Science of the Total Environment 637–638 (2018) 470–479

Contents lists available at ScienceDirect

Science of the Total Environment

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

Subsurface nutrient processing capacity in agricultural roadside ditches

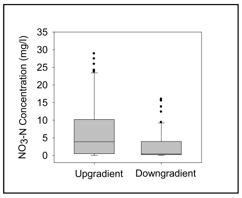
Keith E. Schilling [a],*, Matthew T. Streeter [a], Martin St. Clair [b], Justin Meissen [c]

[a] Iowa Geological Survey, University of Iowa, Iowa City, IA, United States
[b] Department of Chemistry, Coe College, Cedar Rapids, IA, United States
[c] Tallgrass Prairie Center, University of Northern Iowa, Cedar Falls, IA, United States

HIGHLIGHTS

- Roadside ditches are integral components of watershed-scale hydrology.
- Subsurface soil and groundwater conditions were assessed at six sites in Iowa.
- NO3-N concentrations decreased from upgradient to downgradient positions.
- Elevated Cl observed at two sites but no patterns for dissolved P.
- Estimated N reductions in ditches were equivalent to wetlands.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 March 2018
Received in revised form 2 May 2018
Accepted 3 May 2018
Available online xxxx

Editor: D. Barcelo

Keywords:
Nutrients
Roadside ditches
Iowa
Denitrification
NO3-N
Phosphorus
Chloride

ABSTRACT

Roadside ditches located throughout urban and rural landscapes are integral components of watershed-scale hydrologic processes but their capacity to reduce nutrients in the subsurface environment has not been investigated. In this study, vegetation, soil and groundwater conditions were characterized in six roadside ditches in the 66 km^2 Lime Creek watershed in eastern Iowa. Shallow water table wells were installed at 17 locations in six transects and sampled monthly in 2017 to evaluate spatial and temporal patterns. Vegetation characteristics were surprisingly diverse but was not found to be a significant factor in water quality patterns. Groundwater NO_3-N concentrations were <1 mg/L in wells at two transects and were observed to decrease from upgradient to downgradient positions at four locations (average 60% reduction). Water table levels were very shallow (<0.3 m) at nearly all sites, and the loamy and organic rich ditch soils appeared sufficiently anaerobic for subsurface processing of NO_3-N via denitrification to occur. Groundwater dissolved reactive phosphorus concentrations did not vary systematically among the sites whereas two of the roadside ditches had Cl concentrations indicative of road salt encroachment. With estimated NO_3-N reductions equivalent to typical wetland N reductions we recommend consideration of roadside ditches to serve as “linear wetlands” for watershed-scale treatment of nonpoint source pollution.

1. Introduction

Nutrient export of nitrate-nitrogen (NO_3-N) and phosphorus (P) is contributing to degradation of streams, lakes and rivers at local and regional scales (USEPA, 2013), including the Gulf of Mexico (Turner et al., 2008) and Chesapeake Bay (Russell et al., 2008). In the U.S. Midwest, nonpoint sources from agricultural areas, including runoff from fertilizer and manure applications are the dominant sources of nutrients to waterbodies (e.g. Burkart and James, 1999; David et al., 2010). Consequently, many Midwestern states have adopted nutrient reduction strategies to reduce nutrient export (Christianson et al., 2018). Strategies that enhance nutrient processing in agricultural regions while minimizing loss of crop production are highly desired (McLellan et al., 2015).

Roadside ditches located throughout urban and rural landscapes are integral components of watershed-scale hydrologic processes (Wemple

---

* Corresponding author at: 300 Trowbridge Hall, University of Iowa, Iowa City, IA 52242, United States.
E-mail address: keith-schilling@uiowa.edu (K.E. Schilling).

https://doi.org/10.1016/j.scitotenv.2018.05.028

et al., 2017; Buchanan et al., 2013; Forman and Alexander, 1998). As linear features, they cross topographic boundaries and serve to concentrate flow from roadways and the catchment areas that drain into them (Wemple et al., 2017), efficiently delivering runoff, sediment and pollutants to downstream surface water systems (Sheridan and Noske, 2007; Buchanan et al., 2013). Roadside ditches lining >6.3 million km of public roads in the U.S. have the potential to significantly alter watershed-scale hydrology and pollutant transport (Forman, 2003; Buchanan et al., 2013).

The effects of roadside ditches in logged forested areas have been well investigated (e.g., Wemple and Jones, 2003; Sheridan and Noske, 2007; Luce, 2002; Ziegler et al., 2000), but less research has been done on the effects of ditches in other land use areas. Buchanan et al. (2013) examined the effects of roadside ditches in a 38 km^2 agricultural watershed in south-central New York and reported that ditches intercepted surface and subsurface runoff from nearly one-third of the watershed and provided “efficient conduits” for nonpoint source (NPS) pollutant delivery to streams, including sediment, phosphorus and E.coli (Falbo et al., 2013). McPhillips et al. (2016) measured potential denitrification in grassed roadside ditches and lawns and surmised that ditches have the potential to remove significant N loads and could be considered “biogeochemical hotspots” (McClain et al., 2003) if managed correctly. Potential N removal from denitrification has been documented in shallow soils (<5 cm) (McPhillips et al., 2016) but additional research is needed to evaluate the nutrient processing capacity in deeper soils or groundwater within roadside ditches.

