Agricultural Water Management 107 (2012) 23–33

Contents lists available at SciVerse ScienceDirect

Agricultural Water Management

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

Development and application of a distributed modeling approach to assess the watershed-scale impact of drainage water management

S. Ale[a,*], L.C. Bowling[b], P.R. Owens[b], S.M. Brouder[b], J.R. Frankenberger[c]

[a] Texas AgriLife Research (Texas A&M University System), P.O. Box 1658, Vernon, TX 76385, USA
[b] Department of Agronomy, Purdue University, 915W. State St., West Lafayette, IN 47907, USA
[c] Department of Agricultural and Biological Engineering, Purdue University, 225 S. University St., West Lafayette, IN 47907, USA

ARTICLE INFO

Article history:
Received 1 July 2011
Accepted 12 January 2012
Available online 2 February 2012

Keywords:
Controlled drainage
DRAINMOD
Nitrate load
Hydrologic modeling
Soil parent material
Tile drains

ABSTRACT

Drainage water management, also known as controlled drainage, is the practice of using a water table control structure at the end of the subsurface drain pipe to reduce subsurface drainage, and thereby nitrate losses. Methods to quantify the potential effects of drainage water management for entire watersheds are needed to evaluate the impacts of large-scale adoption. A distributed modeling approach was developed to apply the field-scale DRAINMOD model at the watershed scale, and used to assess the impact of drainage water management on nitrate load from an intensively subsurface drained agricultural watershed in west central Indiana. The watershed was divided into 6460 grid cells for which drain spacing, soil parent material, and cropping pattern were estimated, resulting in 600 unique field conditions. The annual edge-of-field nitrate load from each grid cell was estimated as the product of DRAINMOD-predicted drain flow and the average annual nitrate concentration in drain flow, estimated from observations from related drainage sites in northern Indiana. Predicted monthly streamflow was in good agreement with the observed streamflow (Nash–Sutcliffe efficiency of 0.87 and 0.84 during the calibration and validation periods, respectively) and the predicted drain flow matched well with the measured drain flow (77.1 cm vs. 77.8 cm and 121.3 cm vs. 128.4 cm). Drainage water management decreased the average annual (1985–2009) predicted drain flow from 11.0 to 5.9 cm, and the total nitrate load through subsurface drainage from 236 to 126 ton (both about 47% reduction). The percent reduction in nitrate load varied between 40% and 53% for all combinations of drain spacing, soil parent material and cropping patterns, with drain spacing and soil parent material having a greater effect than cropping pattern. The methodology developed in this study showed potential for predicting the watershed-scale effects of subsurface drainage and drainage water management in drained agricultural watersheds.

© 2012 Elsevier B.V. All rights reserved.

1. Introduction

Over the last three decades, public concern over the nitrate losses from subsurface (tile) drained agricultural lands in the Midwest to the Mississippi River and its tributaries has increased as problems such as hypoxia became more prominent in the Gulf of Mexico (Alexander et al., 2008; Burkhart and James, 1999; Petrolia and Gowda, 2006; Rabalais et al., 1996). Improved management of the subsurface drained lands is necessary to minimize the off-site environmental impacts. Drainage water management (DWM), also known as controlled drainage, is an edge-of-field strategy designed to reduce nitrate load from subsurface drainage systems. DWM is the practice of using a water control structure in a main, submain, or lateral drain to vary the depth of the drainage outlet (Frankenberger et al., 2006). With DWM, the water table must rise above the outlet depth for drainage to occur. The outlet depth, as determined by the control structure, is raised after harvest to limit drainage outflow and reduce the delivery of nitrate to ditches and streams during the off-season, lowered in early spring and again in the fall so that the drain can flow freely before field operations such as planting or harvest, and raised again after planting and spring field operations to create a potential to store water for midsummer crop use.

Numerous field studies (Drury et al., 1996; Evans et al., 1995; Fausey et al., 2004; Kalita and Kanwar, 1993; Lalonde et al., 1996; Woli et al., 2010) as well as modeling studies (Ale et al., 2009, 2012; Luo et al., 2009; Singh et al., 2007; Thorp et al., 2008) conducted in North Carolina and the Midwest of the United States and Canada have reported significant reductions in annual drain flow and nitrate load with DWM, on the order of 20–58%. However, most of the studies from the Midwest have been conducted at field-scale and only a few studies have predicted the effect of DWM at watershed scale in this region. Thorp et al. (2008) simulated 53%

---

* Corresponding author. Tel.: +1 940 552 9941; fax: +1 940 552 2317.
E-mail addresses: sriniale@ag.tamu.edu, Srinivasulu.Ale@gmail.com (S. Ale).

0378-3774/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.agwat.2012.01.003

and 51% reductions in annual drain flow and nitrate losses, respectively with DWM averaged over 48 locations in the Midwest using the Root Zone Water Quality Model (USDA-ARS, 1992). Although this study simulated the long-term performance of DWM across the Midwest, this was still essentially a field scale study that did not consider variability in soils and cropping pattern at each location. The Soil and Water Assessment Tool (SWAT) model was also used in some studies to predicted drain flow and nitrate loss in tile-drained watersheds (Hu et al., 2007; Du et al., 2006; Sui and Frankenberger, 2008). However, the practice of DWM cannot be effectively simulated using SWAT at this time.

