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Nitrate Transport In The Unsaturated Zone

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NITRATE TRANSPORT IN THE UNSATURATED ZONE

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62 Pages

Abundance of nitrate in the soil is a basic issue in agricultural land-use regions, causing eutrophication and pollution of water bodies. The study focuses on the role of a saturated buffer zone (SBZ) to remove nitrate from the groundwater resulting from agricultural activities. The study area is herbaceous SBZ located in central Illinois (40.614382ºN, -89.023542ºW), which lies between a stream and a farm located upgradient. The SBZ has been outfitted with an agricultural runoff treatment system that diverts tile drainage into the subsurface of the SBZ rather than discharging into the stream. Within the SBZ three experimental areas composed of two plots were established; one plot allowed the plants, Switchgrass (*Panicum virgatum* L.) to grow, and the other plot served as the control, with no plant growth. The main objective of this research was to understand the role of plants in the transport and fate of nitrate in the unsaturated by addressing two hypotheses 1) during the growing season nitrate removal will be greater in the presence of plants than where plants are absent and 2) following a growing season, nitrate concentration in the soils underlying a barren plot (no plants) will be less than in the soils underlying a plot with plants. Statistical comparison between the NO_3^--N among the treatments, Pre-growing season, Plot with Plants, and Barren plot, and among the different depths, 30 cm, 60 cm, and 90 cm were significantly different. The presence of plants provided a mechanism to withdraw NO_3^--N in the vadose zone. The plots with plants experienced a reduction NO_3^--N from the soil and vadose waters due to plant uptake and denitrification. NO_3^--N concentration in the

soils underlying the barren plot were high because the plants materials decomposed to increase the NO_3^--N concentration in the vadose. The low NO_3^--N concentration observed in the soil within the SBZ were similar to what was observed four years prior, suggesting that the NO_3^--N concentration in the vadose remains stable year-to-year. The study established temporal removal of NO_3^--N in the vadose zone of the SBZ and the SBZ serve as a short-term sink.

KEYWORDS: Nitrate, Saturated buffer zone, Vadose zone, Plot with plants, Barren plots, Assimilation, Plant Uptake, Nitrification, Denitrification

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P. B.

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CHAPTER I: INTRODUCTION

Nitrogen (N) is among the vital elements needed for the survival of plants but also a major groundwater and surface water pollutant, which has become an environmental problem of widespread concern (Castaldelli et al., 2019; Xin et al., 2019; Wang et al., 2019a, b; Zhang et al., 2018a,b,c,d). In most parts of the world, successful agricultural productivity depends on the addition of nitrogen-based fertilizers, both synthetic N-fertilizers and animal manures (Smith et al., 2018; Liu et al., 2014; Li et al., 2012; Robertson et al., 2012). Once nitrogen-based fertilizers are applied to agricultural systems, the fertilizers in the soil may be absorbed by plants or converted into various other forms of nitrogen through oxidation-reduction processes (Xin et al., 2019; Liu et al., 2014).

The Midwest states, including Illinois, represent one of the most intense areas of agricultural production in the world. The Midwest has over 127 million acres of agricultural land with 75% of that area in corn and soybean production, and the other 25% is used to produce other market value of crops (USDA, 2017). Illinois farmland covers 27 million acres, which is approximately about 75 percent of the state's total land area (USDA-NASS, 2019) Approximately 7.7 billion kilograms of nitrogen fertilizer are applied to Illinois corn fields annually (National Agricultural Statistics 2004). Grain crops get their N from sources such as manure and fertilizer, in which the N is in forms that the plants can utilize (Fernández et al., 2009). Upon examining field-scale nitrogen balances, Karlen et al. (1998) found that about 50% of nitrogen applied under traditional fertilization management practice was not accounted for by crop removal. A significant amount of nitrogen applied was lost to the environment via nitrification, denitrification, leaching, and volatilization (Ciampitti & Vyn, 2014; Cassman et al., 2002; Tilman et al., 2002; Smil, 1999). Excess and repeated fertilizer application into the vadose

zone resulted in greater residual nitrate (NO_3^-) in soil and increased NO_3^- leaching to the groundwater (Bakhsh et al., 2005; Karlen et al., 2004; Kanwar et al., 1995). In much of Illinois and across the Midwest, farmers have installed tile-drain systems to drain water from the soils to increase crop yield and growth (Keller et al., 2008; Fausey et al. 1995). During precipitation events, NO_3^- rich runoff from farmlands infiltrates and leaches into the groundwater or is captured by tile drainage systems that discharge directly into surface waters causing pollution (Wu et al., 2019; Xin et al., 2019; Liu et al., 2014; Sebilo et al., 2013).

The Upper Mississippi River flows roughly 2,092,147 m from Lake Itasca in northern Minnesota to the confluence with the Ohio River at the southern tip of Illinois, representing over half of the length of the entire Mississippi River. Surface waters located within the Upper Mississippi River basin contain some of the highest concentrations of nonpoint source NO_3^- in the United States (Schilling et al., 2012; David et al., 2010). Nitrate as nitrogen (NO_3^- -N) concentrations in surface waters that exceed the United States Environmental Protection Agency (USEPA) maximum contaminant level for drinking water of 10 mg/L can threaten public water supplies that use surface water (Jha et al., 2010; Schilling & Wolter, 2009). The NO_3^- -N concentrations in Iowa, Illinois, Ohio, and Upper Mississippi Rivers in the Midwest in 2013 after the 2012 drought during the May to August 2013 sampling period ranged from < 0.04 to 41.8 mg/L with mean of 5.31 mg/L (Van Metre et al, 2016). The Illinois River is a major tributary of the upper Mississippi River and has one of the largest fluxes of nitrogen in the Mississippi River Basin (Illinois State Geological Survey, 2019; Goolsby, 2000). The Illinois River contributes from 15% to 20% of the total nitrogen that goes into the Gulf of Mexico from the Mississippi River (Keeney & Hatfield, 2008; Goolsby et al., 2000; David & Gentry, 2000).

Excess NO_3^- in surface waters leads to eutrophication. Eutrophication is the enrichment of an aquatic ecosystem with excess nutrients (Boesch 2002; Nixon 1995; Ryther & Dunstan, 1971). Eutrophication causes "dead" or hypoxic zones at the Gulf of Mexico. Hypoxic zones are defined by low dissolved oxygen concentrations of less than 2-3 mg/L (U.S. Environmental Protection Agency, 2017). The hypoxic zone in the Gulf of Mexico is the second largest human-caused hypoxic area in global coastal waters (Rabalais et al., 2002). The combination of increased nutrient loads (from human activities) and increased freshwater discharge will aggravate the already high loads of nutrients from the Mississippi River to the northern Gulf of Mexico (Rabalais et al., 2009).

When a body of water (mostly marine) becomes overly enriched with NO_3^-, excessive growth of photosynthetic organisms such as algae is stimulated (Figure 1). Excess plants and algae will create conditions where organic matter accumulates. High densities of algae will create a condition where sunlight cannot reach very far into the water (Chislock et al., 2013). Since plants and algae require some sunlight, they will die off (Figure 1). The dead plant materials will settle to the bottom of the water, and bacteria that feed on decaying organic material will greatly increase in numbers (Chislock et al., 2013). Decomposition of plant material in the water consumes dissolved oxygen in the water column that could affect aquatic lives (Ryther et al., 1971) (Figure 1). Therefore, the concentration of NO_3^- in surface waters and groundwater could have impacts on ecosystem function and public health.

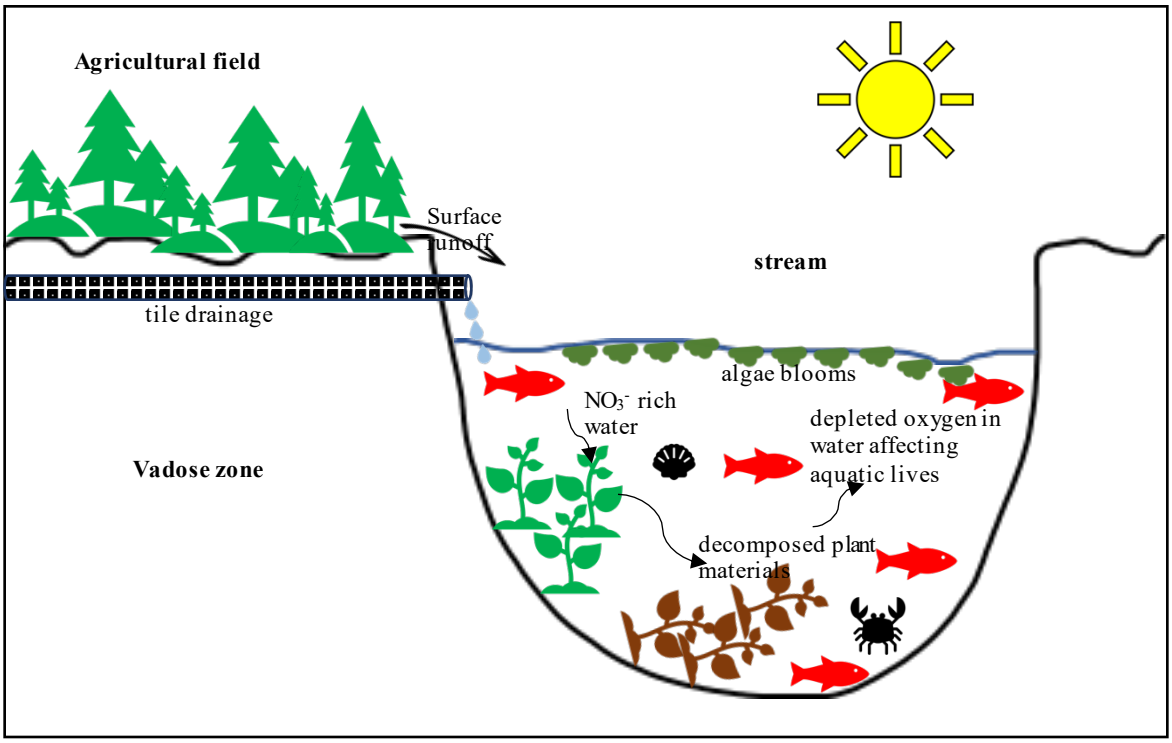

Figure 1. Schematic representation of eutrophication in surface waters. NO_3^- loading from tile drains and surface runoff from agricultural fields enriches surface wasters with NO_3^- leading to eutrophication.

In 2008, a national strategy action plan was implemented to reduce, mitigate, and control hypoxia in the Northern Gulf of Mexico and to improve water quality in the Mississippi River Basin (U.S. Environmental Protection Agency, 2019). The State of Illinois developed the Illinois Nutrient Loss Reduction Strategy (Illinois NLRS) released in 2015 to improve water quality, not only in Illinois, but downstream, to reduce the hypoxic zone in the Gulf of Mexico (Illinois NLRS Biennial Report, 2019). The strategy sets a long-term goal of reducing loads from Illinois for total phosphorus and total nitrogen by 45%, with interim reduction goals of 15% NO_3^--N and 25% total phosphorus by 2025 (Illinois NLRS Biennial Report, 2019). Most recommended practices, such as installing buffer strips along streambanks to filter runoff, planting cover crops

to absorb nutrients, and adjusting nitrogen fertilizing practices have been used successfully in Illinois for years (Illinois ACES, 2020).

SBZ and how they Work

Saturated buffer zones (SBZ) are areas where plants are grown along the banks of rivers or streams designed to absorbs nitrate from drain tiles and to limit overland flow or runoff from farmlands. SBZ are a part of the overall national strategy to reduce nitrate export to surface water (USDA, 2016). Tile drainage can be diverted into the buffer as surface flow or subsurface flow to restore the connection between the tile and the soils (Jaynes and Isenhart, 2014) rather than discharging directly into streams. Tile-drainage diversion into SBZ can result in the reduction of nitrate loading (Miller et al., 2018; Tomer et al., 2017) by temporary or permanent removal (Hill, 1996). To achieve nutrient removal capabilities within SBZs that has been established in tile-drained landscapes, the hydrology between the uplands drained by tiles and the buffer has to be reconnected (Jaynes and Isenhart, 2014). However, in landscapes with artificial subsurface (tile) drainage, most of the subsurface flow leaving fields is passed through the buffers in drainage tiles, leaving little opportunity for natural processes to remove NO_3^- (Jaynes and Isenhart, 2014).

