Agricultural Water Management 96 (2009) 1021–1030

Contents lists available at ScienceDirect

Agricultural Water Management

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

Nitrate-N loadings through subsurface environment to agricultural drainage ditches in two flat Midwestern (USA) watersheds

D. Goswami [a], P.K. Kalita [b,*], R.A.C. Cooke [b], G.F. McIsaac [c]

[a] Southwest Florida Research and Education Center, Department of Agricultural and Biological Engineering, University of Florida, 2686 State Road 29 N, Immokalee, FL 34142, United States

[b] Department of Agricultural and Biological Engineering, University of Illinois at Urbana-Champaign, AESB, 1304 West Pennsylvania Avenue, Urbana, IL 61801, United States

[c] Department of Natural Resources and Environmental Sciences, University of Illinois at Urbana-Champaign, S-524 Turner Hall, 1102 South Goodwin Avenue, Urbana, IL 61801, United States

ARTICLE INFO

Article history:
Received 14 May 2008
Accepted 7 February 2009
Available online 12 March 2009

Keywords:
Water quality
Nitrate-N
Tile drains
Baseflow
Hydrology
Tile-drained watershed

ABSTRACT

A study was conducted to understand the contributions of tile flow and baseflow to total nitrate-N (NO_3-N) loadings in two subsurface (tile)-drained watersheds, namely the Big Ditch (BD) and the Upper Embarras River (UER) watersheds in Illinois. Two stream sections were selected in the watersheds and rectangular cutthroat flumes were installed at the upstream and downstream ends of the stream sections to calculate the flow mass balance for separating baseflow. The stream section at BD site had two tile outlets draining into it. The stream section at UER watershed did not have any tile drain. Tile flow was also measured along with stream flow. Water samples were collected not only from the stream sections using auto-samplers but also manually from the tile drains. Average baseflow rates per unit lengths of the stream sections at BD and UER sites were 3.5×10^{-04} and 9.4×10^{-05} $m^2 s^{-1}$, respectively. At BD site, for six study periods, the percentages of baseflow and tile flow contributions of NO_3-N loads within the stream section were 90 and 10%, respectively. Annual NO_3-N contributions by the upstream subwatersheds for BD and UER stream sections were 61,819 and 16,155 kg, respectively. Annual NO_3-N loss from these two subwatersheds within BD and UER watersheds was 42.9 and 7.0 kg ha^{-1}, respectively. For the stream section at BD site, baseflow seemed to play a more important role than tile flow in raising the NO_3-N concentration level in the stream water. Land use seemed to play a major role in the significant difference in NO_3-N concentrations at the two subwatersheds upstream from the project sites. Nitrate-N loadings primarily depended on precipitation, antecedent moisture condition (AMC), fertilizer application time, and evapotranspiration (ET).

1. Introduction

The types of soil and the climatic conditions in the Great lakes and Midwestern Corn Belt states in the USA necessitated the introduction of subsurface (tile) drainage systems to make agriculture economically viable (Fausey et al., 1995). The installation of subsurface tile drainage systems in this region resulted in the creation of some of the most productive agricultural lands in the world. Illinois, Indiana, Iowa, Ohio, Minnesota, Michigan, Missouri and Wisconsin are the Midwestern states with heavily tile (subsurface)-drained watersheds. There has been a concern that subsurface drainage has negative environmental impacts. Even though tile drains enhance productivity and reduce sediment and phosphorous contents in runoff, they increase NO_3-N delivery to the receiving water bodies (Fausey et al., 1995). Tile drains can work as a direct conduit for soluble nitrogen (N) movement to surface water.

Nitrate-N concentrations in drinking water reservoirs in many Midwestern states usually exceed the US Environmental Protection Agency's (EPA) maximum contaminant level (MCL) of 10 mg L^{-1} (Mitchell et al., 2000). Nitrogen in surface waters has been linked to NO_3-N transported by tile drainage (Gentry et al., 1998). Nitrate-N is mobile and it can be lost from the soil profile by leaching (Kladivko et al., 1991; Randall and Mulla, 2001; Ng et al., 2002). Agricultural lands usually receive N as a major plant nutrient through fertilizer application. David et al. (2001) estimated that 50% of surplus N was exported from Illinois by rivers and this high load was attributed to the intensity of corn and soybean agriculture, enhanced by tile drainage. McIsaac and Hu (2004) reported that for tile-drained watersheds in Illinois, 100% of residual N was exported to streams.

Corn, soybean, wheat, sorghum, oat and potato are grown in Illinois with corn and soybean covering 57 and 36%, respectively, of the total cropped area in the state (USDA, 2008). Corn is planted in

* Corresponding author. Tel.: +1 217 333 0945; fax: +1 217 244 0323.
E-mail address: pkalita@illinois.edu (P.K. Kalita).

0378-3774/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.agwat.2009.02.007

spring (usually April and May) and harvested beginning in August and continuing until October. Therefore, the growing season of corn is from April to October (Randall et al., 2003). No-till and ridge-till planting are established conservation tillage systems in the Midwest for corn and soybean (Wilhelm and Wortmann, 2004). The primary reason for practicing conservation tillage is reduced costs, soil protection, water conservation, and increased yield (Wilhelm and Wortmann, 2004). In Illinois, corn is usually grown in continuous monoculture (30% of corn cultivation land) or in rotation with soybean (EPA, 2008). Rotation of corn and soybean is often preferred to continuous corn because the rotation produces greater grain yield for both crops (Peterson and Varvel, 1989).

