Agriculture, Ecosystems and Environment 265 (2018) 513–523

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Winter cover crops reduce nitrate loss in an agricultural watershed in the central U.S.

Brittany R. Hanrahan[a,b,*], Jennifer L. Tank[a], Sheila F. Christopher[a], Ursula H. Mahl[a], Matt T. Trentman[a], Todd V. Royer[c]

[a] Department of Biological Sciences, 192 Galvin Life Sciences, University of Notre Dame, Notre Dame, IN 46556, United States
[b] Soil Drainage Research Unit, USDA ARS, 590 Woody Hayes Drive, Columbus, OH 43210, United States
[c] School of Public and Environmental Affairs, 1315 E. 10th Street, Indiana University, Bloomington, IN 47405, United States

ARTICLE INFO

Keywords:
Water quality
Agriculture
Land use
Conservation
Watershed-scale

ABSTRACT

Agricultural land use in the Midwestern U.S. is the major source of nitrogen (N) causing recurring hypoxia in the northern Gulf of Mexico. Despite efforts to reduce losses, N export from tile-drained, agricultural watersheds throughout the Corn Belt persists. The use of effective agricultural conservation practices can reduce N loss from fields, yet little is known about how field-scale implementation will translate into watershed-scale reductions in N export. In this study, we used a sampling approach with high spatial and temporal resolution to quantify changes in tile drain load and watershed export of nitrate (NO_3^--N) after planting cover crops on > 60% of croppable acres in a small, agricultural watershed. We found that median NO_3^--N losses from tiles draining fields with cover crops were 69–90% lower than tiles draining fields without cover crops during winter/spring. Measured instantaneous flow was the major driver of NO_3^--N losses from tile drains, though results suggest that this relationship differed between tiles with and without cover crops in spring. The signature of cover crops at the field-scale was evident in watershed NO_3^--N export, particularly during times of elevated flows; median daily NO_3^--N exported in elevated flows was 18–22% lower during years with watershed-scale planting of cover crops compared to years without. Nevertheless, changes in watershed NO_3^--N export were smaller than the observed reductions in tile drain loads. Results indicate that tile drain reductions directly reflected the influence of cover crops at the field-scale while watershed export integrated both past and present management, ultimately complicating attempts to distinguish the effect of conservation efforts at larger spatial scales.

1. Introduction

Nutrient runoff from agricultural land in the Midwestern United States stimulates annual algal blooms in the Gulf of Mexico that lead to recurring hypoxia (Goolsby et al., 1999; Rabalais, 2002; Van Meter et al., 2018). Specifically, runoff of nitrogen (N) fertilizer applied to row crops in the Midwest contributes > 50% of N entering the Gulf (Alexander et al., 2008; Robertson and Saad, 2013). The combined economic and environmental costs of the hypoxic zone (Rabotyagov et al., 2014) have led to numerous regional and national efforts to curb export of excess N from agricultural lands. However, recent studies have shown that N export from the Mississippi River Basin (MRB) has not decreased since 1985 (Sprague et al., 2011; Porter et al., 2015) and the size of the hypoxic zone continues to exceed the 5000 km^2 goal set forth by a governmental task force (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2008). Recurring hypoxia in the Gulf of Mexico is just one of more than 400 hypoxic zones occurring in coastal waters that lie downstream of major population centers and agricultural areas across the globe (Diaz and Rosenberg, 2008). Thus, excess N continues to threaten downstream water bodies, as well as local drinking water supplies (Kovacic et al., 2006) and aquatic biodiversity (Carpenter et al., 1998).