Plants play a major role in the use of nitrate in the SBZ. Through uptake, plants serve as an N-sink when alive. During assimilation, the plants absorb some portion of the nitrate from diverted tile, and the remaining nitrate is used by micro-organisms found in the soil or within the subsurface (Miller et al., 2018). The micro-organisms create organic nitrogen (Figure 2) and converts the dissolved organic nitrogen (DON) to ammonium ion (NH_4^+) through ammonification. The microorganisms then convert the NH_4^+ into nitrite (NO_2^-) and then into nitrate (nitrification). The roots of the plants (Figure 2) absorb part of the NO_3^- and NH_4^+ for

photosynthesis (assimilation) and microorganisms also use part the nitrate instead of oxygen when obtaining energy for survival and releases nitrogen gas (N_2) to the atmosphere

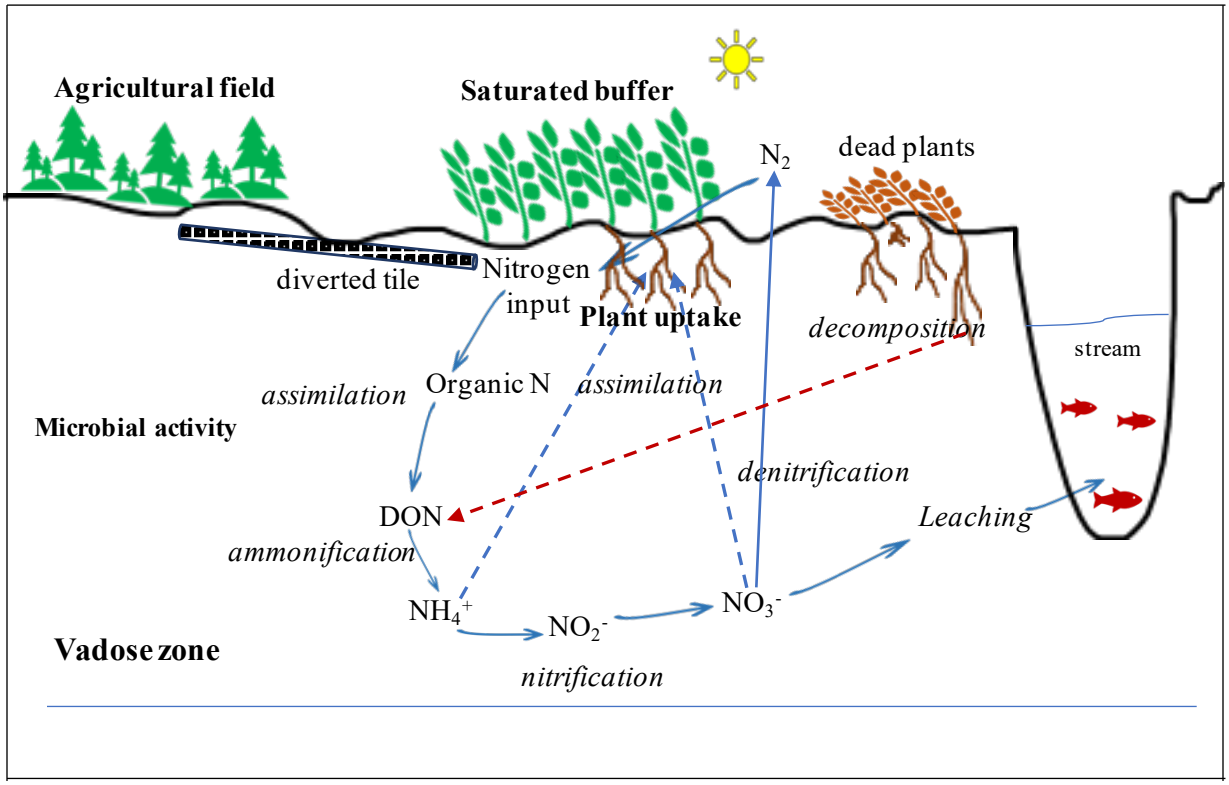

Figure 2. Schematic representation of the nitrogen cycle in the vadose. NO_3^- diverted from agricultural fields into a SBZ is assimilated, denitrified, the atmospheric nitrogen is assimilated into organic compounds and nitrified back to NO_3^- in the vadose which could leach into surface waters causing pollution.

(denitrification) (Addiscott, 2005). The N_2 from the atmosphere diffuses into the soil, and a species of bacteria (microorganisms) converts the nitrogen back to NH_4^+ and NO_3^- and the cycle continues (Figure 2). When the plants grow and eventually die (Figure 2), the nitrogen compounds in the organic matter re-enter the soil and the DON are broken down by

microorganisms, producing NH_4^+ (decomposition). The NH_4^+ is converted back to NO_3^- (nitrification) by microorganisms and the cycle continues (Figure 2).

Many studies have suggested that SBZ are a proven practice for removing NO_3^- from overland flow and shallow groundwater. In the Midwest, implementing saturated buffers widely could result in a 5 to 10% reduction of the estimated N load from tile-drained land (Chandrasoma et al., 2019). Jaynes and Isenhart (2018) monitored nearly 20 saturated buffer sites in Iowa finding an average of approximately 50% of the annual drainage volume was treated within the buffers and nearly all (mean: 83%) of the nitrate N within that water was removed. Additionally, Groh et al. (2018) carried out a study in the Midwest on two SBZ and indicated about 96% of the total diverted NO_3^- rich water from the tile drainage was removed. Across the Midwest, Utt et al. (2015) documented that 15 saturated buffers had nitrate N load reductions averaging 28%. Furthermore, several of the 15 initial SBZ across the Midwest were monitored by Brooks and Jaynes (2017) from September 2016 to February 2017, and they observed 61% reduction in nitrate loading. This shows the effectiveness of SBZ to reduce nitrate loading into the subsurface. Although the mechanisms responsible for NO_3^- reduction in SBZ are well characterized, little is known about the role of vegetation controlling NO_3^- transport and fate in the unsaturated zone. A study by Miller et al. (2018) analyzed NO_3^--N concentration in groundwater samples collected hourly for 24 h from an unconfined aquifer in the SBZ and identified plant uptake as a removal pathway, but they did not document whether the removal was permanent or short-term.

Research Questions and Hypotheses

This research seeks to determine the role plant uptake in N-cycling within a SBZ. Is the uptake a short-term sink in which that the plants continually recycle the N overtime or is there actual removal of N from a system. Thus, what happens to the nitrate in the unsaturated zone

when the plants die? Does the nitrate become a short-term reservoir, or the nitrate just keep recycling itself amongst the plants or it make its way deep into the unsaturated zone? To understand the role of plants in the transport and fate of nitrate in the SBZ, two hypotheses are addressed:

1) Nitrate removal will be greater in the presence of plants than where plants are absent
2) Following a growing season, nitrate concentration in the soils underlying a barren plot (no plants) will be less than in the soils underlying a plot with plants.

Site Description

The study area is called T3 and is a restored prairie serving as a SBZ located 3 km NW of Hudson, Illinois (40.614382°N, -89.023542°W). T3 was farmed but has since been converted to a switch grass prairie. T3 receives tile-drainage from a farm located approximately 120 m east of the study area and has been outfitted with an agricultural runoff treatment system that diverts the tile-drainage waters into the subsurface of the SBZ (Figure 3). The diverted tile-drainage is directed into three perforated pipes ~1m below the surface by a diversion system, while the remaining volume is discharged directly into the stream.

Geology

Throughout the site, the surface (0- 0.63 m) is dark organic-rich topsoil, which is underlain (0.66- 1.5 m) by a firm clay loam composed of silty clay, clay, and sandy clay. The clay loam is graded with an increasing sand and gravel percent composition with depth. The clay loam transitions to a coarse-grained material composed of gravely silt with sand, sandy silt, and clayey sand from 1.5 m to 2 m depth, but the thickness of this coarse-grained zone spatially varies. The coarse-grained material is underlain by a blue-grey, dense diamicton that is

interpreted as the Wedron Formation (Weedman et al., 2014). The thickness of the diamicton is 30 - 45 m, terminating at Silurian dolomite bedrock (Wickham et al., 1988).

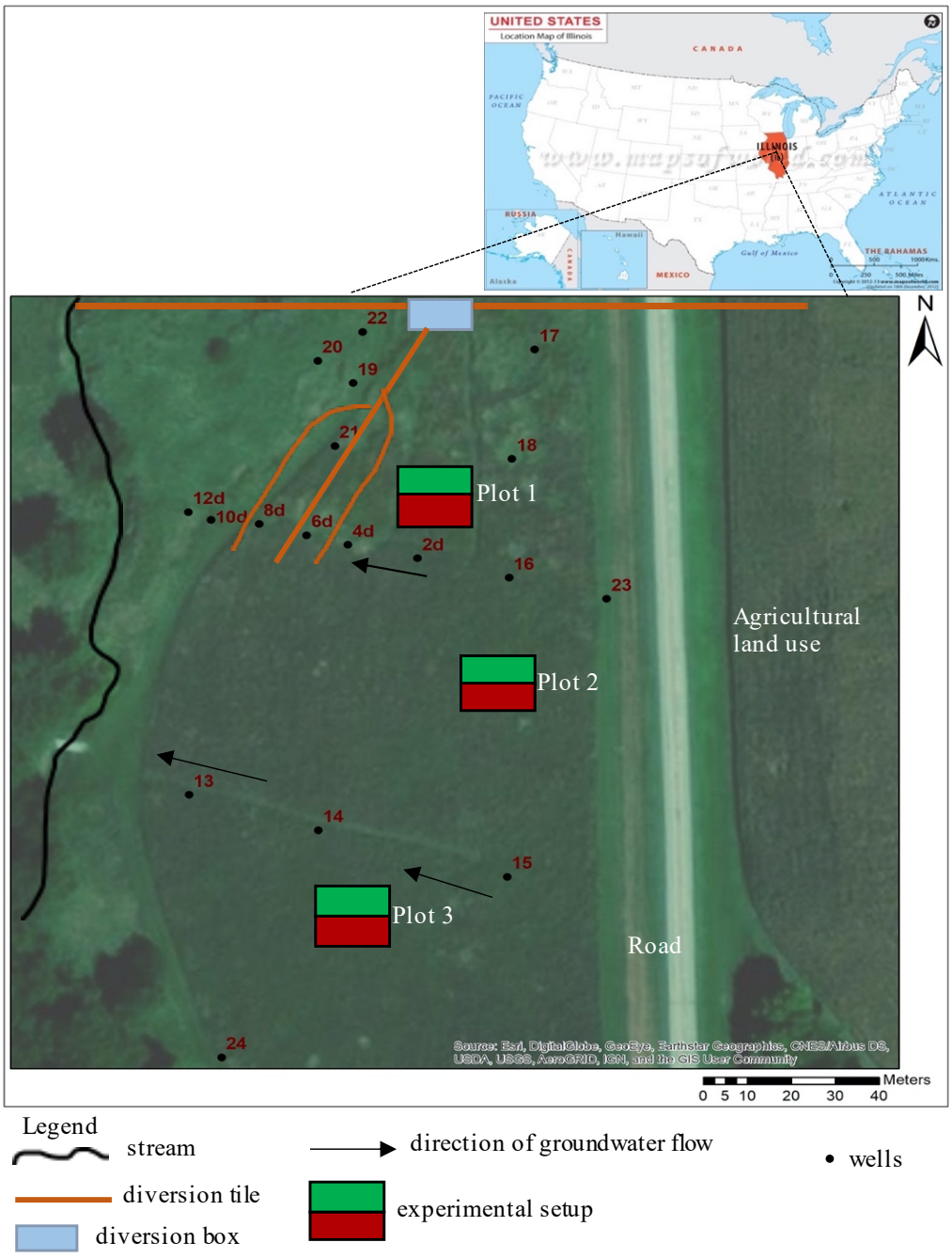

Figure 3. T3 field site (40.614382°N, -89.023542°W), highlighting the tile-drainage system, experimental setup (Figure 4) with the green indicating plot with plants and the red indicating barren plots, and groundwater wells. Note upgradient the agricultural land use.