In the corn fields in the Midwest, fertilizer is generally applied during spring and fall. Fall fertilization is very common in the Midwest because it improves the availability of nutrients to plant root zone and lightens the labor and equipment load during spring planting (Otto, 2008). Commercial fertilizers are commonly used in corn. Commercial forms of N fertilizers used are NH_3 (anhydrous ammonia), urea and UAN (a urea ammonia nitrate liquid solution) (Otto, 2008). Corn covers about 21% of US crop lands and it receives the highest amount of fertilizer-N among all crops (NRC, 1993). Based on a survey by Smiciklas et al. (2008) at 36 study sites in Illinois, the median N fertilizer application rates were between 169 and 202 kg N ha^{-1}. Fertilizer rate is linked to the concentration of NO_3-N in the streams and groundwater. The massive NO_3-N loss from these regions has caused serious water quality problems and is responsible for the increase in the hypoxic zone in the Gulf of Mexico (Jaynes et al., 2004).

Water flowing in a stream generally comes from overland flow as well as from groundwater that has seeped into the streambed. The groundwater contribution to a stream is termed as baseflow (Fetter, 2001). Where tile drains are available, a portion of the groundwater is drained by the tiles. The recent developments in understanding the hydrology of subsurface-drained watersheds, with the complexities of flat topography and intense subsurface-drained systems, have raised more questions than answers about water and crop management in these watersheds (Mitchell et al., 2000). Since surface runoff rarely occurs in these highly productive watersheds (Mitchell et al., 2001), questions are often raised about the individual contributions of subsurface drainage systems and conventional baseflow to total watershed nutrient loadings, and the dynamics of the N cycle in such watersheds. If the answers to these questions are known, appropriate water table management guidelines for crop production and environmental benefits may be developed. Baseflow into drainage channels in subsurface-drained watersheds is still not thoroughly understood and has not been widely documented by field research.

In order to quantify the impacts of tile drainage systems on water quality, an understanding of tile-drained watershed hydrology, more specifically the contribution of flow and nutrient (NO_3-N) loadings through tile drains and baseflow from the subsurface environment, is important. No study has been conducted to separate baseflow and tile flow, and quantify the corresponding NO_3-N loads to compare the roles of baseflow and tile flow in elevated NO_3-N loads in these watersheds. This study was conducted to understand the roles of baseflow and tile flow in high NO_3-N concentrations in stream water by separating baseflow and tile water NO_3-N loads. Effects of precipitation, antecedent moisture condition (AMC), fertilizer application time, and evapotranspiration (ET) on NO_3-N loadings were also studied.

2. Materials and methods

2.1. Study area

The study was conducted in two watersheds, namely the Big Ditch (BD) and the Upper Embarras River (UER) watersheds in Champaign County, Illinois (Fig. 1). The Big Ditch is a 100 km^2 watershed and agriculture is the major land use, with row crop comprising about 87% of the watershed area (Rejesus and Hornbaker, 1999). The watershed is within the humid continental climatic region with predominant soil types being poorly drained Drummer, Sable silty clay loams and somewhat poorly drained Flanagan and Ipava silt loams (Demissie and Keefer, 1996).

The Upper Embarras River watershed is in the northern part of the Embarras River Basin. The Embarras River drains a land area of approximately 6320 km^2. It originates in the upland prairies of southern Champaign County near Urbana and runs south until it converges with the Wabash River in Lawrence County, Illinois (Ettinger, 1989). The watershed is primarily under row-crop agriculture (91%) with 46–49% of the land in corn and 41–44% in soybean from 1990 to 1995 (David et al., 1997). Approximately 70% of the basin area is composed of four soil associations, with the Flanagan–Drummer–Catlin and the Camden–Drummer–Starks being dominant in the northern part of the basin including Champaign County (ERMA, 1996).

One stream section was selected in each watershed after studying the topographic maps and surface drainage conditions to make sure that there was no surface runoff contribution into the stream section. The lengths of the stream sections at BD and UER sites were 194 and 183 m, respectively. There were two tile drains (from the north and south banks) contributing to the stream section at BD site. They will be referred to as NT (north tile) and ST

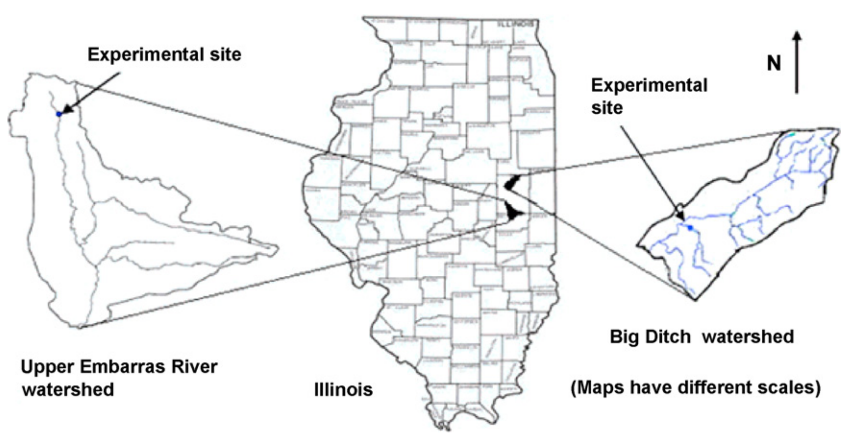

Fig. 1. Locations of the experimental sites in the Big Ditch and Upper Embarras River watersheds.