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Simulated effect of drainage water management operational strategy on hydrology and crop yield for Drummer soil in the Midwestern United States

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ABSTRACT

The hypothetical effects of drainage water management operational strategy on hydrology and crop yield at the Purdue University Water Quality Field Station (WQFS) were simulated using DRAINMOD, a field-scale hydrologic model. The WQFS has forty-eight cropping system treatment plots with 10 m drain spacing. Drain flow observations from a subset of the treatment plots with continuous corn (*Zea mays* L.) were used to calibrate the model, which was then used to develop an operational strategy for drainage water management. The chosen dates of raising and lowering the outlet during the crop period were 10 and 85 days after planting, respectively, with a control height of 50 cm above the drain (40 cm from the surface). The potential effects of this operational strategy on hydrology and corn yield were simulated over a period of 15 years from 1991 to 2005. On average, the predicted annual drain flows were reduced by 60% (statistically significant at 95% level). This is the most significant benefit of drainage water management since it may reduce the nitrate load to the receiving streams. About 68% of the reduced drain flow contributed to an increase in seepage. Drainage water management increased the average surface runoff by about 85% and slightly decreased the relative yield of corn crop by 0.5% (both are not statistically significant at 95% level). On average, the relative yield due to wet stress (RYw) decreased by 1.3% while relative yield due to dry stress (RYd) increased by 1%. Overall, the relative crop yield increased in 5 years (within a range of 0.8–6.9%), decreased in 8 years (within a range of 0.2–5.5%), and was not affected in the remaining 2 years. With simulated drainage water management, the water table rose above the conventional drainage level during both the winter and the crop periods in all years (except 2002 crop season). The annual maximum winter period rise ranged between 47 cm (1995) and 87 cm (1992), and the annual maximum crop period rise ranged between no effect (2002) and 47 cm (1993).

1. Introduction

Agricultural subsurface drainage, popularly known as tile drainage, is an essential water management practice in agricultural regions with seasonal, high water tables. Subsurface drainage systems have been installed in more than 20.2 million ha in the Midwestern states, of which Indiana has the second largest subsurface drained area (3.3 million ha, which

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is about 50% of Indiana's crop land) (USDA-ERS, 1987). Although subsurface drainage provides many agronomic and environmental benefits, it increases losses of nitrate-N through the enhanced leaching of the soil profile (Gilliam et al., 1999). Nitrate loading from agricultural lands of the Midwest has become a major concern in recent years, since nitrate has been shown to contribute to hypoxia, which causes a severe reduction in aquatic life in parts of the Gulf of Mexico (Goolsby et al., 2001).

Traditional free-flowing subsurface drainage systems require minimal maintenance and management after installation. However, concern about negative environmental effects has led to the development of management systems that reduce nitrate loading from subsurface drainage systems. A drainage water management system (also called controlled drainage system) consists of installing a water table control structure at the outlet of the subsurface drainage system with which the outlet elevation can be managed at different times of the year (Frankenberger et al., 2006). The water table control structure contains movable flash boards that can be raised and lowered, thus raising and lowering the outlet elevation. Continued management of subsurface drainage systems may minimize some off-site environmental impacts such as nitrate loading. Measurements made at monitored sites in northern and southern Indiana indicate that about 40–75% of the annual nitrate load from the subsurface drainage systems occurs during the non-growing season when there is no crop-based need for drainage to occur (Brouder et al., 2004). Several field as well as modeling studies have reported reductions in subsurface drainage and associated nitrate load due to drainage water management practices while maintaining the necessary drainage during critical periods of the crop season and for periods of high water table during spring, summer, and early autumn (Evans et al., 1995; Lalonde et al., 1996; Breve et al., 1998; Fausey, 2004; Singh et al., 2007).

Limited field data from Midwestern states and eastern Canadian provinces show the potential for large reductions in nitrate loads with drainage water management (Kalita and Kanwar, 1993; Drury et al., 1996; Fausey et al., 2004). Drury et al. (1996) reported a 25% decrease in mean nitrate concentration, and a 49% decrease in the total annual nitrate load when drainage water management was implemented on a clay loam soil in Southwestern Ontario. Lalonde et al. (1996), working with a 2-year corn (*Zea mays* L.)/soybean (*Glycine max* L.) rotation on a silt loam soil in Quebec, measured drain flow reductions of 59 and 65%, and nitrate concentration reductions of 76 and 69%, compared to conventional subsurface drainage, for two outlet levels (0.25 and 0.50 m above drain level) in drainage water management systems, respectively. A conservative estimate by a consensus of drainage researchers is that drainage water management can lead to a 30% reduction in average annual nitrate loads in regions where appreciable drainage occurs in late fall and winter (Cooke et al., 2005).

Although drainage water management practices have been adopted at several locations in the Midwest, strategies for operating these systems under Midwestern conditions are not well-defined. Operational and management choices include the dates relative to planting/harvesting to raise and lower the outlet, and the height to which the outlet should be raised, both during the cropping season and during the non-growing season. Optimal outlet operation timing should minimize winter drain flow and possibly help increase crop yields. Modeling studies of potential management strategies can provide guidance during early adoption of the practice and inform ongoing research. Furthermore, such modeling studies can evaluate the potential role of drainage water management in altering seasonal hydrologic fluxes and reducing nitrate loads during critical periods.

Among the few models available for evaluation of drainage water management systems for soils with natural or induced high water tables, DRAINMOD (Skaggs, 1978) is one of the most widely used (Wright et al., 1992; Singh et al., 2007). DRAINMOD has the capability to model all the three components of water table management: subsurface drainage, controlled drainage and subirrigation. Using the controlled drainage mode, it is possible to simulate the long-term impacts of drainage water management in terms of drain flow and water table behavior, and potential crop yield. Singh et al. (2007) used DRAINMOD to predict the effects of drainage water management on subsurface drainage, surface runoff, and crop production in Webster soil, one of Iowa's most commonly drained soils. Their modeling analysis over a period of 60 years (1945–2004) indicated an 8–18% reduction in subsurface drainage outflow and a slight reduction in relative yield due to increased excess water stress with shallow drainage (drain depth of 0.75 m instead of conventional drain depth of 1.2 m) and drainage water management (outlet control level at 0.6 m below the soil surface during November through March in winter and from June to August in summer).

The overarching goal of this study is to determine the effect of various drainage water management operational strategies on hydrology and crop yield for Drummer soil in the Midwestern United States and to simulate the hydrologic effects of drainage water management at Purdue University's Water Quality Field Station (WQFS), located in West Lafayette, Indiana for the period from 1991 to 2005 (15 years). The specific objectives of the study are to (i) calibrate and validate DRAINMOD model for the conventional drainage case using the drainage flow data from the WQFS drainage lysimeter plots, (ii) apply the calibrated model for hypothetical drainage water management plans to determine trade-offs in management parameters including the periods and height of control during cropping season and winter, and (iii) predict the effects of drainage water management on potential corn yield, drain flow, surface runoff, and average water table depth.

2. Methodology

2.1. *Description of study site*

Purdue University's WQFS is dedicated to studying the impacts of drain spacing and cropping system treatments on water quality. It is located in the Tipton till plain region of west central Indiana. Soils at the WQFS are predominantly Drummer silty clay loam (fine-silty, mixed, superactive, mesic Typic Endoaquoll) (USDA, 1998; Hofmann et al., 2004). The soil overlies glacial till found at a depth of approximately 147 cm (Hofmann, 2002). The field site has 0–2% slope across the