Transport of N, typically as nitrate (NO_3^--N), is facilitated by subsurface tile drainage systems that convey water and associated solutes from agricultural fields to adjacent streams (Jaynes et al., 1999; Blann et al., 2009) and are prevalent throughout the Midwestern U.S. (Sugg, 2007). Subsurface tile drains bypass biogeochemical processing that would typically retain or remove NO_3^--N (e.g., denitrification) and as a result, tile drains discharge water high in NO_3^--N, often > 10 mg NO_3^--N L^{-1}, into adjacent streams and ditches (Kladivko et al.,

* Corresponding author at: Soil Drainage Research Unit, USDA ARS, 590 Woody Hayes Drive, Columbus, OH 43210, United States.
E-mail addresses: bhanrah3@nd.edu, brittany.hanrahan@ars.usda.gov (B.R. Hanrahan), tank.1@nd.edu (J.L. Tank), sheila.christopher@nd.edu (S.F. Christopher), umahl@nd.edu (U.H. Mahl), mtrentma@nd.edu (M.T. Trentman), troyer@indiana.edu (T.V. Royer).

https://doi.org/10.1016/j.agee.2018.07.004
Received 16 May 2018; Received in revised form 6 July 2018; Accepted 10 July 2018
0167-8809/

2004; Williams et al., 2015a). Nitrate yields from tile-drained watersheds in the Midwestern U.S. ranges from 15 to 60 kg NO_3^--N ha^{-1} (David et al., 1997; David and Gentry, 2000; Royer et al., 2006; Ikenberry et al., 2014; Williams et al., 2015a,b), which is orders of magnitude higher than that for watersheds dominated by native tallgrass prairie (0.16 kg NO_3^--N ha^{-1}) or hardwood forest in the same region (< 0.25 kg NO_3^--N ha^{-1}) (Dodds et al., 1996; Swank and Vose, 1997).

Most NO_3^--N exported from tile-drained watersheds in the Midwest occurs from January to June, coinciding with seasonal patterns of increased precipitation, elevated stream discharge, and fertilizer application (Royer et al., 2006; David et al., 2010; Raymond et al., 2012). This seasonal increase in both NO_3^--N concentration and discharge impacts in-stream processing by simultaneously decreasing water residence times and saturating biological demand for inorganic N (Raymond et al., 2012) thereby limiting the efficiency of N removal via assimilatory uptake (Mulholland et al., 2009) and permanent N removal via denitrification (Royer et al., 2004). Therefore, management strategies, including agricultural conservation practices, that prevent NO_3^--N loss to adjacent waterways have been suggested as potential solutions for reducing excess NO_3^--N export from the MRB (Dinnes et al., 2002; Schilling et al., 2012).

Watershed-scale conservation practices that effectively retain NO_3^--N on fields contribute to building productive, sustainable agricultural systems (Magdoff et al., 1997) and one such example, winter cover crops, could be effectively implemented at large spatial scales. Winter cover crops are planted near the end of the growing season for the cash crop (typically corn [*Zea mays* L.] or soybeans [*Glycine max* L.] in the upper Midwest) and terminated, via herbicide or tillage, the following spring before planting of the next cash crop. Cover crops have been used historically to reduce soil erosion and improve soil quality in some U.S. agricultural systems (Dabney et al., 2001; Blanco-Canqui et al., 2015). More recently, studies have found that cover crops reduce NO_3^--N leaching from tile drains (Strock et al., 2004; Kaspar et al., 2007, 2012; Krueger et al., 2012) by immobilizing N (via uptake) from the soil profile during growth (Staver and Brinsfield, 1998; Dinnes et al., 2002). Additionally, cover crops have the potential to reduce drainage volume by increasing water loss via evapotranspiration (Reicosky and Warnes, 1991; Strock et al., 2004; Qi and Helmers, 2010). While cover crops have the potential to decrease NO_3^--N inputs to streams and ditches, this practice remains untested at the watershed-scale in intensively-managed systems that represent the archetype of agricultural production in the MRB. Thus, it is unclear if field-scale effects of cover crops will translate to watershed-scale reductions in N losses.

