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Reducing Nitrogen Loss in Subsurface Tile Drainage Water with Managed Drainage and Polymer-Coated Urea in a River Bottom Soil

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Abstract

Poorly-drained, river bottom soils can be high corn (*Zea mays* L.) yielding environments, but saturated soil conditions often reduce corn yields. Wabash soils located in river bottoms in Northeast Missouri have not been traditionally tile drained due to high clay content which requires narrow tile drain spacings. Increased land prices in the region have increased interest in tile draining poorly-drained bottom land soils to increase corn yields which could have a deleterious effect on water quality. The objectives of the three-year study were to determine whether use of managed subsurface drainage (MD) in combination with a controlled release N fertilizer could reduce the annual amount of NO_3^--N loss through tile drainage water compared to free subsurface drainage (FD) with a non-coated urea application. Annual NO_3^--N loss through tile drainage water with FD ranged from 28.3 to 90.1 kg·N·ha^{-1}. Nitrogen fertilizer source did not affect NO_3^--N loss through tile drainage water, which was likely due to limited corn uptake over the three-year study due to adverse weather conditions. Averaged over three years, MD reduced tile water drained 52% and NO_3^--N loss 29% compared to FD. Reduction in NO_3^--N loss through tile drainage water with MD compared to FD was due to reduced tile flow during the non-cropping period. Annual flow-weighted mean concentration of NO_3^--N in the tile water was 5.8 mg·N·L^{-1} with FD and 8.1 mg·N·L^{-1} with MD. Tile draining river bottom soils at this location for continuous corn production may not pose a health risk over the evaluated duration.

Keywords

Free Drainage, Managed Drainage, Nitrate, Nitrogen, Polymer-Coated Urea, Subsurface

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Tile Drainage

1. Introduction

Poorly-drained, silty clay soils in river bottoms located in Northeast Missouri and throughout the Midwestern U.S. often have high soil fertility [1] and can produce high corn yields. However, saturated soil conditions due to poor drainage, high seasonal water tables, and flooding due to the low landscape position often reduce corn yields. Soils of the Wabash soil series located in Northeast Missouri have a low overall soil hydraulic conductivity (Ksat = 0.01 to 0.10 μm·sec^{-1}) due to high clay content throughout the soil profile, which requires narrow subsurface tile drain spacing. Therefore, poorly-drained Wabash soils have not traditionally been tile drained as the cost of installing subsurface tile drainage systems is relatively high. Increased land prices in the region [2] and relatively high grain prices may now make tile draining poorly-drained, river bottom soils that have not traditionally been drained an economically viable management option to reduce excessive soil moisture and increase corn yields.

The increased use of free subsurface drainage (FD) in agricultural fields has led to environmental concerns regarding N loading of surface waters [3]. An increased rate of water infiltration and transport out of soils with FD has increased N entering surface waters [4] [5]. Aquatic ecosystems can be sensitive to an anthropogenic addition of N as it is one of the most limiting nutrients in aquatic ecosystems. Nitrogen concentrations above natural levels in surface waters can result in hypoxia and eutrophication [3], which involves rapid algae growth and decomposition which in turn depletes oxygen levels below what is required for high forms of aquatic life [6]. Additionally, nitrate-N concentration above 10 mg·N·L^{-1} in drinking water has been reported to cause health problems [7].

The potential for NO_3^--N entering surface waters as a result of agricultural fields with tile drainage is high due to N inputs and the high mobility of NO_3^--N in soil [6] [8]. Additionally, the recent shift toward continuous corn production could further increase NO_3^--N loss in tile drainage water as higher annual rates of N are required to obtain maximum yield compared to crop rotations with soybean, small grains, or forage grasses [9]. A three-year continuous corn study with N applied at 224 kg·N·ha^{-1} annually, reported NO_3^--N loss through tile drainage water as high as 59 kg·N·ha^{-1} annually [10]. Annual flow-weighted mean concentration of NO_3^--N in tile water from fields in corn production can be greater than 10 mg·N·L^{-1} [11] [12] and have been reported as high as 43 mg·N·L^{-1} [10]. However, drier conditions that reduce tile flow can result in higher flow-weighted mean concentrations of NO_3^--N in tile water compared to what would commonly be observed [13].