Hydrogeologic Setting

Groundwater flow is from the east to west, with flow towards the stream T3 (Taye, 2016) (Figure 3). The 60-year average annual air temperature is 11.2°C with a monthly average variance of 30°C depending on the season (Changnon et al., 2004; Beach, 2008). Precipitation occurs year-round, with 40-year monthly averages showing greatest precipitation in the spring and lowest precipitation in the winter. The yearly average precipitation is 950mm ± 100mm (Changnon et al., 2004). Growth of plants begin in early to mid-spring, flowering occurs from mid spring to early summer, and seed maturity is reached by mid to late fall (Ogle et al., 2002).

CHAPTER II: METHODS

Within the saturated buffer zone (SBZ), three experimental blocks were established (Figure 4). Each block was composed of two plots (treatments), 6.1 m long and 2.7 m wide (Figure 4). A barren plot served as the control with all vegetation removed and covered with weed-barrier; the plot with plants was unaltered, with the switch grass left to naturally grow.

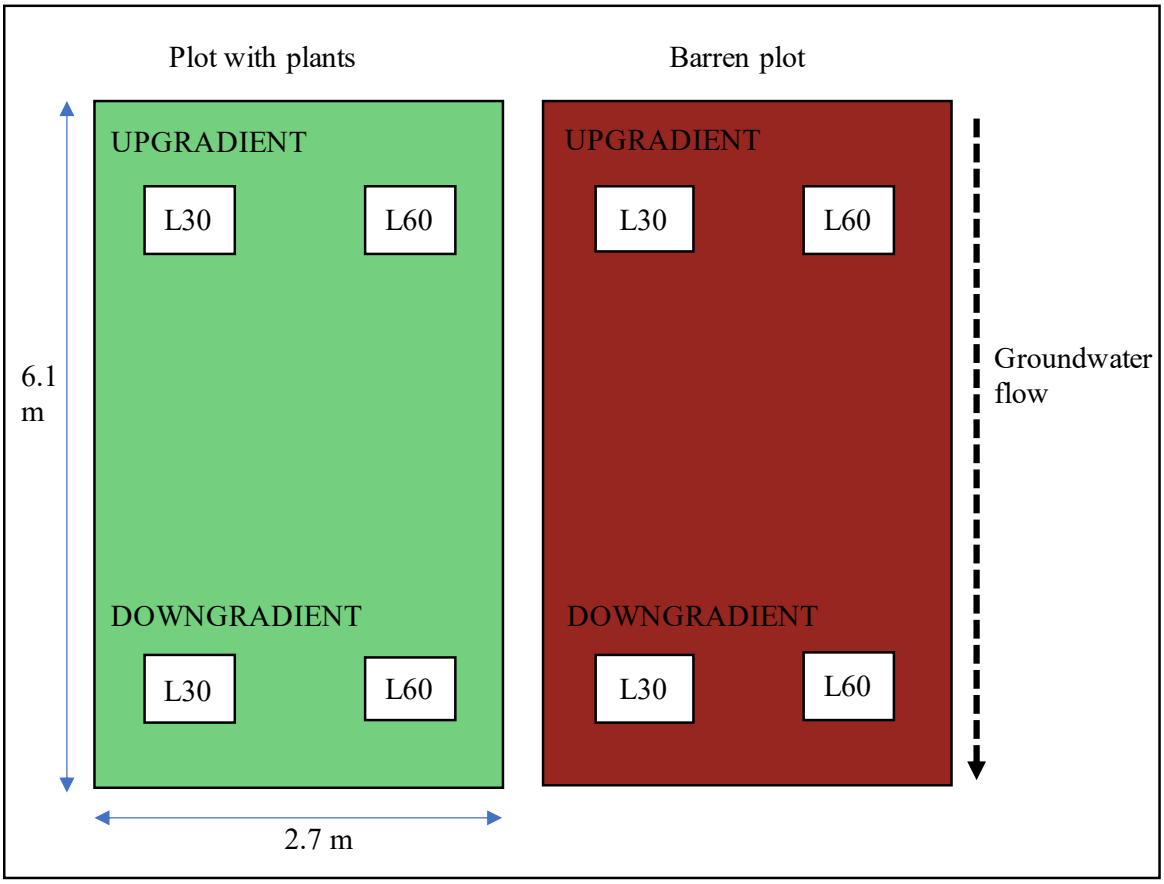

Figure 4. Experimental design showing two plots: plot with plants (green) and barren plot (red). L30 and L60 represent lysimeters installed at 30 cm and 60 cm below the ground surface, respectively.

Before the growing season and prior to development (May), soil core samples were collected from different locations within the plots. From each core, soil samples were collected at 30 cm,

60 cm, and 90 cm below the surface for analysis. Collection was repeated in October as the plants were going dormant for the season. During each sampling event, cores were extracted using either a 0.05 m and 0.02 m internal diameter split spoon sampler.

At intervals of 30 cm, 60 cm and 90 cm the cores were split vertically, and two composite samples were collected. One sample was used to determine the physical properties of the soil, and the second sample was used to quantify the nitrate nitrogen (NO_3^--N) within the soil. The physical properties measured include gravimetric moisture content (Θ_m), bulk density (ρ_β), and porosity (n) (Marshall et al. 1996). The organic matter (OM) content was measured using loss on ignition at 500°C (Schulte & Hopkins 1996).

Soil samples designated for NO_3^--N analysis were frozen immediately upon return to the lab for preservation until NO_3^--N extraction and analysis could be performed. NO_3^--N was extracted from within the sediment following the method presented by Mulvaney (1996). Ten grams of oven-dried sediment were placed in a glass container and 100 mL of 0.01 M solution of potassium chloride (KCl) was added to the sediment. The sediment and solution mixture was shaken for 60 min and allowed to settle. Five milliliters of the solution was withdrawn from the container, filtered, and analyzed using a DIONEX ICS-1100 ion chromatography system, owned by Illinois State University. The measured NO_3^--N concentrations represented the NO_3^--N mg/L in the extracted solution and were converted to grams of NO_3^--N per kilogram soil (g/kg).

Prior to the growing season (early spring) when the grass was about to green up, two soil-lysimeter arrays were installed, one along the upgradient boundary and one along the down gradient boundary within each plot (Figure 4) of the three locations (Figure 3). Each array included two suction lysimeters installed at depths of 30 cm and 60 cm upgradient and downgradient (Figure 4) of the study area. Attempts to draw waters samples occurred once

every week over six months (June -Nov) from each array. Soil moisture conditions limited collection, and not all lysimeters yielded water during each sample event. The sampled waters were filtered and analyzed for NO_3-N using the ion chromatography system. Box and whisker plots were drafted and the median NO_3^--N content in the soils and vadose waters were compared to determine if the presence or the absence of the plants controlled the movement of NO_3^--N. During the growing season (August 2019) and post growing season (October 2019), biomass samples were collected from the plot with plants. The vegetation above the surface in a square meter was harvested and the wet and dry mass was weighed. The mean of the dry biomass samples during growing and post- growing season was determined.

Statistical Analysis

A two-way ANOVA ($\alpha = 0.05$) was run to identify statistically differences between the NO_3^--N among the treatments, Pre-growing season, Plot with Plants, and Barren plot, and among the different depths, 30 cm, 60 cm, and 90 cm. If the analysis revealed a significant difference among the treatments or depths, a Tukey Test was conducted to determine which differences were significant.

CHAPTER III: RESULTS

Nitrate-N Data in Soils

Prior to the growing season, 24 soil core samples were collected from the experimental plots. For the cores, individual sample were analyzed from materials collected at 30 cm, 60 cm and 90 cm depths (Table 1 and Appendix A). Post-growing season, six soil core samples were collected from the plots with plants and six from the barren plots, with individual samples from 30cm, 60cm and 90cm depths below the ground surface (Table 1). NO_3^--N concentration in the soil pre-growing, plot with plants and barren plot at 30 cm, 60 cm and 90 cm depths revealed a significant difference ($p < 0.05$) among the treatments (Figure 5). Pre- Growing season the nitrate nitrogen (NO_3^--N) concentration in the soil within the saturated buffer zone (SBZ) ranged from 0.002 to 0.006 grams NO_3^--N per kilogram of soil water-(g/kg) with a median of 0.0039 g/kg at 30 cm (Table 1), 0.0005 to 0.005 g/kg with a median of 0.0039 g/kg at 60cm and 0.0005 to 0.004 g/kg with a median of 0.0031 g/kg at 90cm (Figure 5). Following the growing season, the NO_3^--N concentration within the soils underlying the plot with plants ranged from 0.0005 to 0.005 g/kg at 30cm and 0.0005 to 0.003 g/kg at 60 cm and 90 cm (Appendix A). After the growing season, the median concentration at the 30 cm depth was 0.0044 g/kg for the plot with plants and 0.0055 g/kg for the barren plot (Table 1). At 60cm depth the NO_3^--N content in the soil was 0.0039 g/kg pre-growing season and 0.0005 g/kg in the plot with plants and 0.0057 g/kg for the barren plots post-growing season (Table 1). At 90 cm depth, the NO_3^--N content in the soil was 0.0031 g/kg pre- growing season and 0.0023 g/kg in the plot with plants and 0.0034 g/kg for the barren plots (Table 1). Compiling the treatments, the median soil NO_3^--N was 0.0037 g/kg for the pre- growing conditions, 0.0024 g/kg for the plot with plants at the post-growing time, and 0.0054 g/kg for the barren plot at the post-growing period (Figure 6).

Table 1

Summary of the soil NO_3^--N content as gram of NO_3^--N per kilogram of soil water and the organic matter (OM) content as mass percent in the sampled soils.