To address this knowledge gap, we initiated a multi-year project in October 2012, which ultimately involved planting cover crops on 65–68% of croppable acres in an agriculturally-dominated watershed in northern Indiana. This provided an opportunity to document the effects of cover crops in a production landscape typical of intensively-managed systems with artificial, subsurface drainage. Quantifying the effects of cover crops in production landscapes is a critical need, but approaches used in controlled studies, such as experimental plots with monitored tile lines, are not feasible in most cases. Thus, an objective of this study was to investigate a sampling approach for documenting the effects of cover crops in a production landscape where tile spacing, depth, length, and drainage areas were variable and generally unknown. This situation characterizes much of the upper Midwest where tiles were initially installed more than a century ago, often occur in random patterns, and detailed records and maps are often unavailable. The overall goals of this study were to examine changes in NO_3^--N load from tile drains to the stream before and after watershed-scale planting of cover crops, and determine the influence of cover crops on annual and seasonal NO_3^--N watershed export.

We first hypothesized that tile drains under fields planted with cover crops would have lower N concentrations and loads than those under fields without cover crops. We further expected that the reductions in N concentrations and loads in tile drains would be most pronounced during spring, when the cover crops were actively growing. Additionally, we hypothesized that planting cover crops on a majority of row-crop acres would reduce NO_3^--N export from the watershed relative to years when cover crops were planted on only a small fraction of row-crop acres. Again, we expected this response to be most pronounced in spring. Finally, we expected that reductions in N loss might be less than those reported for controlled experiments at the plot-scale or from modeling studies (e.g., Kaspar et al., 2007, 2012; Malone et al., 2014). This expectation is based on the fact that decisions regarding agronomic practices, such as crop rotations, tillage, chemical input rates, and the species, seeding date, and termination date of cover crops were made by individual farmers and, therefore, varied across the watershed. Additionally, there were sources of N to the stream that could not be quantified within the scope of this study, including N from groundwater, overland flow, and possibly other sources that varied in space and time, which could have obscured the effect of cover crops at the watershed scale. Nonetheless, the study design represents the best attempt to date to empirically quantify cover crop effects on N loss in a production landscape and the results provide realistic expectations for the scale of N loss reductions that can be achieved with wide-scale adoption of winter cover crops.

2. Experimental materials and methods

2.1. Study area

We conducted this study in the Shatto Ditch Watershed (SDW), which drains 1333 ha in Kosciusko County, Indiana (Fig. 1). Land use in the watershed is predominately row-crop agriculture, covering ~75% of the total watershed area. From 2011–2016, area planted in corn ranged from 544 to 747 ha and soybean ranged from 286 to 455 ha, averaging ~47% and ~30% of total watershed area, respectively (USDA National, 2016). Soils in the SDW range from organic muck to loam to sandy loam, and a recent study in SDW used GIS and remote sensing analysis to estimate that between 55–75% of the agricultural area, specifically, was underlain with subsurface tile drainage (Gökkaya et al., 2017). The Shatto Ditch is a first-order stream (total length of 8 km) that drains into the Tippecanoe River. Physiochemical characteristics of SDW are listed in Table 1 and similar to agricultural streams in the Midwestern US (David et al., 1997; Royer et al., 2006) with high dissolved nutrient concentrations and flashy discharge regime. Streamflow is perennial, even during late summer and fall when tile flow typically subsides, suggesting some influence of groundwater. We focused on the effects of cover crops on NO_3^--N specifically, as it dominates N loads in Midwestern US streams (Tomer et al., 2008; Williams et al., 2015a).

2.2. Experimental treatment and establishment

We have been collecting water chemistry samples at the outlet of SDW since October 2007 when a two-stage ditch (600 m in length) was constructed at the SDW outlet (Roley et al., 2012; Davis et al., 2015). We also have measured daily discharge, thus providing a long-term record of water quality and streamflow prior to watershed-scale planting of cover crops initiated by this study in fall 2013. All fields in the watershed are operated by agricultural producers such that SDW is a real-world representation of working lands in the Midwestern US. Strong partnerships with producers were established with the help of staff members from the local Soil and Water Conservation District (SWCD) and The Nature Conservancy (TNC) from 2007 to 2011, helping to facilitate the execution of the study described here, which began in fall 2012 or the beginning of 2013 water year. Hereafter, all reference to years indicate water year (e.g., water year 2013 refers to Oct 1, 2012 to Sept 30, 2013).