Research has shown up to 34% of the annual NO_3^--N loss through tile drainage water occurred during the non-cropping period [14]. A managed subsurface drainage system (MD) is similar to FD, except for the addition of a water level control structure, which allows for the control of tile drainage flow. Managed drainage has reduced annual water drained 30% to 50% compared to FD [14]-[16]. Annual reductions in NO_3^--N loss in tile drainage water with MD compared to FD ranged from 32% to 58% [8] [10] [17]. The ability to reduce annual NO_3^--N loss through tile drainage water with MD compared to FD was derived from reducing the amount of water drained during the non-cropping period [4] [18].

Controlled-release, polymer-coated urea fertilizer (PCU) may further reduce NO_3^--N loss in tile drainage water flow. The rate of N release from PCU was a function of moisture and temperature [19]. In Missouri, PCU applied in April released less than 30% urea-N into the soil by June when broadcast on the soil surface [20] and less than 40% when incorporated in the soil at a shallow depth (2 - 5 cm) [21]. The controlled-release of urea-N with this technology could reduce the availability of applied N until later in the growing season when soil conditions are less conducive to environmental N loss and when plant N uptake is greater. Noellsch *et al.* (2009) [22] reported that PCU increased corn N uptake 24% in a low-lying landscape position compared to non-coated urea (NCU). Nelson and Motavalli (2013) [23] reported PCU increased corn yield 7% compared to NCU with FD.

Combining PCU with MD may greatly reduce early season N loss and increase corn uptake of applied N which could further reduce annual nitrate-N loss through tile drainage water. No research has evaluated the effect of PCU on NO_3^--N loss through tile drainage water flow. With a shift towards continuous corn production in the Midwestern U.S. and increasing environmental concern with water quality regarding N and subsurface tile drainage, research is needed to determine if combining PCU and MD management can reduce annual nitrate-N loss through tile drainage water. The objectives of the study were to 1) quantify the average concentration and annual loss of NO_3^--N in tile drain water from a poorly-drained river bottom soil, and 2) determine whether MD with PCU could reduce NO_3^--N loss in tile water compared to FD with NCU.

2. Materials and Methods

2.1. Site Description and Experimental Design

This three-year study (June, 2010 to June 2013) was conducted on a private farm production field in a river bottom soil located in Northeast Missouri (40˚3'11.5"N, 92˚4'21.2"W). The investigation was part of a larger project evaluating the effects of subsurface tile drainage and N fertilizer source on continuous corn production [24]. Subsurface tile drains (10.2 cm diameter, perforated plastic tubing) and water level control structures (AgriDrain Corporation, Adair, IA) were installed in the summer prior to the initiation of the study in April 2010. Tile drains were installed at a depth of 0.9 m with 6.1 m spacings. An additional 6.1 m separated each plot in order to limit movement of water and N into adjacent plots (**Figure 1**). Plots were 18 by 366 m long. Study years represented the period of time from application of N in the spring until the application of N the following season (**Table 1**).

The study was arranged as a two-way factorial, two-replication, randomized complete-block design. Treatments included drainage (FD and MD) in combination with N fertilizer sources [NCU and PCU (ESN, Agrium Advanced Technology, Denver, CO)]. Nitrogen fertilizer was broadcast applied at 202 $kg \cdot N \cdot ha^{-1}$ and incorporated into the soil (5 - 10 cm) directly after application and prior to planting (Sunflower disk harrow, Beloit, KS). Deep tillage (Blu-Jet, SubTiller 4, Thurston Manufacturing Company, Thurston, NE) was used after harvest as a form of residue management. Harvest did not occur in 2010 as a flood in June 2010 resulted in a total crop failure. Field site management including N application rates and dates, plant dates, harvest dates, and water level control with MD can be found in **Table 1**.

The soil type was a Wabash silty clay (fine, smectitic, mesic Cumulic Vertic Endoaquolls) located in a river bottom. Soil samples (composites of three subsamples) were collected from each plot to a depth of 0.0 to 0.3 m, 0.3 to 0.6 m, and 0.6 to 0.9 m in the fall after harvest each year using a Giddings hydraulic probe (Giddings Machine Company, Windsor, CO) fitted with a 4.5 cm diameter steel probe. Soil properties combined over plots are presented by depth over years in **Table 2** were analyzed using standard soil testing analytical procedures for Missouri [25]. Soil NH_4^+-N and NO_3^--N concentrations were converted from $mg \cdot kg^{-1}$ to $kg \cdot ha^{-1}$ based on soil bulk density measurements taken at the depths of 0 - 0.3, 0.3 - 0.6, and 0.6 - 0.9 m at the field site in 2013. Daily rainfall was measured on-site using a rain gauge and datalogger (Automata, Nevada City, CA).