Treatment	Season	Depth	n	Median NO_3^--N g/kg	Median OM n *	Median OM %
	Pre-Growing	30	24	0.0039	14	4.0
	(April)	60	24	0.0039	20	3.1
		90	8	0.0031	7	1.6
Plot with plants	Post-Growing	30	5	0.0044	5	5.8
	(November)	60	6	0.0005	6	6.0
		90	5	0.0023	4	4.0
Barren plot	Post-Growing	30	6	0.0055	6	3.8
	(November)	60	4	0.0057	4	3.0
		90	3	0.0034	3	0.4

n- number of samples;
*- for certain samples there was insufficient soil mass recovered to measure the organic content

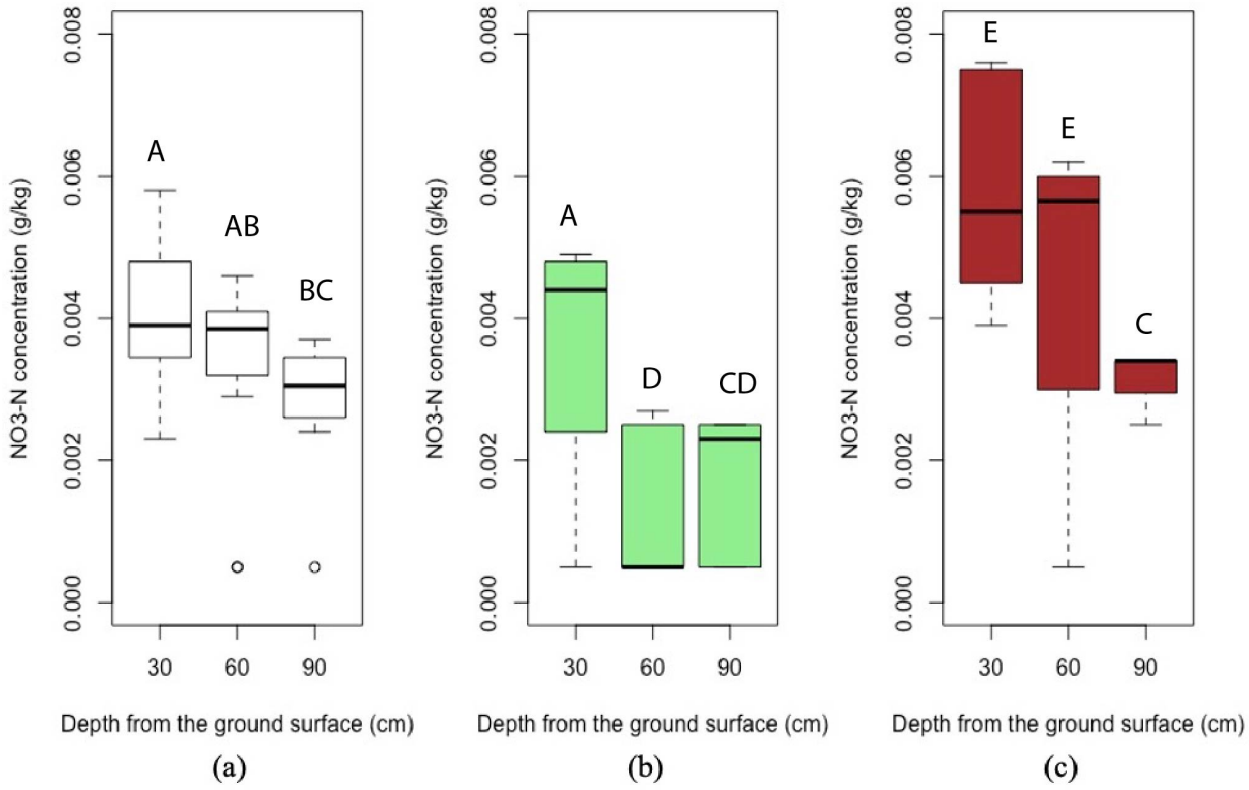

Figure 5. Soil NO_3^--N content as gram per kilogram of soil water with depth. (a)Pre-growing season (white); (b) Post-growing season - plots with plants (green); (c) Post growing season - barren plots (red). The ends of the boxes represent the 25th and 75th percentiles with the solid line at the median (50th percentiles); the error bars depict the 10th and 90th percentiles; the circles depict the outliers. Letters signify statistically similar concentrations among the treatment and depths, e.g. the measured concentrations at the 30-cm depth in the Pre-growing season samples (A) were similar to those at 60-cm depth in the Pre-growing season and the 30-cm depth in the Post-growing season - plots with plants.

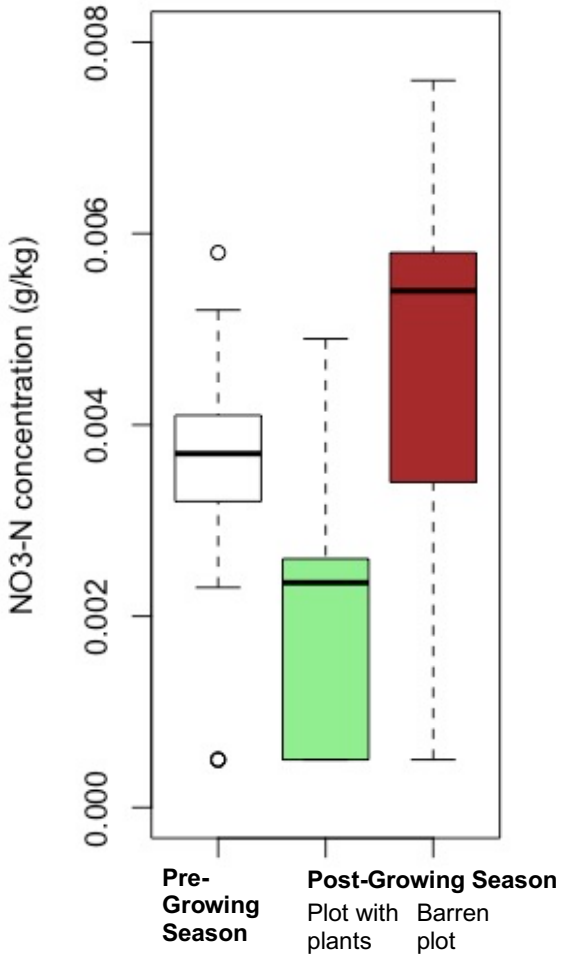

Figure 6. Soil NO_3^--N content as milligram per liter of soil water within the cumulative soil column. Pre-growing season (white); Post-growing season - plot with plants (green); Post-growing season - barren plots (red). The ends of the boxes represent the 25th and 75th percentiles with the solid line at the median (50th percentiles); the error bars depict the 10th and 90th percentiles; the circles depict the outliers.

Organic Matter Content

Soil samples were analyzed for organic matter (OM) content as mass percent of soil. Prior to the growing season 14 soil core samples were analyzed for OM at 30 cm, 20 soil core samples at 60 cm and seven soil core samples at 90 cm depths below the ground surface (Table 1, Figure 7, and Appendix A). Post-growing season five soil core samples were analyzed for OM at 30 cm, six soil core samples at 60 cm and four soil core samples at 90 cm for the plots with plants. For the barren plots six soil core samples were analyzed for OM at 30 cm, four soil core samples at 60 cm and three soil core samples at 90 cm depths below the ground surface (Table 1, Figure 7, and Appendix A). While the OM content in the soil pre- growing and the barren plot had similar OM content among the depths, both were significantly different ($p < 0.05$) than those within the plot with plants (Figure 7). Before the growing season, the median OM content, reported as mass percent in the soil at the 30 cm depth was 4.0 % (Table 1). After the growing season, the measured OM at the 30 cm depth was 5.8 % for the plot with plants and 3.8 % for the barren plot (Table 1). At 60 cm depth the OM content in the soil was 3.1 % pre-growing season and 6.0 % in the plot with plants and 3.0 % for the barren plots post-growing season (Table 1). At 90 cm depth, the OM content in the soil was 1.6 % pre- growing season and 4.0 % in the plot with plants and 0.4 % for the barren plots (Table 1).

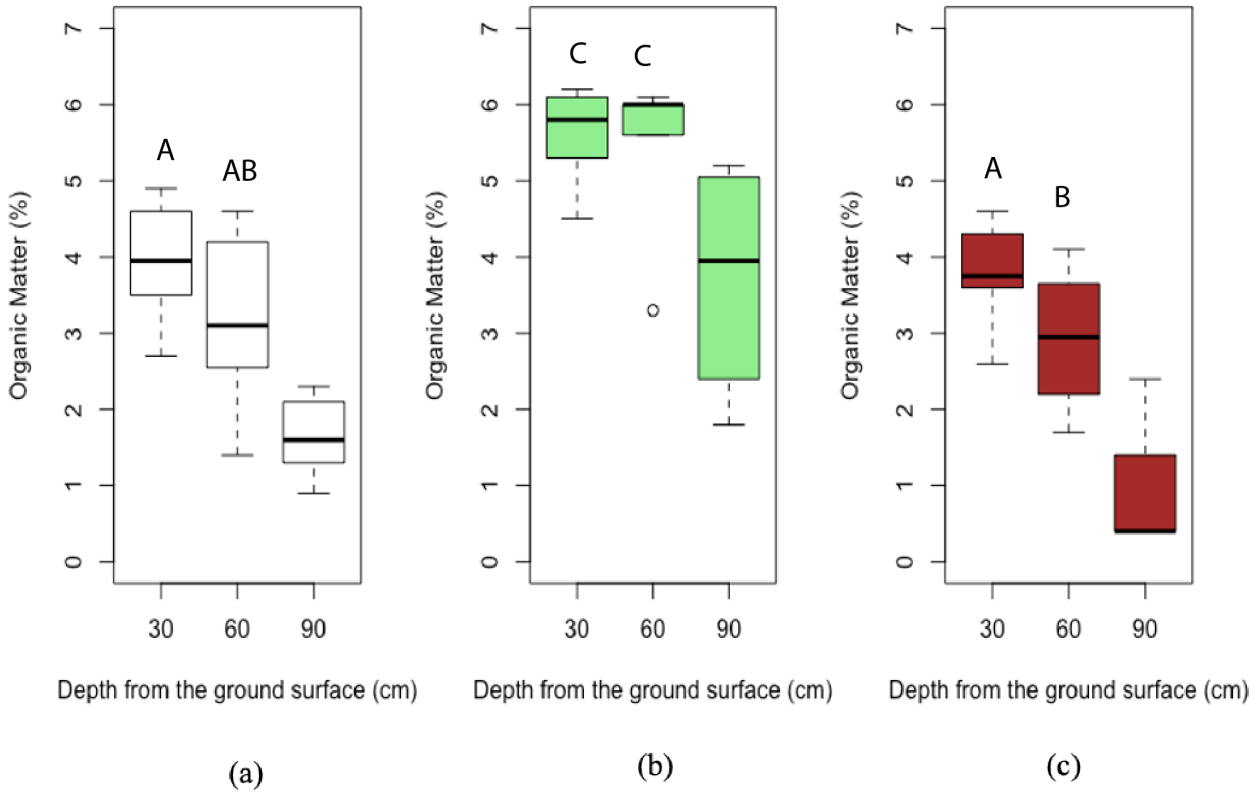

Figure 7. Organic matter content as mass percent in soil with depth. (a)Pre-growing season (white); (b) Post-growing season - plots with plants (green); (c) Post growing season - barren plots (red). The ends of the boxes represent the 25th and 75th percentiles with the solid line at the median (50th percentiles); the error bars depict the 10th and 90th percentiles; the circle depicts the outlier.

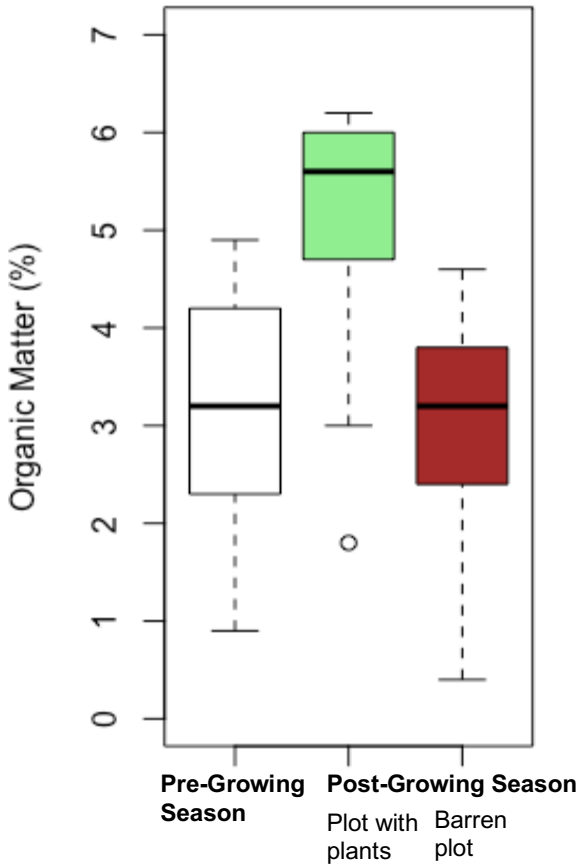

Figure 8. Organic matter content as mass percent in soil as a whole. Pre-Growing Season before the experimental design (white); Post-Growing Season for plot with plants (green); Post-Growing Season for Barren plots (red). The ends of the boxes represent the 25th and 75th percentiles with the solid line at the median (50th percentiles); the error bars depict the 10th and 90th percentiles; the circle depicts the outlier.

