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Impacts of nitrogen application timing and cover crop inclusion on subsurface drainage water quality

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ABSTRACT

Significant reductions in nitrogen loading from sub-surface drainage fields of the Upper Mississippi River Basin to the Gulf of Mexico will most likely be achieved from the mass adoption of nutrient loss reduction strategies at a watershed scale. Few studies have quantified the efficacy of cover crops to reduce NO_3-N loading in nitrogen fertilizer management systems, where the dominant portion of the N rate is applied in the spring or fall, both of which are common practices in the Upper Mississippi River Basin. In this experiment we quantified the impact of N application timing and cover crop inclusion on NO_3-N loss (leaching) from agricultural sub-surface drainage within five nitrogen management scenarios: a zero control, applying the dominant portion of the N rate in the spring, applying the dominant portion of the N rate in the fall, augmenting the a spring and Fall N application system with cover crop. Each of the five nitrogen management scenarios was replicated three times on individually monitored sub-surface drainage plots established in Lexington, IL. During the experiment, a cereal rye (*Secale cereal* L.) and radish (*Raphanus sativus* L.) blend was interseeded within both corn (*Zea mays* L.) and soybean (Glycine max L.). Fertilizer N application timing did not affect cover crop growth or N uptake. The inclusion of cover crop resulted in more consistent and greater NO_3-N loss reductions relative to adjusting fertilizer N application timing from fall to spring. Cover crop reduced the flow-weighted NO_3-N concentrations by 39% and 38% and the N load by 40% and 47% when added to spring and fall fertilizer N management systems, respectively. Cover crop proved to be effective in reducing NO_3-N loss through sub-surface drainage across the spectrum of N fertilizer management systems common to the Upper Mississippi River Basin.

1. Introduction

Inorganic fertilizer nitrogen (N) management for row crop production only affects a minute percentage of the soils total N; however, within exported tile drainage-water inorganic N is a significant proportion of the total N (Blesh and Drinkwater, 2014). Furthermore, low fertilizer N efficiency of row crops combined with high tile drainage density in the Upper Mississippi River Basin (UMRB) contribute to the export of excessive N, local water quality issues and the hypoxic zone in the Gulf of Mexico (Gardner and Drinkwater, 2009; Smil, 1999). The severity of this N loading issue resulted in the United States Environmental Protection Agency Gulf of Mexico Hypoxia Task Force requiring UMRB states to develop a Nutrient Loss Reduction Strategy (NLRS) to reduce N and P loading (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2008). The NLRS Science Assessment of each UMRB state estimated that the manipulation of N application timing and rate result in an N loading reduction of 10–20% on tile-drained land, while cover cropping alone was estimated to reduce N loading by 28–40% (David et al., 2013; Illinois Nutrient Loss Reduction Strategy, 2015; Iowa Nutrient Reduction Strategy, 2013; Minnesota Nutrient Reduction Strategy, 2014; Missouri Nutrient Loss Reduction Strategy, 2014; Wisconsin Nutrient Reduction Strategy, 2013). Among all UMRB NLRS, cover crops demonstrated the highest efficacy to achieve the proposed non-point source nutrient loss reduction targets on a watershed scale.

The scientific literature has demonstrated that actively growing cover crops (CC) influence the concentration of nitrate (NO_3-N) in tile water during the fallow period of the year, which frequently results in less nitrate loading (Drury et al., 2014; Kaspar et al., 2007, 2012; Strock et al., 2004). CC absorb inorganic N from the residual, fertilized and mineralized soil N pools affecting the distribution of inorganic N in the soil profile (Kaspar et al., 2007; Lacey and Armstrong, 2014). The presence of both winter-kill and winter hardy CC species result in significantly less soil inorganic N at lower soil depths closer to the location

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of the tile drainage (Cooper et al., 2017; Lacey and Armstrong, 2014). Studies have also demonstrated that evapotranspiration from CC reduces the soil moisture content in the fallow period without negatively affecting cash crop yield (Basche et al., 2016). This reduction in soil moisture content has resulted in a higher soil matric potential, a lower soil leaching potential, and less tile drainage resulting in reduced N loading (Daigh et al., 2014; Kaspar et al., 2007; Qi and Helmers, 2010).

Few studies have quantified the environmental impacts of systematic conservation, where multiple nutrient loss reduction strategies are concurrently applied to one field, such as N application timing and CC. In spring N application systems, the ability of cover crops to improve water quality has been documented in the literature. For example, in Iowa, Kaspar et al. (2007) studied the system of spring N management combined with CC inclusion and determined that a rye CC significantly reduced the average annual flow-weighted NO_3-N concentration of drainage water by 50% or more compared to the control. In Minnesota, Strock et al. (2004) also studied the impact of establishing a cereal rye CC following corn, within a spring N application system, and found a 13% reduction in NO_3-N loading via tile drainage. While fertilizer N applications have been trending toward the spring, there remains a large percentage (41–46%) of row crop acreage in the UMRB that receives fall-applied N (Bierman et al., 2012; Illinois Nutrient Loss Survey Results, 2016; Lemke et al., 2011; Ribaudo et al., 2012; Smiciklas et al., 2008). The source of N during this fall N application could be anhydrous ammonia, ammonium phosphate or livestock manure. Equipment and labor availability in the fall, reduced N fertilizer costs, and spring soil conditions have all been suggested as reasons for fall N application (Ribaudo et al., 2012; Smiciklas et al., 2008). To achieve the targeted surface area reduction of the Gulf of Mexico Hypoxic Zone established by the USEPA, all agricultural fertilizer N management systems common to the UMRB must significantly improve N retention. Currently, there remains a dearth of research concerning the ability of cover crops to reduce tile nitrogen concentrations within fall N application systems, and that investigates the concurrent adoption of both N timing and CC. Therefore, the objectives of this study were to quantify the impact of N application timing and CC inclusion on the flow-weighted NO_3-N concentration and loading from agricultural tile drainage within five N management scenarios (i) applying the dominant portion of the N rate in the spring, (ii) applying the dominant portion of the N rate in the fall, (iii) augmenting the a spring N system with CC, (iv) and augementing the Fall N application system with CC, and (v) a zero control without N fertilizer or CC.