2.2. Water Sample Collection, Flow, and Nitrate Loss Measurements

Pressure transducers (American Sensor Technologies, Mount Olive, NJ) measured water height year-round in each plot's water-level control structure. Water height was measured every five minutes, and dataloggers stored the data (Automata, Nevada City, CA). During periods of flow in 2012 and 2013, daily water height readings were recorded manually in the water-level control structures using a Little Dipper field instrument (Heron Instruments, Dundas, Ontario), as a means of data quality assurance. Flow rates were obtained by subtracting the height of the slides from the water height readings in the control structures and then using the equation:

$$\text{Flow rate } \left(\text{L} \cdot \text{m}^{-1}\right) = 1.4533 * \text{Flow depth } \left(\text{cm}\right)^2 \quad (1)$$

The equation, obtained through laboratory testing [26], was specific to the dimensions of the water-level control structures and angle of the top weir slides used in the study. Flow rates were divided by the area drained (12.2 × 366 m) to obtain measurements of flow over time and area, which estimated total daily flow from each plot.

Portable automated water samplers (Teledyne ISCO, Lincoln, NE) were used in conjunction with liquid level actuators (Teledyne ISCO, Lincoln, NE) to collect water samples every six hours when flow was present. Water samples were combined into daily composite samples. During winter, water samples were manually collected approximately every other day when flow was present. Tile drainage water samples were stored in a refrigerator (5˚C) and filtered (1.5 μm, 934-AH, Whatman Glass Microfiber, General ElectricBio-Sciences, Pittsburgh, PA) prior to being analyzed for NO_3^--N concentration (10-107-04-1-F Quick Chem) using an automated ion analyzer (Lachat Quik Chem 8000, Loveland, CO).

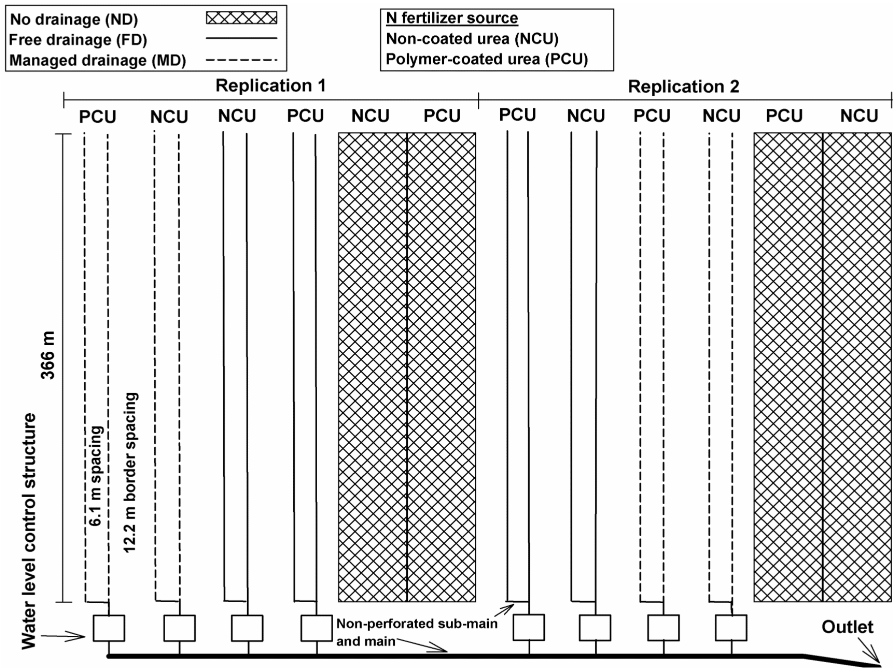

Figure 1. Field layout and plot treatments, including the subsurface tile drainage design.

Table 1. Field site management including fertilizer applications, plant and harvest dates, and water level control management with managed drainage during the study.