Nitrate-N Data in Vadose Waters

During the growing and post growing seasons, pore waters were drawn from the lysimeters at 30 cm and 60 cm below the ground surface from the plots with plants and the barren plots. Because during growing and post-growing season the collection of vadose water in the vadose zone was sporadic and there were not always waters samples at the 30 cm and 60 cm lysimeters at the same time, the NO_3^--N concentration in the vadose waters were grouped

together to represent the vadose zone (Table 2, Figure 9 and Appendix B). During the growing season, 22 samples were drawn from the lysimeters within the plots with plants and 45 vadose water samples drawn from the lysimeters within the barren plots. Post-growing season, 15 and 17 water samples were also analyzed from the plots with plants and barren plots respectively. During the growing season the median NO_3^--N concentration in the vadose waters for the plot with plants was 0.33 mg/L and 0.37 mg/L for the barren plot. After the growing season the median NO_3^--N concentration for the plot with plants was 0.30 mg/L and 0.36 mg/L for the barren plot.

Table 2

Summary of NO_3^--N concentration (mg/L) in vadose waters drawn from lysimeters during growing and post-growing seasons.

Treatment	Season	Number of samples	Median NO_3^--N (mg/L)
Plots with plants	Growing	22	0.33
Plots with plants	Post-Growing	15	0.30
Barren plots	Growing	45	0.37
Barren plots	Post-Growing	17	0.36

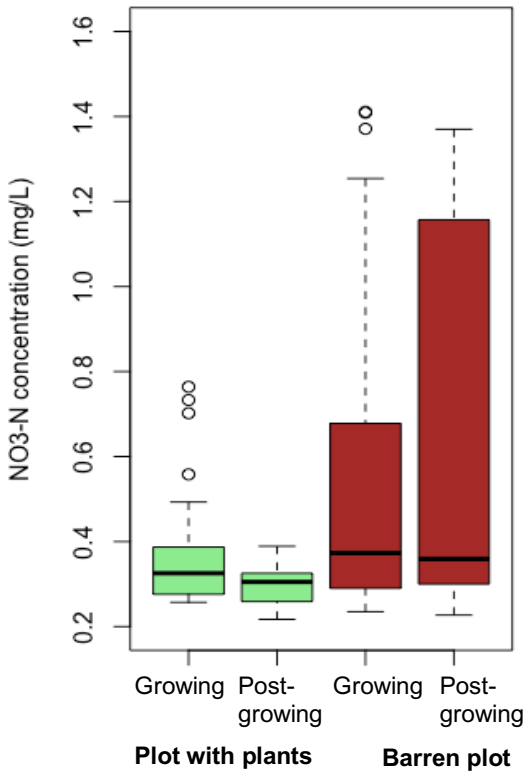

Figure 9. NO_3^--N concentration in the vadose waters collected from lysimeters during the growing season and post-growing seasons for plots with plants (green) and barren plots (red). The ends of the boxes represent the 25th and 75th percentiles with the solid line at the median (50th percentiles); the error bars depict the 10th and 90th percentiles; the circles depict the outliers.

CHAPTER IV: DISCUSSION

During the growing season, switchgrass generated biomass within the plots with plants in contrast to the barren plots. During the peak part of the growing season (August) there were 265.3 ±28.6 g m^{-2} mean dry biomass in the SBZ and as the plants went dormant (October) the mean dry biomass decreased to 177.6±47.4 g m^{-2}. With no plants present, the biomass was 0 g m^{-2} on the barren plots. The decreased biomass suggests the decomposition of plant materials that add part of the biomass to the soil. The generated biomass and the presence of roots increased the organic matter (OM) within the soil over the course of the growing season (Table 1 and Figure 9). The source of the OM in the soil is as a result of biological activity and plant growth at the roots. (Ge et al., 2010; Leifeld et al., 2002). During the growing season, plants use carbon dioxide (CO_2) from the atmosphere and nutrients from the soil to build complex organic carbon molecules (Addiscott 2005; Schlesinger & Andrews, 2000). These organic carbon molecules form complex structures of plants such as leaves, stems, branches, and roots (D'Augustino, 2015). As the plants grow, some of the produced organic materials goes into the soil as plant root exudates (sugars and amino acids) increasing the OM content in the soil (Addiscott 2005). During the post-growing season, plants go dormant, and the organic materials returns to the soil as shoot and root residues. Residues from the decomposing shoots and roots in the soil enhance the level of the organic matter in the soil.

Over the growing season, the nitrate as nitrogen (NO_3^--N) within the soil decreased as the plants were actively taking up nutrients. Post- growing season, the lower NO_3^--N concentration observed in the soil from the plots with plants (Table 1 and Figure 5b) alludes to assimilation by the plants. This is because the switchgrass in the SBZ have well-developed root system (Schimel, 1986) that absorbs NO_3^--N for growth during the growing season. The lower concentrations of

NO_3^--N within the vadose zone underlying the plots with plants (Table 2 and Figure 10) occurs in response to plant growth during the growing season, which is consistent with the removal of NO_3^--N by plants (Miller et al., 2018; Taye, 2016). In addition, when the plants die and the organic matter (decays) is released it provides a source of carbon for the denitrifying bacteria lowering NO_3^--N in the soil.

In the absence of plant growth in the barren plots, OM was not produced. Rather, the OM in the barren plots remained the same or decreased, ranging from 0.4% to 4.6% (Appendix A). The reduction of OM in the barren plots (Table 1 and Figure 8) indicates the decomposition of the residual materials in the soil, but unlike the plots with plants, no new biomass was generated to replace the materials that were decomposed.

Over the growing season, the barren plots had no active plants to withdraw the NO_3^--N from the soil and vadose waters. Post- growing season, the higher NO_3^--N concentration observed in the barren plot for the soils (Table 1 and Figure 5c) and vadose waters (Table 2 and Figure 10) suggests no uptake of NO_3^--N. During the growing season, the barren plot would have had roots from plants growing the previous year (prior to the growing season) actively decaying. As the plant materials decomposed, organic nitrogen from the plant residue goes through the nitrogen cycle and gets converted back to NO_3^--N in the vadose through nitrification (Xin et al, 2019; Hefting et al., 2013; Addiscott 2005). This could contribute to the elevated NO_3^--N concentrations in the soil (Figure 6) and vadose waters (Figure 10) post- growing season.

Based on the soils and vadose water data, the absence of plants precludes the uptake of NO_3^--N in the vadose zone and the lower NO_3^--N concentration observed in the plot with plants supports the hypothesis that nitrate removal will be greater in the presence of plants than where plants are absent. Post- growing season the NO_3^--N concentration in the soil for the barren plots

(Figure 6) was higher than the plot with plants since no plants were growing to take up the nitrates and there could also be nitrification occurring to alter the organic nitrogen to nitrate. Therefore, the hypothesis that following a growing season, nitrate concentration in the soils underlying a barren plot (no plants) will be less than in the soils underlying a plot with plants is rejected.

Although this study was carried out in one growing cycle, the OM content observed is consistent with what was observed in 2015 prior to the growing season. Within the SBZ, Sanks et al. (2015) oberved 7.5 % median OM at 30 cm depth and 6 % median OM at 60 cm depth. These values are similar to the median OM content of 5.8 % at 30 cm depth, 6.0 % at 60 cm depth and 4 % at 90 cm depth observed at the plot with plants post growing season (Table 1). Grasslands have high OM content that supplies plants with essential nutrients for growth (Miller & Donahue, 1990). In the plot with plants the growth of plants continually generates and sustains OM within the soil. This suggests that the plants are creating a sustainable reservoir that continuously depletes and restores OM from year-to-year.

Generally, the NO_3^--N concentration observed in the soil within the SBZ was lower than NO_3^--N observed in active agricultural fields located around the study area. Moore and Peterson (2007) observed nitrate concentration up to a magnitude higher within active soybean and corn fields in central Illinois. At depths of 30 cm within the soils underlying the soybean fields, the nitrate levels ranged from 0.01 to 0.2 g/kg, while in the soils growing corn, the levels ranged from 0.02 to 0.05 g/kg. The active fields were continuously farmed, and the fields received an annual application of synthetic fertilizers or manure. The soils within the SBZ have maintained consistent levels of NO_3^--N, albeit a magnitude lower in concentration than in the corn field soils analyzed by Moore and Peterson (2007). Prior to the growing season, the median NO_3^--N

concentration measured (Table 1) were similar to the median NO_3^--N concentration observed by Sanks et al. (2015). The median NO_3^--N concentration observed in the SBZ at 30 cm depth was 0.0039 g/kg, 0.0039 g/kg at 60 cm and 0.0031 g/kg at 90 cm whereas the median NO_3^--N concentration observed by Sanks et al. (2015) at the 30 cm depth was 0.004 g/kg and 0.003 g/kg at 60 cm. This suggests that over the past four years, the NO_3^--N levels in the SBZ have been maintained and there seem to be no significant loss of NO_3^--N in the soil. Within the SBZ, the NO_3^--N in the soils have been incorporated into the plants year after year; this suggests recycling of NO_3^--N in the vadose zone over the period of time. The cycle also keeps the N higher in the profile which decrease the potential for leaching. The observed NO_3^--N concentration in the SBZ were of a magnitude lower than an active farm because no fertilizers were applied on the SBZ following the transition to switchgrass prairie over six years ago. The switchgrass has been observed to assimilate nitrate (Miller et al., 2018), suggesting that plants have been serving as a nitrate sink.

The data provide a limited timeframe. Monitoring occurred over only six months, May to November and allowed only a comparison of pre-growing seasons conditions to post-growing season conditions for one season. This constraint limits the extension of the data; however, the presented data coupled with the 2015 data (Sanks et al., 2015) suggest that the NO_3^--N concentrations in the vadose have remained stable year-to-year. When the plants grow and eventually go dormant the plant material and its root system decompose. The nitrogen compounds in the organic matter re-enter the soil and the microorganisms convert the DON back to NO_3^- (Figure 2). Part of the NO_3^- generated in the vadose is taken up by the roots of plants for growth and part is denitrified releasing N_2 gas into the atmosphere and the cycle starts all over again.

In addition, the study could not explore how much NO_3^--N was incorporated into the plants. Miller et al. (2018) and Taye (2016) determined NO_3^--N removal by plants in the SBZ, but neither documented whether the removal was temporary or permanent. The results of this study suggest that within the SBZ NO_3^--N removal by the plants is temporary and the SBZ serves as a short-term sink, recycling the nitrate on an annual basis.

CHAPTER V: CONCLUSIONS

The presence and absence of plants in a SBZ affects NO_3^--N concentration in the vadose zone. Plots with plants witnessed a reduction NO_3^--N from the soil because plants were actively growing and used the available nitrate for photosynthesis, generating increased OM. NO_3^--N concentration in the barren plot were high because there were no plant materials actively growing to use the nitrate in the soil lowering the OM. The plants materials rather decomposed to increase the NO_3^--N concentration in the soil. The lower NO_3^--N concentration in the soil and vadose waters that were observed in the plot with plants illustrates removal of NO_3^--N by the plants and confirms the hypothesis that nitrate removal will be greater in the presence of plants than where plants are absent. The higher NO_3^--N concentration observed in the soil underlying the barren plot was because there were no plants removing the NO_3^--N and the decomposition of plants materials would have recycled nitrogen from the plants that were decaying. Hence the hypothesis that following a growing season, nitrate concentration in the soils underlying a barren plot (no plants) will be less than in the soils underlying a plot with plants is rejected. The low NO_3^--N concentration observed in the soil within the SBZ were similar to what was observed by Sanks et al. (2015) four years ago. This suggests that there is no overall loss or actual removal of nitrate from the SBZ. The NO_3^--N uptake in the SBZ is a short-term sink in which the plants continually recycle the N overtime. Future research could focus on the NO_3^--N concentration in the soil during the same time of data collection (Summer) to know if there has been a significant change of NO_3^--N in the SBZ over time and how much nitrogen is in the plant material over one-year treatment.