The goal of this study was to assess the subsurface nutrient reduction capacity of roadside ditches in a highly agricultural, eastern Iowa watershed. Specifically, our objectives were to 1) characterize vegetation, soil and groundwater conditions in six roadside ditches present in Lime Creek watershed; 2) assess the potential for the ditches to serve as nutrient reduction hotspots; and 3) evaluate the role and scale of roadside ditches to reduce nutrient export at the watershed scale.

2. Materials and methods

2.1. Study area

Roadside ditch monitoring sites were located in the 66 km^2 Lime Creek watershed in eastern Iowa (Fig. 1). Lime Creek is a fourth-order stream that discharges in the middle Cedar River watershed near the town of Brandon in Buchanan County. Lime Creek is located in the Iowan Surface landform region of Iowa and is characterized by rolling, weathered till-plain hills and a well-integrated drainage network (Prior, 1991). Most of the soils are loams or sandy loams formed in loess and/or weathered and fractured pre-Illinoian glacial till. Land cover in the watershed consists of 79% row crops of corn and soybeans, 12% grass, 2% roads/impervious surfaces and 7% trees and other mixed land covers.

The middle Cedar River watershed area receives an average of approximately 900 mm in annual precipitation, with the most rainfall associated with convective thunderstorms in May and June. The majority of streamflow occurs during spring and summer, with peak monthly streamflow following the rainfall patterns. A United States Geological Survey (USGS) stream gauge on the Cedar River is located at Cedar Rapids (Fig. 1). At Lime Creek near Brandon (Lat. 42.1742; Long. −92.0140), NOx-N concentrations are measured every 5 m from approximately April to November using the Hach Nitratax SC plus using a 5 mm path length that can quantify nitrate in the range of 0.1–25 mg/L (IIHR-IWQIS).

2.2. Site selection

Site selection for ditch monitoring was based on several factors. First, ditches were split between gravel and paved road types. This was necessary to distinguish between gravel roads where ditches were generally narrower and in some cases incised and paved roads where ditches were generally wider and bowl shaped. In order to select ditch locations within road types, a modified geographic information system (GIS) flow accumulation chart (FAC) which was developed by the Iowa Flood Center was used to determine where significant overland water flow entered a ditch, and similarly, where the water left the ditch either by entering a culvert or a stream. The FAC used a flow direction raster (FDR) which was modified from a standard 3 m digital elevation model (DEM) in order to account for the location of man-made diversions (i.e. road, culverts, bridges, etc.). At each point where water exited a ditch within the study area, watershed area was determined via a “watershed” GIS tool, which allowed us to determine the area of Lime Creek watershed that drains to a roadside ditch. Utilizing this information, the three sites with the largest watershed area and ditch length of at least 100 m were selected from the paved roads and three from the gravel roads (Fig. 1). The watershed areas draining into the ditches ranged from 8 to 122 ha (Table 1). The land cover of these ditch watersheds was overwhelming dominated by corn (*Zea mays* L.) and soybean (*Glycine* max (L.) Merrr.) production at all sites (>95%). The dominant soil association for the project area is Kenyon, Floyd, Clyde (Typic Hapludoll, Aquic Pachic Hapludoll, and Typic Endoaquoll, respectively). In proportion, these soils represented 12, 13, and 16% of the drainage basins area along with Readlyn (Aquic Hapludoll; 23%) and Olin (Typic Hapludoll; 10%).

At each of these six sites, well locations were located approximately 10 m downstream from the point of water entry in the ditch and 10 m upstream from the point of water exit. A third site was placed in the middle between the two end points (Fig. 1). At the southern-most ditch, shallow bedrock was encountered during well installation. Hence only two points (upstream and middle) were monitored at this transect location.

2.3. Field investigation

A vegetation survey was conducted in July 2017 to characterize vegetation types and conditions at the monitoring well transects. Twenty random points were selected using GIS that encompassed the entire ditch (foreslope, bottom, backslope) within each ditch site (120 total). At each point, vegetation was surveyed within a 1 m^2 quadrat. All species present were identified (excluding seedlings) and canopy cover for each species was assessed using Daubenmire cover classes.

Ditch monitoring wells were installed using a 4 in-diameter hand auger. Soil stratigraphy was described according to Schoeneberger (2002) at the time of sampling and soil samples were collected for physical and chemical analyses. Soil samples were analyzed for total carbon (TC) and total nitrogen (TN) via dry combustion using an elemental analyzer. Soil organic matter (SOM) was determined by weight loss on ignition (Walkey and Black, 1934) as described by Schulte (1995). Nitrate nitrogen was determined by segmented flow analysis. Soil texture was measured by x-ray absorption (Micromeritics Instrument Corporation). Bulk density was measured in triplicate at 2 depths (5–10 and 15–20 cm) at each monitoring well site using a slide hammer with a 5 by 5 cm core barrel and a 5 cm waste tube.

Well depths ranged from approximately 3 to 4 m below land surface. A 1.5-m long factory-slotted PVC well screen and a solid PVC riser were installed in the borehole. A silica sand filter pack was poured around the screen, bentonite chips were added to provide a seal and drill cuttings were backfilled in the rest of the borehole. The middle well of each transect was instrumented with a vented In-Situ pressure transducer to measure hourly water table fluctuations. Soil infiltration was measured in triplicate at each monitoring well site using a double ring infiltrometer. Regional precipitation was downloaded from the Iowa Environmental Mesonet (http://mesonet.agron.iastate.edu/) for the City of Independence (Fig. 1).

The monitoring wells were sampled approximately monthly from December 2016 to November 2017 ($n = 11$). At the transect 5 location,