Field site management	2010	2011	2012
N fertilizer application	28 June 2010	8 May 2011	14 May 2012
Rate ($kg \cdot N \cdot ha^{-1}$)	202	202	202
Planting date	29 June 2010	9 May 2011	15 May 2012
Rate ($seeds \cdot ha^{-1}$)	79,000	79,000	79,000
Harvest date†	-	7 Nov. 2012	9 Nov. 2012
Water level control—Free drainage mode	28 Jun. 2010	25 Mar. 2011	23 Mar. 2012
Water level control—Managed drainage mode	6 Aug. 2010	13 July 2011	25 May 2012
Water level control—Free drainage mode	-‡	8 Oct. 2011	-
Water level control—Managed drainage mode	-	13 Dec. 2011	-

†Corn crop was lost in 2010 due to a flood. ‡Not applicable.

Table 2. Selected soil chemical properties from fall soil analysis at depths of 0 to 0.3, 0.3 to 0.6, and 0.6 to 0.9 m in 2010, 2011, and 2012. Data were averaged over tile drainage systems and N fertilized sources.

							Exchangeable (1 M NH_4AOc)				
Year	Depth	pH	Organic matter	Neut. acidity	CEC†	Bray I P	Ca	K	Mg	NH_4^+-N	NO_3^--N
	m	0.01 M $CaCl_2$	$g \cdot kg^{-1}$	$cmol_c \cdot kg^{-1}$		$mg \cdot kg^{-1}$			$kg \cdot ha^{-1}$		
2010	0 - 0.3	5.2	26.0	5.1	27.7	46.5	8368	242	992	18.3	24.8
	0.3 - 0.6	5.3	18.9	4.3	26.4	13.3	8026	191	1071	14.3	11.5
	0.6 - 0.9	5.6	14.3	2.7	26.1	12.6	8321	208	1243	13.2	9.7
2011	0 - 0.3	5.4	31.4	4.2	25.5	44.2	7671	395	1003	32.9	14.1
	0.3 - 0.6	5.9	24.6	2.4	26.3	11.6	8422	371	1252	18.2	11.5
	0.6 - 0.9	6.3	18.5	0.9	24.2	6.3	8117	387	1284	15.6	8.8
2012	0 - 0.3	5.1	26.8	5.8	25.8	58.4	7255	256	928	16.1	47.7
	0.3 - 0.6	5.5	20.3	3.7	25.5	9.5	7745	220	1155	5.5	14.1
	0.6 - 0.9	5.9	14.9	2.0	23.7	4.2	7575	219	1208	5.3	6.7

†Abbreviations: CEC = cation exchange capacity; Neut. = neutralizable.

2.3. Statistical Analysis

Soil N concentration, water drained, NO_3^-N loss, and flow-weighted mean concentration of NO_3^--N in the tile drainage water by drainage period (FD period, MD period, and cumulative) and study year were statistically analyzed for treatment effects using ANOVA and PROC GLM with SAS v9.3 [27]. Soil NH_4^+-N and NO_3^--N concentration after harvest was only affected by depth and year. Water drained, NO_3^--N loss, and flow-weighted mean concentration of NO_3^--N in the tile drainage water were not affected by N fertilizer source or year, but were affected by subsurface drainage system. Significant differences in treatment means were determined using Fisher's Protected LSD at P = 0.05 or 0.10.

3. Results and Discussion

3.1. Precipitation

The intensity and distribution of precipitation varied over the three year study (July, 2010 through May, 2013) (**Figure 2**). High precipitation throughout the 2010 growing season resulted in two flood events (June and September), which resulted in a complete crop failure. Precipitation over the period of July through September, 2010 was 532 mm, which was 280 and 349% greater than in 2012 and 2011, respectively. From October 2010 through March 2011, precipitation totaled 147 mm. Similar to 2010, high intensity precipitation during the spring resulted in a flood event in June; however, crop failure did not occur in 2011. Precipitation over the period of April through June, 2011 was 402 mm, which was 51% greater than in 2012. From July through October 2011, precipitation was low (168 mm) which resulted in drought conditions. Precipitation in November 2011 was high (226 mm), while precipitation from December 2011 through February 2012 was 184 mm which was common for the region and similar to 2010-2011 and 2012-2013. Drought conditions occurred through the spring, summer, and fall in 2012. High intensity precipitation events during the non-cropping period in April and June of 2013 (454 mm) resulted in multiple flooding events.