Future Work

The results of this study have provided understanding on the role of plants in the removal of NO_3^--N in the SBZ. Future research can be focused on knowing the amount of NO_3^--N in the soil during the growing season. This will help determine how much NO_3^--N concentration was removed by the plants over the growing season. In addition, soil samples should be collected in the plot with plants and barren plots prior to the growing season (over the summer) to know how much NO_3^--N concentration remained in the vadose zone of the SBZ.

Further studies should be conducted to determine whether there is an additional capacity of the vadose zone to remove more nitrate. Prior to growing seasons (early spring) when the grass is about to green up, slugs of chloride and NO_3^- solution could be injected into unsaturated zone wells upgradient of each plot. This could further reveal whether another source of NO_3^- added in the vadose zone will be used or leached. This will help provide additional information on the fate and transport of NO_3^- in the vadose zone of the SBZ.

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APPENDIX A: SOIL DATA

Table A

Analyzed soil data sampled in the study area

Date	Location	Treatment	Season	Depth (cm)	ρ_β (g/cm3)	mc		η	NO_3^--N		OM (%)
						θvol	θmass		g/kg	mg/L	
4/27/19	Plot 1		Pre- Growing	30	1.03	0.44	0.43	0.60	0.0039	0.009	4.3
4/27/19	Plot 1		Pre- Growing	60	1.37	0.33	0.22	0.47	0.0041	0.018	2.7
4/27/19	Plot 1		Pre- Growing	90	1.32	0.33	0.23	0.49	0.0037	0.016	0.9
4/27/19	Plot 1		Pre- Growing	30	0.85	0.24	0.28	0.67	0.0039	0.014	3.7
4/27/19	Plot 1		Pre- Growing	60	1.04	0.10	0.09	0.60	0.0041	0.013	2.6
4/27/19	Plot 1		Pre- Growing	30	1.38	0.45	0.32	0.47	0.0045	0.014	3.5
4/27/19	Plot 1		Pre- Growing	60	1.49	0.40	0.27	0.43	0.0031	0.012	2.5
4/27/19	Plot 1		Pre- Growing	90	1.23	0.31	0.23	0.53	0.0029	0.013	2.3
4/27/19	Plot 2		Pre- Growing	30	1.17	0.38	0.33	0.55	0.0035	0.011	4.7
4/27/19	Plot 2		Pre- Growing	60	1.20	0.40	0.32	0.54	0.0039	0.012	4.3
4/27/19	Plot 2		Pre- Growing	90	1.53	0.53	0.32	0.41	0.0035	0.011	1.5
4/27/19	Plot 2		Pre- Growing	30	1.09	0.22	0.20	0.58	0.0031	0.015	3.5

(Table continues)

Table A, continued

Date	Location	Treatment	Season	Depth (cm)	ρ_β (g/cm3)	mc θvol	mc θmass	η	NO_3^--N g/kg	NO_3^--N mg/L	OM (%)
4/27/19	Plot 2		Pre- Growing	60	1.36	0.32	0.23	0.48	0.0032	0.014	2.6
4/27/19	Plot 2		Pre- Growing	30	1.56	0.12	0.08	0.40	0.0023	0.030	3.5
4/27/19	Plot 2		Pre- Growing	60	1.32	0.40	0.30	0.49	0.0029	0.010	3.2
4/27/19	Plot 3		Pre- Growing	30	1.26	0.44	0.34	0.51	0.0052	0.015	4.8
4/27/19	Plot 3		Pre- Growing	60	1.23	0.43	0.34	0.53	0.0045	0.013	4.4
4/27/19	Plot 3		Pre- Growing	90	1.77	0.53	0.27	0.32	0.0024	0.009	1.9
4/27/19	Plot 3		Pre- Growing	30	0.91	0.33	0.32	0.65	0.0035	0.011	4.4
4/27/19	Plot 3		Pre- Growing	60	1.17	0.40	0.31	0.55	0.0031	0.010	2.3
4/27/19	Plot 3		Pre- Growing	90	1.24	0.40	0.30	0.52	0.0032	0.011	1.6
4/27/19	Plot 3		Pre- Growing	30	1.12	0.41	0.33	0.57	0.0037	0.011	4.6
4/27/19	Plot 3		Pre- Growing	60	1.14	0.39	0.30	0.56	0.0041	0.014	3.9
4/27/19	Plot 3		Pre- Growing	90	0.54	0.24	0.39	0.79	0.0034	0.009	1.1

(Table continues)

Table A, continued

Date	Location	Treatment	Season	Depth (cm)	ρ_β (g/cm3)	mc		η	NO_3^--N		OM (%)
						θvol	θmass		g/kg	mg/L	
4/27/19	Plot 3		Pre- Growing	30	1.12	0.41	0.33	0.57	0.0034	0.010	
4/27/19	Plot 3		Pre- Growing	60	1.02	0.32	0.29	0.61	0.0005	0.002	4.6
4/27/19	Plot 3		Pre- Growing	90	1.11	0.33	0.27	0.57	0.0028	0.011	2.3
4/27/19	Plot 3		Pre- Growing	30	0.92	0.35	0.34	0.65	0.0032	0.009	
4/27/19	Plot 3		Pre- Growing	60	0.98	0.32	0.30	0.62	0.0005	0.002	4.2
4/27/19	Plot 3		Pre- Growing	30	1.23	0.27	0.21	0.53	0.0028	0.013	
4/27/19	Plot 3		Pre- Growing	60	1.54	0.47	0.28	0.41	0.0032	0.011	2.3
4/27/19	Plot 1		Pre- Growing	30	0.27	0.11	0.34	0.90	0.0035	0.010	
4/27/19	Plot 1		Pre- Growing	60	0.15	0.04	0.21	0.94	0.0041	0.019	4.2
4/27/19	Plot 1		Pre- Growing	30	0.53	0.18	0.31	0.80	0.0034	0.011	2.7
4/27/19	Plot 1		Pre- Growing	60	0.38	0.11	0.28	0.85	0.0038	0.014	
4/27/19	Plot 1		Pre- Growing	30	0.65	0.17	0.25	0.75	0.0042	0.017	

(Table continues)

Table A, continued

Date	Location	Treatment	Season	Depth (cm)	ρ_β (g/cm3)	mc		η	NO_3^--N		OM (%)
						θvol	θmass		g/kg	mg/L	
4/27/19	Plot 1		Pre- Growing	60	0.17	0.04	0.20	0.93	0.0034	0.017	
4/27/19	Plot 1		Pre- Growing	30	0.46	0.12	0.23	0.82	0.0047	0.020	
4/27/19	Plot 1		Pre- Growing	60	0.17	0.04	0.21	0.93	0.0040	0.019	
4/27/19	Plot 2		Pre- Growing	30	0.42	0.14	0.29	0.84	0.0050	0.017	4.2
4/27/19	Plot 2		Pre- Growing	60	0.27	0.08	0.28	0.90	0.0041	0.015	1.4
4/27/19	Plot 2		Pre- Growing	30	0.70	0.23	0.30	0.73	0.0049	0.016	3.1
4/27/19	Plot 2		Pre- Growing	60	0.32	0.10	0.29	0.88	0.0037	0.013	4.3
4/27/19	Plot 2		Pre- Growing	30	0.47	0.13	0.24	0.82	0.0051	0.021	3.0
4/27/19	Plot 2		Pre- Growing	60	0.21	0.06	0.27	0.92	0.0041	0.015	1.7
4/27/19	Plot 2		Pre- Growing	30	0.61	0.16	0.25	0.77	0.0044	0.018	4.9
4/27/19	Plot 2		Pre- Growing	60	0.16	0.05	0.26	0.94	0.0036	0.014	3.9
4/27/19	Plot 2		Pre- Growing	90					0.0005		
4/27/19	Plot 3		Pre- Growing	30	0.36	0.12	0.29	0.86	0.0042	0.014	

(Table continues)

Table A, continued

Date	Location	Treatment	Season	Depth (cm)	ρ_β (g/cm3)	mc θvol	mc θmass	θmass	NO_3^--N g/kg	NO_3^--N mg/L	OM (%)
4/27/19	Plot 3		Pre- Growing	60	0.25	0.07	0.27	0.90	0.0039	0.014	
4/27/19	plot 3		Pre- Growing	90	1.18	0.37	0.29	0.54	0.0005	0.002	
4/27/19	Plot 3		Pre- Growing	30	0.24	0.07	0.26	0.91	0.0035	0.013	
4/27/19	Plot 3		Pre- Growing	60	0.14	0.04	0.24	0.95	0.0032	0.013	4.2
4/27/19	Plot 3		Pre- Growing	30	0.28	0.08	0.26	0.89	0.0058	0.022	
4/27/19	Plot 3		Pre- Growing	60	0.16	0.05	0.27	0.94	0.0040	0.015	3.0
4/27/19	Plot 3		Pre- Growing	30	0.33	0.09	0.26	0.87	0.0050	0.019	
4/27/19	Plot 3		Pre- Growing	60	0.14	0.04	0.24	0.94	0.0046	0.019	3.0
11/9/19	Plot 1	Plot with plants	Post- Growing	30	1.22	0.40	0.30	0.54	0.0044	0.013	4.5
11/9/19	Plot 1	Plot with plants	Post- Growing	60	1.46	0.42	0.27	0.45	0.0027	0.010	3.3
11/9/19	Plot 1	Plot with plants	Post- Growing	90	1.72	0.40	0.23	0.35	0.0025	0.011	
11/9/19	Plot 2	Plot with plants	Post- Growing	30	1.31	0.44	0.31	0.51	0.0048	0.016	5.3
11/9/19	Plot 2	Plot with plants	Post- Growing	60	1.15	0.36	0.27	0.56	0.0005	0.002	6.0

(Table continues)

Table A, continued

Date	Location	Treatment	Season	Depth (cm)	ρ_β (g/cm3)	mc		η	NO_3^--N		OM (%)
						θvol	θmass		g/kg	mg/L	
11/9/19	Plot 2	Plot with plants	Post- Growing	90	1.41	0.44	0.29	0.47	0.0023	0.008	4.9
11/9/19	Plot 2	Plot with plants	Post- Growing	30			0.32		0.0024	0.007	6.1
11/9/19	Plot 2	Plot with plants	Post- Growing	60			0.30		0.0025	0.008	5.6
11/9/19	Plot 2	Plot with plants	Post- Growing	90			0.28		0.0025	0.009	5.2
11/9/19	Plot 3	Plot with plants	Post- Growing	30			0.34		0.0049	0.014	5.8
11/9/19	Plot 3	Plot with plants	Post- Growing	60	1.12	0.38	0.31	0.58	0.0005	0.002	6.1
11/9/19	Plot 3	Plot with plants	Post- Growing	30	1.46	0.50	0.31	0.45	0.0005	0.002	6.2
11/9/19	Plot 3	Plot with plants	Post- Growing	60			0.31		0.0005	0.002	6.0
11/9/19	Plot 3	Plot with plants	Post- Growing	90	1.26	0.42	0.30	0.52	0.0005	0.002	3.0
11/9/19	Plot 3	Plot with plants	Post- Growing	90	1.02	0.55	0.49	0.61	0.0005	0.001	1.8
11/9/19	Plot 3	Plot with plants	Post- Growing	60			0.31		0.0005	0.002	6.0
11/9/19	Plot 1	Barren plots	Post- Growing	30	1.31	0.45	0.34	0.51	0.0076	0.022	4.6
11/9/19	Plot 1	Barren plots	Post- Growing	60	1.53	0.43	0.26	0.42	0.0005	0.002	1.7

(Table continues)

