied from site to site, depending on field conditions such as planting delays, crop development stage, and field trafficability needs for farm operations and landowner choices. Figs. 2–4 illustrate the periods during which the stoplogs were raised and lowered in the managed zone at each site. The other zone, denoted as conventional zone, was allowed to drain freely throughout the duration of the study.

The sites were continuously monitored for subsurface drainage flow. The duration of monitoring varied between sites (Table 3), but was more than 2 years for any site. The depth of water in each control structure was measured at either 30-min or 1-h intervals using a pressure transducer placed in a stilling well upstream from the V-notch weir. The water depth measurements were further used