3.2. Soil Nitrogen Concentration

Excessive or lack of precipitation significantly ($P \leq 0.05$) affected soil NH_4^+-N and NO_3^--N after harvest at the depths of 0 - 0.3, 0.3 - 0.6 and 0.6 - 0.9 m over the three-year study (**Table 3**). From 2010 to 2011, soil NH_4^+-N concentration increased from 16.3 to 33.6 $kg \cdot N \cdot ha^{-1}$ at 0 to 0.3 m depth, 14.6 to 18.4 $kg \cdot N \cdot ha^{-1}$ at 0.3 to 0.6 m depth, and 12.8 to 16.2 $kg \cdot N \cdot ha^{-1}$ at 0.6 to 0.9 m depth. Soil NH_4^+-N concentration in 2012 compared to 2010 was similar at the 0 to 0.3 m depth, and less at the 0.3 to 0.9 m depth. High soil NH_4^+-N concentration in 2011 was presumably due to low precipitation throughout the summer and fall that limited the conversion of NH_4^+-N to NO_3^--N. Soil NO_3^--N concentration at a 0.3 to 0.9 m depth was similar from 2010 to 2012. However, the soil NO_3^--N at 0 to 0.3 m depth was 14.8 $kg \cdot N \cdot ha^{-1}$ in 2011 which was lower than 2010 (26.4 $kg \cdot N \cdot ha^{-1}$) and 2012 (46.5 $kg \cdot N \cdot ha^{-1}$). The relatively high soil NO_3^--N concentration in 2010 was presumably due to high precipitation and limited corn N uptake due to complete crop failure. In 2012, soil NO_3^--N concentration was greater than in 2010 and 2011, which was likely due to drought conditions throughout the spring and summer that limited environmental N loss and corn N uptake which was followed by high precipitation in the fall prior to harvest and soil sampling. Therefore, dry early growing season conditions in combination with wet fall conditions probably increased the potential for NO_3^--N loss during the non-cropping period, and subsequently increased the potential for reducing annual NO_3^--N with MD compared to FD.

3.3. Tile Water Drained

Cumulative water drained over each study year ranged from 800 to 1150 mm with FD and 201 to 691 mm with MD (**Figure 2**). Throughout the three-year study, tile flow was constant with FD and with MD when in FD mode, except for drought periods that began in July and extended into the fall. Persistent tile flow was likely a result of a high water table due to the low landscape position and resulted in high amounts of water drained in relation to the amount of precipitation received. Averaged over the three-year study, MD drained 487 mm which was 52% lower than the 1020 mm drained with FD (**Table 4**). This was similar to greater than the 30% to 50% reductions in annual water flow with MD compared to FD reported in upland soils [14]-[16]. In two of the three years, tile flow with MD was generally limited to April through June due to mild and extreme drought conditions