Table A, continued

Date	Location	Treatment	Season	Depth (cm)	$\boldsymbol{\rho_\beta}$ (g/cm3)	mc		η	NO_3^--N		OM (%)
						$\boldsymbol{\theta}$vol	$\boldsymbol{\theta}$mass		g/kg	mg/L	
11/9/19	Plot 1	Barren plots	Post- Growing	30			0.33		0.0075	0.022	4.3
11/9/19	Plot 1	Barren plots	Post- Growing	90	1.65	0.35	0.19	0.38	0.0025	0.013	0.4
11/9/19	Plot 1	Barren plots	Post- Growing	90			0.21		0.0034	0.016	0.4
11/9/19	Plot 2	Barren plots	Post- Growing	30	1.36	0.48	0.33	0.49	0.0054	0.016	2.6
11/9/19	Plot 2	Barren plots	Post- Growing	30			0.30		0.0045	0.015	3.7
11/9/19	Plot 2	Barren plots	Post- Growing	60	1.17	0.37	0.29	0.56	0.0058	0.020	4.1
11/9/19	Plot 2	Barren plots	Post- Growing	60			0.32		0.0062	0.019	3.2
11/9/19	Plot 2	Barren plots	Post- Growing	90			0.29		0.0034	0.012	2.4
11/9/19	Plot 3	Barren plots	Post- Growing	30	1.17	0.40	0.32	0.56	0.0056	0.018	3.6
11/9/19	Plot 3	Barren plots	Post- Growing	30			0.32		0.0039	0.012	3.8
11/9/19	Plot 3	Barren plots	Post- Growing	60	1.44	0.27	0.30	0.71	0.0055	0.019	2.7

$\boldsymbol{\rho_\beta}$- bulk density, mc- moisture content, $\boldsymbol{\theta}$vol - moisture content based on volume, $\boldsymbol{\theta}$mass- moisture content based on mass, η- porosity

APPENDIX B: LYSIMETER DATA

Table B

Lysimeter data for the vadose waters

Date	Location	Treatment	Season	Depth (cm)	NO_3^--N (mg/l)
6/18/19	Plot 2	Plot with plants	Growing	60	0.73
6/18/19	Plot 2	Plot with plants	Growing	60	0.49
6/18/19	Plot 1	Barren plot	Growing	30	0.85
6/18/19	Plot 2	Barren plot	Growing	60	0.72
6/24/19	Plot 1	Plot with plants	Growing	30	0.70
6/24/19	Plot 2	Plot with plants	Growing	30	0.39
6/24/19	Plot 1	Plot with plants	Growing	60	0.56
6/24/19	Plot 2	Plot with plants	Growing	60	0.36
6/24/19	Plot 1	Barren plot	Growing	60	0.68
6/24/19	Plot 1	Barren plot	Growing	60	0.43
6/24/19	Plot 2	Barren plot	Growing	60	0.36
6/24/19	Plot 2	Barren plot	Growing	30	0.40
6/24/19	Plot 2	Barren plot	Growing	30	0.96
7/6/19	Plot 2	Plot with plants	Growing	30	0.37
7/6/19	Plot 1	Plot with plants	Growing	30	0.38
7/6/19	Plot 2	Barren plot	Growing	60	0.38
7/6/19	Plot 2	Barren plot	Growing	30	0.40
7/6/19	Plot 1	Barren plot	Growing	60	0.41
7/6/19	Plot 1	Barren plot	Growing	30	0.37

(Table continues)

Table B, continued

Date	Location	Treatment	Season	Depth (cm)	NO_3^--N (mg/l)
7/6/19	Plot 1	Barren plot	Growing	30	0.37
7/6/19	Plot 2	Barren plot	Growing	60	0.46
7/12/19	Plot 1	Plot with plants	Growing	60	0.26
7/12/19	Plot 2	Plot with plants	Growing	60	0.26
7/12/19	Plot 2	Plot with plants	Growing	30	0.28
7/12/19	Plot 1	Plot with plants	Growing	30	0.32
7/12/19	Plot 1	Barren plot	Growing	30	0.32
7/12/19	Plot 1	Barren plot	Growing	60	0.30
7/20/19	Plot 1	Barren plot	Growing	60	0.31
7/20/19	Plot 1	Barren plot	Growing	30	0.29
7/20/19	Plot 2	Barren plot	Growing	30	0.27
7/27/19	Plot 1	Barren plot	Growing	30	0.27
7/27/19	Plot 3	Barren plot	Growing	30	0.27
8/9/19	Plot 2	Barren plot	Growing	30	0.26
8/9/19	Plot 1	Barren plot	Growing	30	0.25
8/9/19	Plot 2	Barren plot	Growing	30	0.26
8/9/19	Plot 1	Barren plot	Growing	30	0.66
8/9/19	Plot 1	Barren plot	Growing	60	1.37
8/13/19	Plot 2	Plot with plants	Growing	30	1.16
8/13/19	Plot 1	Barren plot	Growing	30	0.26

(Table continues)

Table B, continued

Date	Location	Treatment	Season	Depth (cm)	NO_3^--N (mg/l)
8/13/19	Plot 2	Barren plot	Growing	60	0.30
8/13/19	Plot 1	Barren plot	Growing	30	0.26
8/13/19	Plot 2	Barren plot	Growing	60	0.30
8/24/19	Plot 1	Plot with plants	Growing	30	0.28
8/24/19	Plot 1	Plot with plants	Growing	30	0.28
8/24/19	Plot 2	Plot with plants	Growing	30	0.28
8/24/19	Plot 1	Plot with plants	Growing	30	0.28
8/24/19	Plot 2	Barren plot	Growing	30	1.41
8/24/19	Plot 2	Barren plot	Growing	60	0.26
8/24/19	Plot 1	Barren plot	Growing	30	0.26
8/24/19	Plot 1	Barren plot	Growing	60	0.76
8/24/19	Plot 2	Barren plot	Growing	30	0.32
8/31/19	Plot 2	Barren plot	Growing	30	1.25
8/31/19	Plot 2	Barren plot	Growing	60	0.26
9/14/19	Plot 1	Barren plot	Growing	30	0.57
9/14/19	Plot 1	Barren plot	Growing	60	1.41
9/14/19	Plot 1	Barren plot	Growing	30	0.38
9/14/19	Plot 1	Plot with plants	Growing	30	0.33
9/28/19	Plot 1	Barren plot	Growing	30	0.32
9/28/19	Plot 1	Barren plot	Growing	30	0.24

(Table continues)

Table B, continued

Date	Location	Treatment	Season	Depth (cm)	NO_3^--N (mg/l)
9/28/19	Plot 1	Plot with plants	Growing	30	0.32
9/28/19	Plot 1	Plot with plants	Growing	30	0.34
9/28/19	Plot 2	Plot with plants	Growing	30	0.30
10/1/19	Plot 1	Plot with plants	Post- growing	60	0.32
10/1/19	Plot 2	Plot with plants	Post- growing	30	0.31
10/1/19	Plot 1	Plot with plants	Post- growing	30	0.30
10/1/19	Plot 2	Plot with plants	Post- growing	60	0.29
10/1/19	Plot 1	Plot with plants	Post- growing	30	0.31
10/1/19	Plot 1	Barren plot	Post- growing	30	0.31
10/1/19	Plot 1	Barren plot	Post- growing	30	0.26
10/1/19	Plot 2	Barren plot	Post- growing	30	0.31
10/6/19	Plot 1	Plot with plants	Post- growing	60	0.26
10/6/19	Plot 1	Plot with plants	Post- growing	30	0.39
10/6/19	Plot 2	Barren plot	Post- growing	30	0.27
10/6/19	Plot 1	Plot with plants	Post- growing	60	0.37
10/20/19	Plot 1	Barren plot	Post- growing	30	0.30
10/24/19	Plot 1	Barren plot	Post- growing	30	0.23
10/24/19	Plot 2	Barren plot	Post- growing	30	0.36
11/2/19	Plot 1	Plot with plants	Post- growing	30	0.33
11/2/19	Plot 1	Plot with plants	Post- growing	30	0.23

(Table continues)

Table B, continued

Date	Location	Treatment	Season	Depth (cm)	NO_3^--N (mg/l)
11/2/19	Plot 1	Plot with plants	Post- growing	60	0.23
11/2/19	Plot 1	Barren plot	Post- growing	30	0.23
11/2/19	Plot 1	Barren plot	Post- growing	30	0.22
11/2/19	Plot 2	Barren plot	Post- growing	60	0.34
11/2/19	Plot 1	Plot with plants	Post- growing	30	0.26
11/2/19	Plot 1	Plot with plants	Post- growing	30	0.34
11/6/19	Plot 1	Barren plot	Post- growing	60	1.17
11/6/19	Plot 1	Barren plot	Post- growing	30	0.22
11/9/19	Plot 1	Barren plot	Post- growing	30	0.37
11/12/19	Plot 1	Barren plot	Post- growing	60	1.37
11/14/19	Plot 1	Barren plot	Post- growing	30	1.16
11/16/19	Plot 2	Plot with plants	Post- growing	30	0.32
11/16/19	Plot 1	Barren plot	Post- growing	30	0.26
11/16/19	Plot 1	Barren plot	Post- growing	30	1.03
11/20/19	Plot 1	Barren plot	Post- growing	60	1.22
11/27/19	Plot 1	Barren plot	Post- growing	30	1.34
11/30/19	Plot 1	Barren plot	Post- growing	30	1.23
11/30/19	Plot 2	Barren plot	Post- growing	30	1.41
11/30/19	Plot 2	Barren plot	Post- growing	60	1.37
11/30/19	Plot 1	Barren plot	Post- growing	30	1.25

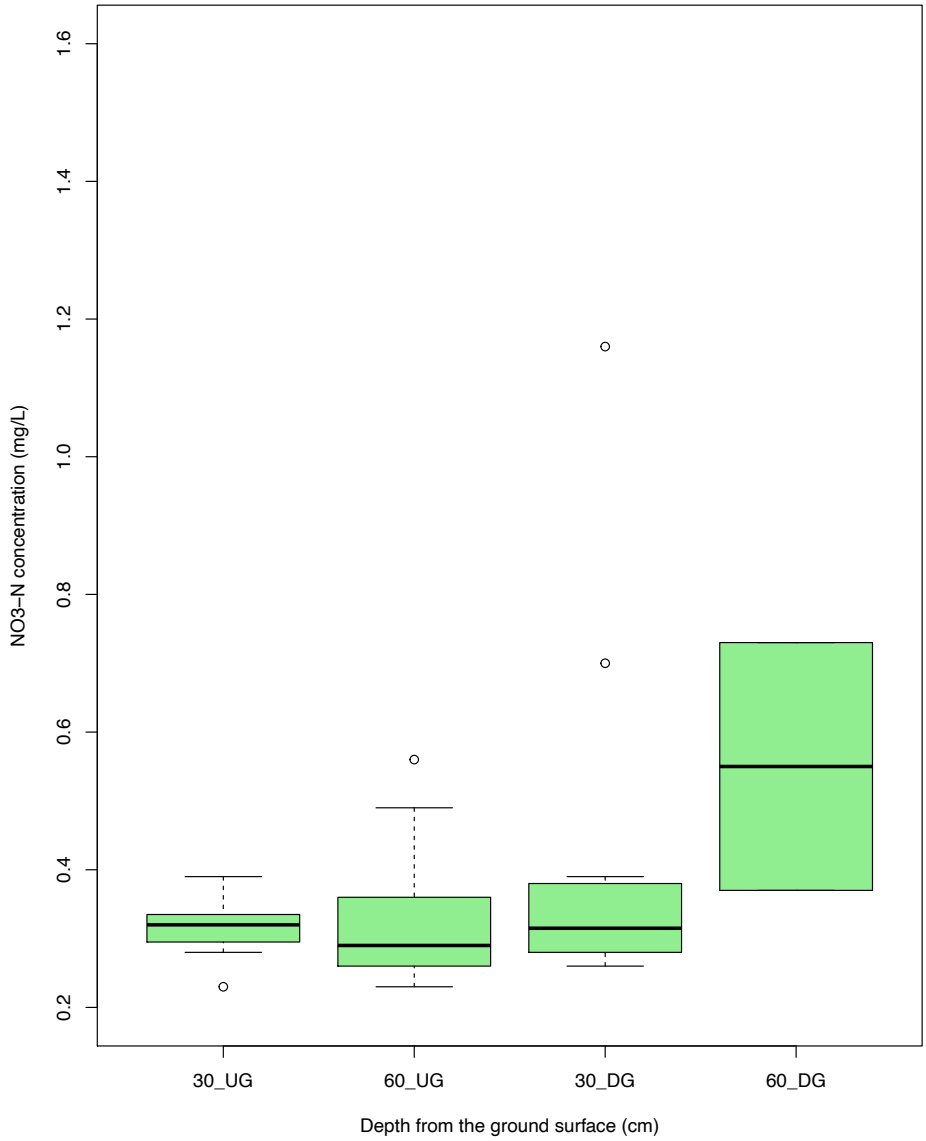


Figure B-1. NO_3^--N concentration in the vadose waters collected from lysimeters upgradient (UG) and downgradient (DG) as a whole at 30 cm and 60 cm depths for the plots with plants (green). The ends of the boxes represent the 25th and 75th percentiles with the solid line at the median (50th percentiles); the error bars depict the 10th and 90th percentiles; the circles depict the outliers.

