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Review

A synthesis and comparative evaluation of factors influencing the effectiveness of drainage water management

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ABSTRACT

Viable large-scale crop production in the United States requires artificial drainage in humid and poorly drained agricultural regions. Excess water removal is generally achieved by installing tile drains that export water to open ditches that eventually flow into streams. Drainage water management (DWM) is a conservation practice that allows farmers to artificially raise the outlet elevation of a field's drain tile and can reduce nutrient loss during wet periods by storing more water in the field. We intended to assess the effectiveness of DWM to reduce drainage discharge and nutrient loads and additionally identify predictor variables that influence DWM effectiveness. We compared managed (i.e., DWM) and free draining records using paired *t*-tests, and identified factors associated with DWM effectiveness using a multiple linear regression approach. T-test results indicated that DWM was highly effective in reducing drainage water discharge and nutrient losses via drain tiles as tile discharge volumes were reduced on average 46%, while tile nitrate loads were reduced by 48%. In addition, total phosphorus and dissolved reactive phosphorus loads were reduced by 55% and 57%, respectively. Based on regression results, we found that several aspects of farm and tile drain management were associated with DWM effectiveness, while site specific landscape characteristics were less likely to predict effectiveness. While DWM is effective as a conservation practice to reduce discharges of water and nutrients from drain tiles, we also identified several knowledge gaps. Future research should investigate effects of DWM on water and nutrients lost in other pathways such as surface runoff, preferential flow, groundwater recharge and biological uptake, and also focus more attention on phosphorus as there is a paucity of research on this topic.

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1. Introduction

Consistent and profitable large-scale crop production in the United States has in part relied upon artificial (tile) drainage, as some of the most fertile soils are found in humid climates and are naturally poorly drained (Fausey et al., 1995). Artificial drainage is achieved by installing subsurface pipes (i.e., tile drains) that help to export excess soil water to drainage ditches that eventually flow into streams. While artificial drainage has led to increased crop yields, as well as reductions in surface runoff and associated sediment loss (Skaggs et al., 1982), it has also contributed to extensive alterations in watershed hydrology and increased transport of nutrients from farm fields into surface waters (Blann et al., 2009). Increased nutrient loading to streams degrades water quality leading to eutrophication of marine and freshwater bodies. This promotes harmful algal blooms (HABs) and subsequent hypoxic and anoxic conditions, including those often found in the Gulf of Mexico and shallow portions of the Great Lakes (David et al., 2010; Smith et al., 2015). These water quality impacts degrade biological integrity in streams and receiving waters (Ludsin et al., 2001; Miltner 2010; Weigel and Robertson 2007) and impact ecological services such as safe drinking water and productive fisheries (Breitburg et al., 2009; Ludsin et al., 2001; Smith et al., 2015).

Drainage water management (DWM), also referred to as controlled drainage, is an agricultural conservation practice that allows tile outlet elevations to be managed. By adding and removing control structures such as weir boards, subsurface drainage is restricted or promoted by raising and lowering tile outlet elevations (Frankenberger et al., 2006). Drainage water management is gaining popularity and being increasingly implemented in the Midwestern U.S. and has received considerable attention in the scientific literature (e.g., Adeuya et al., 2012; Breve et al., 1997; Fausey 2005; Gaynor et al., 2002; Jaynes 2012). Current estimates of land under DWM are not available; however, the implementation of DWM is increasing as a result of water quality concerns. Additionally, state and federal cost share opportunities have contributed to increased implementation of the practice (e.g., Environmental Quality Incentives Program; Minnesota's Clean Water Fund). Many studies have documented that this practice can effectively reduce drainage outflow and nutrient loading from tiles across a range of geographic regions (Skaggs et al., 2012). With the growing body of data and information on DWM comes the opportunity–as well as the need–for synthesizing and evaluating the performance of the practice across these studies.

Our main goal is to assess the performance of DWM as a conservation practice intended to reduce losses of water and nutrients (i.e., nitrogen (N) and phosphorus (P)) from tile discharge while also considering subsequent changes in surface runoff due to DWM. In our analysis we: (1) compare managed and free draining observations to evaluate the effectiveness of DWM, and (2) identify site-specific landscape (e.g., climate, weather, and topography) and farm and tile drain management factors (e.g., nutrient application rate, drain spacing, drain depth, timing of managing tiles) potentially important in influencing the effectiveness of DWM. Our review also takes note of key knowledge gaps that have not been sufficiently addressed in previous studies in an effort to guide future research toward influences of DWM that are currently unclear.

2. Methods

2.1. Literature review and article selection criteria

We searched for both measured and modeled data evaluating the effects of DWM on water quantity and quality in surface runoff and tile discharge from plots, fields, or small watersheds. For any particular study to be included, it had to assess the influence of DWM compared to free draining tiles, and report quantitative values or easily interpretable graphs of at least one response variable of interest. We used literature database search engines, primarily Google Scholar and to a limited extent, Web of Science in our literature search. We used a variety of keywords related to drainage control including but not limited to: controlled drainage; drainage water management; and tile drain management. We considered research from any time period located in any tile drained landscapes flowing into a drainage network. We additionally searched for technical reports; symposium papers; and investigated references from both reviews and the selected papers to identify relevant research not initially obtained in our literature search.

Water quantity and quality response variables of interest included: discharge (surface runoff and tile drainage), and annual nutrient loads (nitrate-nitrogen, dissolved reactive phosphorus, and total phosphorus) in both surface runoff and tile drainage.

We had concerns of confounding effects with studies where sub-irrigation was used concurrently with DWM as details regarding implementation of this practice was either not reported (e.g., volume applied) and/or would likely have an influence on drain flow and nutrient loads because of the added water and the increased crop growth due to irrigation. Because of this, we continued to analyze only those observations that did not employ sub-irrigation. All