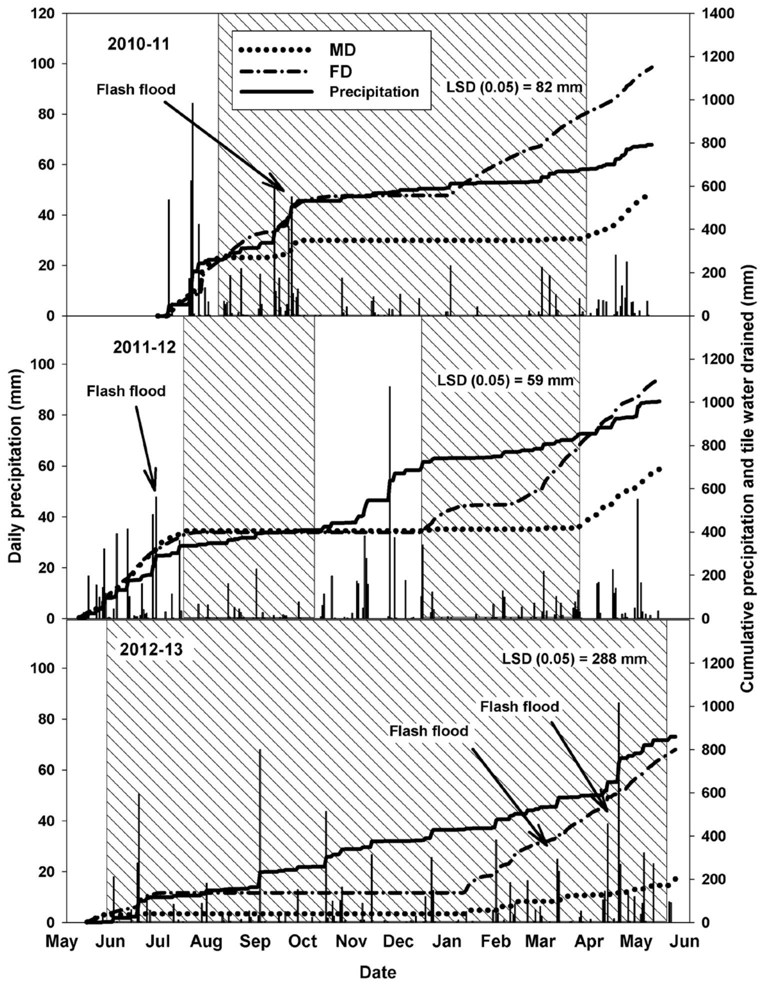

Figure 2. Daily precipitation (bars), cumulative precipitation (solid lines), and tile water drained (dashed/dotted lines) by tile drainage system (FD = free drainage system and MD = managed drainage system) and years. The start of each study year corresponds to the spring N application. Shaded areas represent the period of time that MD treatments were in managed drainage mode.

Table 3. Effect of year and depth on soil NH_4^+-N and NO_3^--N concentrations after harvest. Data were averaged over N fertilizer source and drainage treatments.

	Soil NH_4^+-N			Soil NO_3^--N		
Depth (m)	2010	2011	2012	2010	2011	2012
		$kg{\cdot}N{\cdot}ha^{-1}$			$kg{\cdot}N{\cdot}ha^{-1}$	
0 - 0.3	16.3	33.6	16.4	26.4	14.8	46.5
0.3 - 0.6	14.6	18.4	5.6	11.2	11.3	13.2
0.6 - 0.9	12.8	16.2	5.1	9.8	8.5	6.1
LSD (P = 0.05)		3.7			9.1	

during the summer and fall. The average reduction in water drained over a study year was due primarily to restricted tile water flow with MD during the summer and non-cropping period. Managed drainage reduced tile flow 86% (84 mm) compared to FD (612 mm) during the summer and non-cropping period. Drury *et al.* (2009) [14] reported a 44% reduction in water drained with MD compared to FD over the non-cropping period. A greater reduction in water drained over the non-cropping period in this study may be due to greater tile flow over

Table 4. Effect of drainage water management system on tile water drained, NO_3^--N loss through tile water flow, and flow-weighted mean concentration of NO_3^--N averaged over three years.

	Tile water drained†			NO_3^--N loss through tile water			Flow-weighted mean		
Drainage	FD period‡	MD period	Cumulative§	FD period	MD period	Cumulative	FD period	MD period	Annual
		mm			kg NO_3^--N ha^{-1}			mg NO_3^--N L^{-1}	
FD	407	612	1020	25.7	25.4	51.1	5.9	4.7	5.8
MD	404	84	487	28.7	7.8	36.5	6.1	10.6	8.1
LSD¶	NS	112*	85*	NS	8.6*	12.2	NS	3.0*	1.8*

† Abbreviations: FD = free drainage; LSD = least significant difference; MD = managed drainage; NS = not significant. ‡ FD period represents the period of time that tile flow was not restricted with MD, while MD period represents the period of time when tile flow was restricted with MD. § Cumulative or annual represents the period of time from application of N at planting until the application of N in the following year. ¶ A single asterisk following an LSD value represents a P-level of 0.05 and no asterisk represents a P-level of 0.10.

the winter period due to limited freezing of the soil compared to soils in Ontario, Canada.