2. Materials and methods

2.1. Site description and cultural practices

The experimental site was located east of Lexington, Illinois (40°38′25.9″N 88°43′11.2″W) at the Illinois State University Nitrogen Management Research Field Station. The predominant soil types within the approximately 10 ha site are Drummer and El Paso (67.5%) and Hartsburg (26%) silty clay loams, both soil types are common in the central Illinois region and are classified as poorly drained with a 0–2% slope. The drainage system was established on April 18, 2014. Three 7.6 cm inside diameter tile laterals spaced 13.7 m apart were installed in each plot at an approximate depth of 0.9 m. The laterals merge 4.5 m from a controlled drainage structure before connecting to 15.2 cm main tile. Precipitation and air temperature data were collected from a weather station located at the experimental site in each year of the experiment.

The production history of this field consists of an eight-year rotation of rain-fed strip-tilled corn (*Zea mays* L.) and no-till soybeans (*Glycine max* L.), which were both harvested for grain. This experiment was a continuation of these cultural practices. The site was comprised of fifteen individually tile-drained 0.65 ha plots, each of which included a tile-water monitoring station. The experiment consisted of five treatments replicated three times arranged in a complete randomized block design. The experimental treatments included a zero control (no N, no CC), a spring dominated nitrogen management system with and without CC, and a fall dominated nitrogen management system with and without CC (Table 1). All fall anhydrous ammonia (AA) was applied with a nitrification inhibitor, and application occurred only once soil temperatures fell below 10 °C. The remaining N was applied as a side-dress AA application, without an inhibitor, near the V6 growth stage. Specific N sources and rates for each treatment can be found in Table 1.

Table 1
Nitrogen Fertilizer source and nitrogen rate applied during the 2014–2015 and 2016–2017 corn years.

	Fall Nitrogen System		Spring Nitrogen System	
Nitrogen Source	2014–2015 kg N ha^{-1}	2016–2017	2014–2015	2016–2017
Fall Diammonium Phosphate	40	50	40	50
Fall Anhydrous Ammonia	112	134	0	29
Spring Anhydrous Ammonia	72	90	184	195
Total	224	274	224	274

Corn and soybeans were planted in 76.2 cm rows using a John Deere 1770 N T 24-row planter. Corn was planted at a targeted rate of 86,485 seeds ha^{-1} on April 30, 2015, and April 25, 2017. Population counts resulted in average corn plant stands of 83,520 plants ha^{-1} in 2015 and 87,990 plants ha^{-1} in 2017. Soybeans were planted at a rate of 308,875 seeds per hectare on May 7, 2016. Weather conditions in the early spring of the 2016 growing season caused poor emergence and resulted in an average population of approximately 214,977 soybean plants per hectare. Due to this reduction in the plant stand, a replant at a rate of 135,905 seeds per hectare occurred on May 25, 2016. After a population check, the replant stand was found to be at approximately 133,434 plants per hectare, which resulted in an average of 348,411 plants per ha. Harvest was conducted on September 23, 2015, October 21, 2016, and October 9, 2017, using a John Deere S670 combine with a John Deere 608C 8 row head for corn, and a John Deere 635FD 10.7-meter flex draper head for soybeans (Deere & Company, Moline, Illinois, U.S.).

The CC mixture for this study was a 92% cereal rye (*Secale cereal* L.) and 8% daikon radish (*Raphanus sativus* L.) blend calculated by weight, first established in September 2014 and was grown in the same plots each year. The CC were inter-seeded at a rate of 84 kg ha^{-1} into the standing crops using a Hagie STS12 (Hagie Manufacturing Company, Clarion, Iowa, U.S.) modified with an air seeding box in early September. Throughout the study, the daikon radish self-terminated through vegetative desiccation in mid-to-late December following several days of subfreezing weather conditions. The cereal rye, however, is a winter hardy species that was chemically terminated at least two weeks before the anticipated planting of the cash crop. Along with the chemical termination of the CC, the research plots received pesticide applications dependent upon the primary crop and weather conditions.

2.2. Cover crop shoot samples

CC sampling occurred in both the fall and spring to document both above ground shoot biomass and nitrogen uptake. Within each treatment, two 1 m^2 quadrants were randomly chosen, and the CC shoot biomass was collected to create a representative sample for each treatment. This sampling technique is a modified version of Dean and Weil's method developed in 2009 (Dean and Weil, 2009). In fall 2015 and fall 2016 radish and rye shoot biomass was separated and analyzed by species. The CC biomass samples were oven dried at 60 °C and ground to pass through a 1-mm sieve. The dry weight of each biomass