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Nitrate reduction in a reconstructed floodplain oxbow fed by tile drainage

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ABSTRACT

Conservation practices are needed to reduce the loss of nitrate via subsurface tile drainage systems and in this study we evaluated nitrate retention in a reconstructed oxbow in central Iowa that was engineered to receive inputs from two drainage tiles. Our objectives were to evaluate the hydrogeology and nitrate loading patterns and quantify the average and seasonal nitrate retention efficiency in the reconstructed oxbow. Over a two-year period, water and nitrate concentrations and loads into the oxbow were dominated by tile drainage inputs compared to groundwater seepage. Nitrate concentrations were highest in tile drainage water (9–17 mg/l), similar in upgradient groundwater and in the oxbow itself (4–8 mg/l) and lowest in downgradient groundwater (0.2 mg/l). Using N:Cl ratios, we estimated nitrate retention efficiency from May to September to range from 44% to 47% in 2014 and 2015, respectively, and found that on a monthly basis, greater retention efficiencies were measured in late summer and early fall. The nitrate retention efficiency was similar to other practices such as bioreactors, wetlands and saturated buffers. Given ecosystem benefits of oxbows and similar costs compared to bioreactors, we believe that reconstructing oxbows to receive tile drainage water should be considered a viable practice for tile drainage treatment in agricultural areas.

1. Introduction

Excessive nitrate-nitrogen (nitrate) concentrations and loads from the Midwestern United States are impacting local (USEPA, 2013) and regional water bodies including the Gulf of Mexico (Turner et al., 2008). Recent assessments call for a 45% reduction in total nitrogen (N) and phosphorus (P) loads to reduce the size of the hypoxic zone in the Gulf (USEPA, 2008) although a 70% reduction has also been suggested (Liu et al., 2010). In response to this call for action, many states, including Iowa (INRS, 2013), Ohio (ONRS, 2013), Illinois (INLRS, 2014) and Minnesota (MNRS, 2014) are developing strategies to reduce export of nitrate from agricultural nonpoint sources through implementation of in-field and edge-of-field best management practices (BMPs).

In many regions, BMPs are needed to reduce the loss of nitrate via subsurface tile drainage systems (Jaynes et al., 2001; Tomer et al., 2003; Schilling et al., 2012). Tile drainage increases the efficiency of nitrate delivery to streams (Robertson and Saad, 2011) and is a major source of nitrate loads to Midwest rivers (McLellan et al., 2015; Schilling et al., 2012). Average nitrate concentrations in tile drainage water beneath corn–soybean rotations often exceed 10–20 mg/l (Ikenberry et al., 2015) and nitrate yields are typically greater than 20–40 kg/ha (Jaynes et al., 2001; Ikenberry et al., 2015). McIsaac and Hu (2004) estimated that the 11 million ha of drained cropland in the Mississippi River basin (16% of the drainage area) contributed 30% of the nitrate flux in the lower Mississippi River from 1955 to the 1990s. Traditional BMPs for edge-of-field nitrate reduction from tiled systems include bioreactors (Schipper et al., 2010) and wetlands (Tomer et al., 2013), and a promising new BMP is focused on reconnecting tile drainage networks to riparian buffers (Jaynes and Isenhart, 2014). Beyond these practices, McLellan et al. (2015) suggested that BMPs are needed that enhance nutrient processing in stream channels and floodplains but noted that data are lacking from floodplain restoration projects in agricultural settings.

Oxbow lakes are formed when a river cuts off a meander loop as it migrates within its floodplain (Wohlman and Leopold, 1957). Over time, natural oxbows may fill with sediment and organic materials and transition from lentic to terrestrial habitat (Piegay et al., 2000; Constantine et al., 2010). They are known to pro-

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vide important topographic, hydrological and habitat diversity along floodplain corridors (Ward, 1998). Restoration of floodplain oxbows and wetlands is being increasingly recognized for their ability to treat nutrient loads and provide ecosystem services such as flood storage and aquatic habitat (Fink and Mitsch, 2007; Harrison et al., 2014; Mitsch et al., 2014). Oxbows have been the focus of restoration in central Iowa as an innovative fish habitat improvement and nitrate treatment practice (Jones et al., 2015).

Nitrate reduction benefits of oxbows have been quantified by several investigators. Fink and Mitsch (2007) used an engineered "created" oxbow system to quantify the difference in inflow and outflow water quality associated with flood pulses and reported annual nitrate mass reductions of 48%. Mitsch et al., 2014 reported nitrate retention for the same engineered oxbow diversion system for 32 wetland years to be approximately 15.5%. Harrison et al. (2014) monitored two relict oxbow lakes near an urban environment and reported that the oxbows retained 23–87% of nitrate load that entered the oxbow during four storm events. Using ^{15}N experiments at the same two sites, Harrison et al. (2012) estimated that during the summer, plant and algal uptake accounted for 42–63% of the added $^{15}NO3$, with the remainder assumed to be lost via denitrification. Garcia-Garcia et al. (2009) used nitrate-chloride ratios to quantify nitrate retention and estimated it to be 72% for a wetland-stream system dominated by high inflow nitrate concentrations (above 20 mg/l). Jones et al. (2015) compared mean nitrate concentrations in three oxbows to inlet tile water and found a 45–61% reduction in concentration. These studies indicate that both natural and restored oxbows are capable of retaining a substantial percentage of inflow nitrate.