3.4. Nitrate-N Concentration and Loss in Tile Drainage Water

Cumulative NO_3^--N loss averaged over the three study years ranged from 28.3 (2010-2011) to 90.1 kg·N·ha^{-1} (2011-2012) with FD (**Figure 3**), which was likely due to differences in tile flow, soil N concentration, and plant uptake. Previous research studies on continuous corn with FD have reported that annual NO_3^--N loss through tile drainage water increased from 4 to 59 kg·N·ha^{-1} due to carry-over N [10] and 16.5 to 47.8 kg·N·ha^{-1} due to the application of N in the fall compared to spring [28]. Average NO_3^--N loss through tile drainage water over a study year ranged 12.8 (2012-2013) to 70.2 kg·N·ha^{-1} (2011-2012) with MD. Similar to Gast *et al.* (1978) [10], high NO_3^--N loss in the tile drainage water over the 2011-2012 study year was likely due to wet spring conditions and carry-over N, which resulted in approximately 60 kg NO_3^--N ha^{-1} of loss for both FD and MD during the FD period from 9 May through 12 July, 2011. Additionally, a presumably high water table due to the low landscape position of the river bottom soil likely contributed to tile flow and the high annual NO_3^--N loss through the tile drainage water, as compared to the annual 6 to 66 kg NO_3^--N ha^{-1} loss reported in previous research with FD on upland soils in corn production [12] [28]-[30].

Nitrogen fertilizer source did not affect cumulative NO_3^--N loss over the three-year study. Nitrogen presumably was not a limiting factor over the experiment due to dry summer and fall conditions that limited gaseous N loss and corn N uptake in combination with annual applications of 202 kg·N·ha^{-1}. Averaged over three-years, cumulative NO_3^--N loss though tile drainage water with MD (36.5 kg·N·ha^{-1}) was significantly ($P \leq 0.10$) reduced 29% compared to FD (51.1 kg·N·ha^{-1}) (**Table 4**). Previous research studies on upland soils have reported 32% to 58% reduction in annual NO_3^--N loss through tile drainage water with MD compared to FD, which was attributed to reductions in the annual water drained with MD [14] [17] [18]. Although water drained over a study year was reduced 52% on average with MD compared to FD, NO_3^--N loss was only reduced by 29%. Higher NO_3^--N concentration in the tile water observed at times with MD compared to FD over the three-year study partially offset the reduction in water drained and subsequent NO_3^--N loss through tile drainage water with MD (**Figure 3**). Increased NO_3^--N concentration in the tile drainage water with MD compared to FD was likely due the annual reduction in tile flow and limited corn uptake of applied N which may have increase soil N concentration.

Over the FD period, NO_3^--N loss was similar between FD (25.7 kg·N·ha^{-1}) and MD (28.7 kg·N·ha^{-1}) on average (**Table 4**). While over the MD period, MD significantly ($P \leq 0.05$) reduced NO_3^--N loss 69% compared to FD due to an 86% reduction in water drained over that period. In Ontario, Drury *et al.* (2009) [14] reported a 38% reduction in NO_3^--N loss over the non-cropping period with MD compared to FD, which was due to a 34% reduction in water drained over non-cropping period. Greater reduction in water drained and subsequent NO_3^--N loss over the non-cropping period in this study may have been due to reduced freezing of the soil in Missouri as compared to in Ontario, Canada. These results indicate the potential to reduce the annual NO_3^--N loss from tile drainage with MD may be greater in warmer climates with less potential for freezing of soil during the non-cropping period.

3.5. Flow-Weighted Mean Concentration of Nitrate-N in Tile Drainage Water

Similar to water drained and NO_3^--N loss, flow-weighted mean concentration of NO_3^--N in the tile water was