The field-scale DRAINMOD model has been used in watershed-scale studies in the Midwest to predict drain flow by dividing the watershed area into a number of grid cells (Northcott et al., 2002; Sammons et al., 2005). Northcott et al. (2002) subdivided the 6910 ha Upper Little Vermilion River watershed into four hundred and sixty-five 16-ha cells and predicted streamflow by developing a GIS-integrated DRAINMOD model. They mapped individual tile lines in the watershed and represented spatial variation in drain spacing across the watershed in the modeling methodology, but did not consider spatial variation in soil properties and cropping rotation. The approach presented in this study builds on the Northcott et al. (2002) approach by representing spatial variation in soil parent material and crop rotation. Several variations in DRAINMOD such as DRAINWAT (Amatya et al., 2004), DRAINMOD-W (Fernandez et al., 2001) and DRAINMOD-GIS (Fernandez et al., 2006) have been developed, and applied primarily to watersheds in North Carolina, to expand the applicability of the field-scale DRAINMOD to the watershed scale, by representing linked fields with different characteristics. All of these models use DRAINMOD for prediction of hydrologic fluxes from individual agricultural fields and they differ from one another in the representation of hydraulic routing in drainage canals and streams (Skaggs et al., 2003). These DRAINMOD-based watershed applications have also not considered the variations in soil physical properties, cropping pattern and drainage characteristics across the watershed.

Water quality models used for predicting nitrate load from subsurface drained landscapes require considerably more, often unavailable input data than hydrologic/water balance models. In addition, water quality models require substantial amounts of time and considerable expertise for model calibration (Skaggs et al., 2010). Therefore, prediction of drain flow using hydrologic models and estimating nitrate load from the predicted drain flow and the observed nitrate concentrations in drain flow in the drained catchments could save the time and effort needed for collecting the required input data and calibrating water quality models. Recently, Skaggs and Youssef (2009) and Skaggs et al. (2010) used this methodology to estimate nitrate losses from subsurface drainage systems at study sites in North Carolina and compared them with DRAINMOD-NII (a carbon and nitrogen companion model to DRAINMOD) estimates. This method estimated the annual nitrogen losses within 3 kg ha^{-1} of that predicted by DRAINMOD-NII in 18 of 35 years and accurately predicted the average effect of DWM.

Nitrate loads from subsurface drainage systems vary widely across a watershed, depending on factors such as drain spacing, soil properties, and cropping patterns. Lack of information on drain spacing, which is an important parameter that influences drainage efficiency as a percentage of precipitation (and hence nitrate load), is often the limiting factor in watershed-scale assessments of drainage water quality. Field studies in Indiana have indicated that nitrate concentrations do not vary significantly with drain spacing and both drain flow and nitrate losses are greater per unit area for narrower drain spacings (Kladivko et al., 2004). Drain flow volume therefore appears to influence the nitrate losses more compared to nitrate concentration in drain flow. Studies conducted in North Carolina (Evans et al., 1995) and Minnesota (Luo et al., 2009) have also indicated that reductions in nitrate load with DWM are primarily due to reductions in drain flow. Accurate prediction of drain flow through representation of variations in drainage, soil and crop parameters across the watershed in the modeling framework is therefore very important for assessing the impact of DWM on nitrate load reduction.

The overall goal of this study was to propose a distributed modeling framework to incorporate spatial variability of drain spacing, soil properties and cropping pattern in assessing the potential impact of DWM on nitrate load from subsurface drainage systems at the watershed scale, and to use the method to assess the potential impact of DWM on nitrate load reduction from the Hoagland Ditch watershed in west-central Indiana.

2. Materials and methods

A distributed modeling approach was developed to apply the field-scale DRAINMOD model at the watershed scale by estimating the drain spacing, cropping pattern and key soil properties for each of 6460 grid cells within the Hoagland Ditch watershed, and running DRAINMOD on each combination. In the watershed, six different drain spacings, 10 different cropping patterns, and 10 different soil types were represented, resulting in 600 ($6 \times 10 \times 10$) combinations of inputs. DRAINMOD was then run for each combination, both for conventional drainage and DWM and the results were applied to the appropriate spatial locations in the watershed. Methods for estimating each spatially varying property in the watershed are described in detail below, along with the evaluation of the method in this highly drained watershed.

2.1. Study area

The Hoagland Ditch watershed, located in west central Indiana has an area of 209 km^2 (Fig. 1). The relief within the watershed is about 46.6 m, with an average slope of less than 0.6%. In 2005, land use in the watershed was 92% agricultural with most acreage in corn and soybeans, 5% urban, and about 2% pasture and forest (USDA-NASS, 2008). The watershed also includes livestock operations, wastewater treatment plants, forested areas, and septic systems from low intensity residential areas (Rice, 2003). Soils are primarily poorly to very poorly drained (71% very poorly drained and 18% poorly drained) due to the low relief and dense glacial till layer which restricts vertical movement of water.

As a part of a previous study (Rice, 2003), the streamflow in the Hoagland Ditch was measured at a gauging station near the watershed outlet (Fig. 1) during the period from August 2000 to June 2002. The stage in the ditch was measured at a daily interval and was converted into flow by developing a stage-discharge rating curve. The measured streamflow data was used for calibrating and validating the model hydrology. Two DWM experimental study sites designated as Site 1 [grown in continuous corn (CC)] and Site 2 [grown in corn-soybean (CS) rotation] were also available in the watershed. At these sites, paired fields, one with conventional drainage and the other with DWM system were monitored (Adeuya, 2009). The measured drain flow and nitrate concentration data from these sites were used for validating model drain flow predictions and estimating average nitrate concentration in drain flow for the watershed.

The 30-m resolution Digital Elevation Model (DEM) of Indiana, which was created by the Indiana Geological Survey (IGS, 2008) from the 1999 National Elevation Dataset (NED) of the United States Geological Survey (USGS), was resampled to 180 m resolution and used for the Hoagland Ditch watershed delineation. The resampling of the DEM was done to divide the watershed into 180 m × 180 m grid cells (resulting in 6460 grid cells) and apply the field-scale

Download English Version:

https://daneshyari.com/en/article/4479195

Download Persian Version:

https://daneshyari.com/article/4479195

Daneshyari.com