In this study, we evaluated nitrate retention in a reconstructed oxbow in central Iowa that was engineered to receive inputs from two drainage tiles in addition to seepage from natural groundwater inflow. Our study sought to combine the need to develop new BMPs for tile drainage with the interest in enhancing nutrient processing and habitats in floodplain environments. Specifically, our study objectives were to evaluate the hydrogeology and nitrate loading patterns in the floodplain environment and quantify the average and seasonal nitrate retention efficiency in the reconstructed oxbow. Developing a better understanding of the nitrate retention capacity of the reconstructed oxbow will enable landowners and conservation professionals to incorporate these features in non-point source reduction strategies.

2. Methods and materials

2.1. Site description

The Frye oxbow site (named after the landowner) is located along White Fox Creek in Hamilton County, Iowa (Fig. 1). White Fox Creek drains a watershed area of approximately 19,500 ha above the monitoring site and it flows downstream into the Boone and Des Moines rivers. White Fox Creek and the Boone River are located within the Des Moines Lobe ecoregion of Iowa, a landscape region of recent glaciation (<12,000 years old) containing many drained pothole wetlands (Prior, 1991). Dominant soils include the Canisteo-Nicollet-Webster soil association consisting of silty and loamy soils formed in glacial till and wetlands. Land cover in the White Fox Creek watershed above our oxbow site is dominated

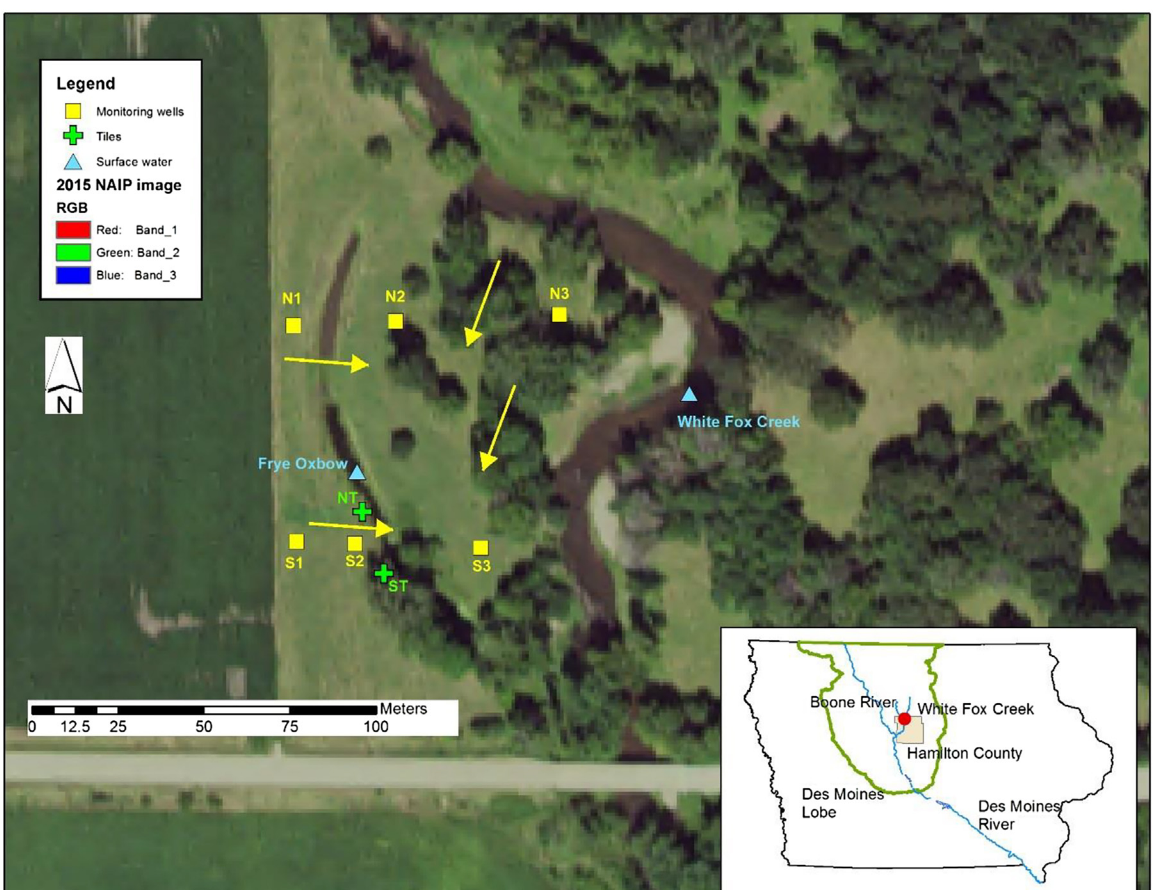

Fig. 1. Location of Frye oxbow site along White Fox Creek in north-central Iowa. Sampling sites are identified and approximate shallow groundwater flow directions are shown.