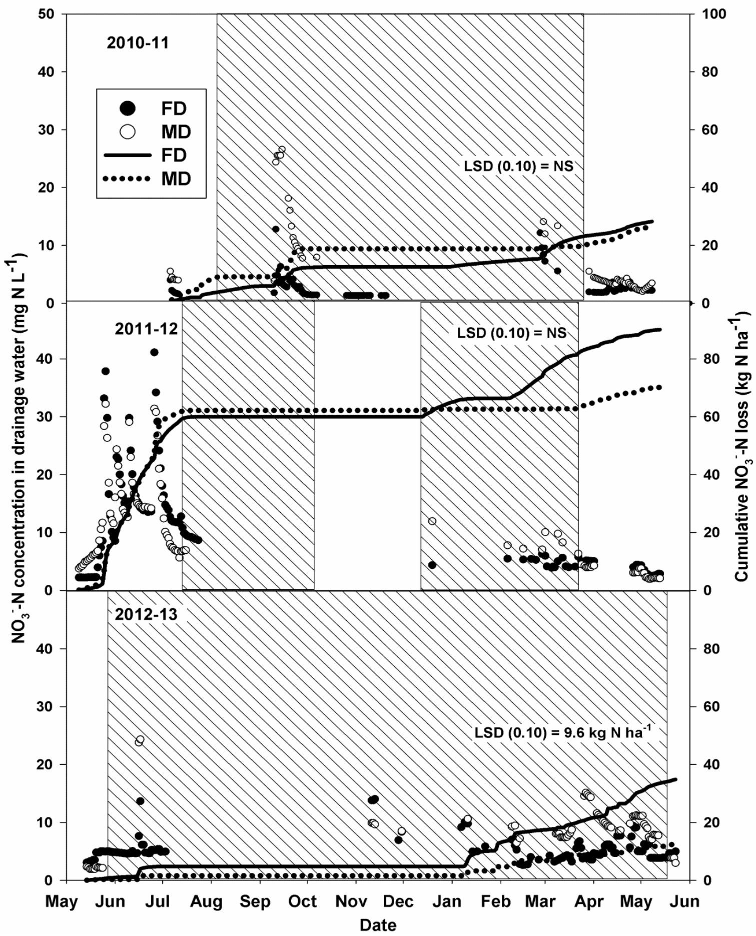

Figure 3. Daily concentration of NO_3^--N in tile drainage water (circles) and cumulative NO_3^--N loss (lines) by tile drainage treatment (FD = free drainage system and MD = managed drainage system) and years. The start of each study year corresponds to the spring N application. Shaded areas represent the period of time that MD treatments were in managed drainage mode. NS = not significant.

significantly ($P \leq 0.05$) affected by drainage systems during the MD period and the entire study year (**Table 4**). Over the FD period, flow-weighted mean concentration of NO_3^--N in the tile drainage water was similar between MD (6.1 mg·N·L^{-1}) compared to FD (5.9 mg·N·L^{-1}). Over the MD period, flow-weighted mean concentration of NO_3^--N in the tile drainage water was 125% greater with MD (10.6 mg·N·L^{-1}) compared to FD (4.7 mg·N·L^{-1}). Increased flow-weighted mean concentration of NO_3^--N in the tile water with MD during the MD period as compared to the FD period was likely due to reduced tile flow, which has been reported between growing seasons with FD [13].

Average flow-weighted concentrations of NO_3^--N over a study year were greater with MD (8.1 mg·N·L^{-1}) compared to FD (5.8 mg·L·ha^{-1}). Previous tile drainage research in corn production on upland soils have reported annual flow-weighted mean concentration of NO_3^--N in tile water in the range of 6 to 43 mg·N·L^{-1} [10]-[13]. Annual flow-weighted mean concentration of NO_3^--N was below what was commonly reported in upland soils in corn production, as well as below the 10 mg·N·L^{-1} required for drinking water standards [7]. This indicates that subsurface tile draining silty clay river bottom soils may not pose a health concern.

4. Conclusion

Similar to previous research on continuous corn in upland soils, cumulative NO_3^--N loss through tile drainage water with FD ranged from 28.3 to 90.1 kg·N·ha^{-1}. High NO_3^--N loss in the tile drainage water in one of the study years was likely due to carry-over N from the previous season in combination with high tile flow due to wet conditions, as well as a presumably high water table due to the low landscape position that contributed to the tile water flow. Managed drainage was effective in reducing NO_3^--N though the tile drainage water (29%) compared to FD over the three-year study. A reduction in NO_3^--N loss with MD compared to FD was primarily due to reduced tile flow over the non-cropping period. However, reduced tile flow with MD in combination with dry growing season conditions likely limited environmental N loss and corn N uptake during non-flow periods did result in slightly higher NO_3^--N concentration in the tile drainage water with MD compared to FD. However, flow-weighted mean concentration of NO_3^--N was rarely higher than the 10 mg·N·L^{-1} drinking water standard. Therefore, tile draining river bottom soils for improved continuous corn production may not be a major health risk.

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