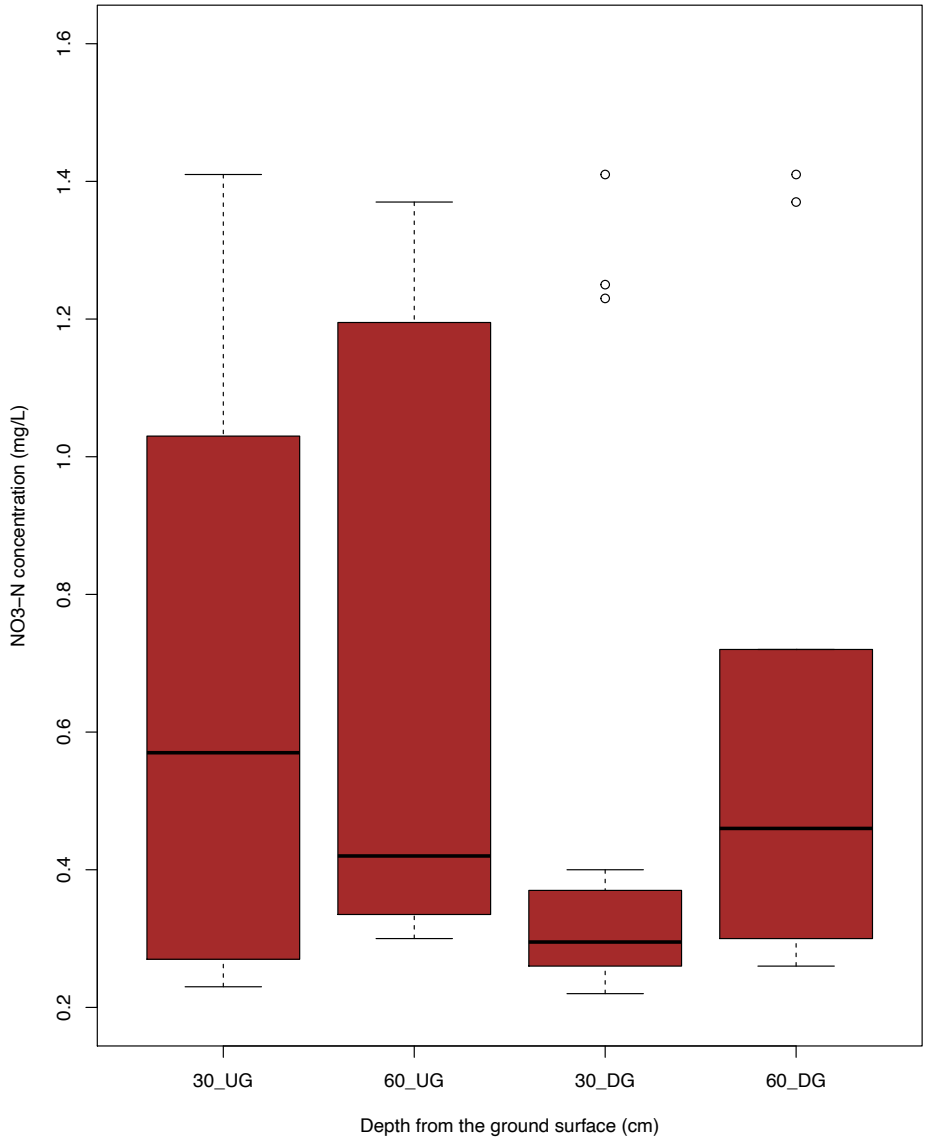


Figure B-2. NO_3^--N concentration in the vadose waters collected from lysimeters upgradient (UG) and downgradient (DG) as a whole at 30 cm and 60 cm depths for the barren plots (red). The ends of the boxes represent the 25th and 75th percentiles with the solid line at the median (50th percentiles); the error bars depict the 10th and 90th percentiles; the circles depict the outliers.

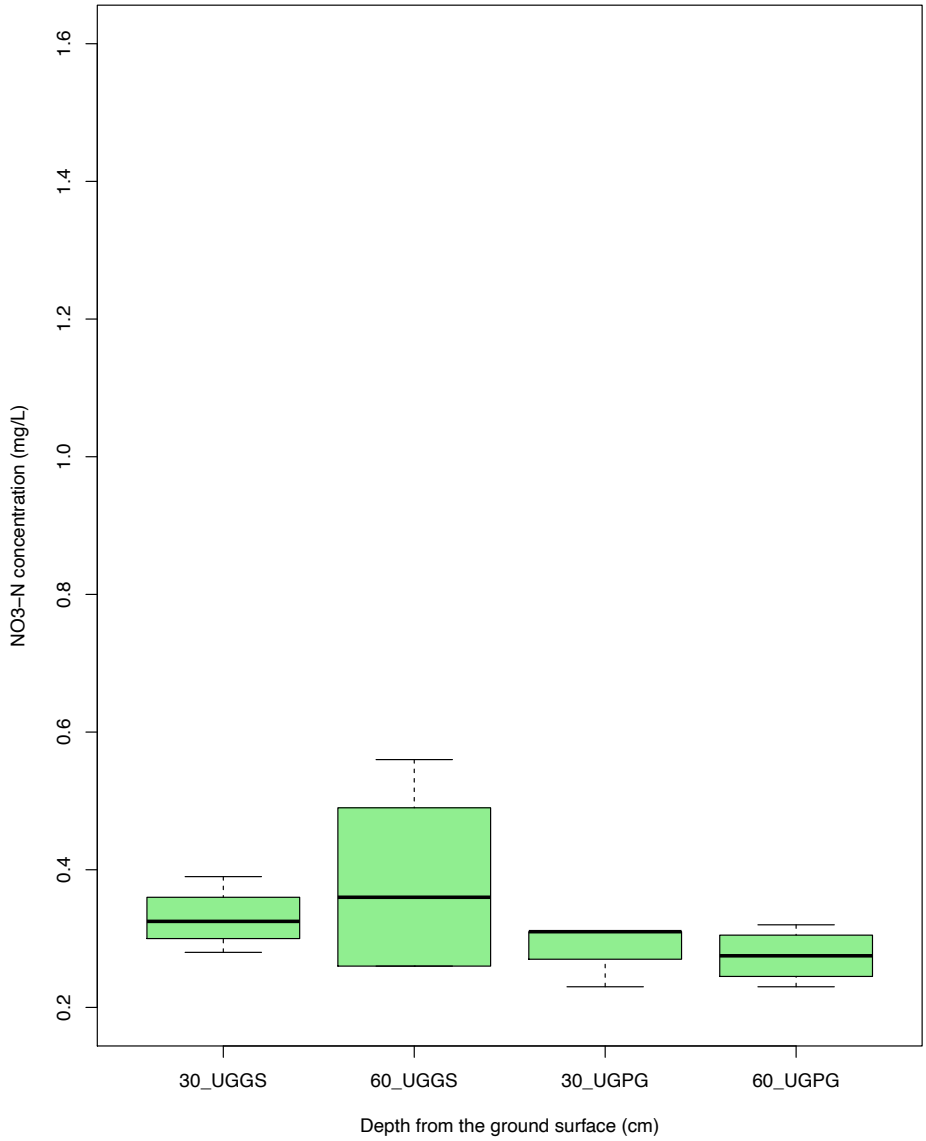


Figure B-3. NO_3^--N concentration in the vadose waters collected from lysimeters upgradient (UG) at 30 cm and 60 cm depths for the plots with plants (green) during growing season (GS) and post- growing season (PG). The ends of the boxes represent the 25th and 75th percentiles with the solid line at the median (50th percentiles); the error bars depict the 10th and 90th percentiles.

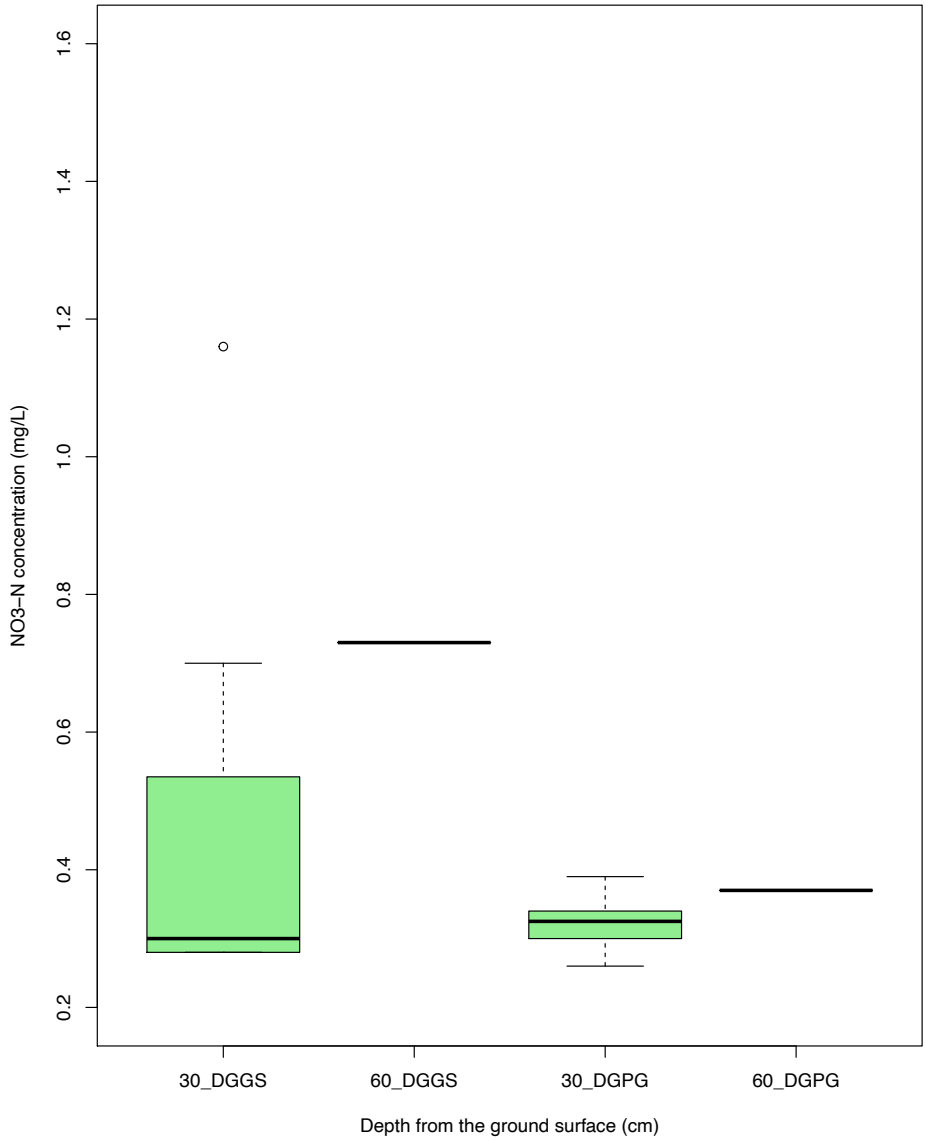
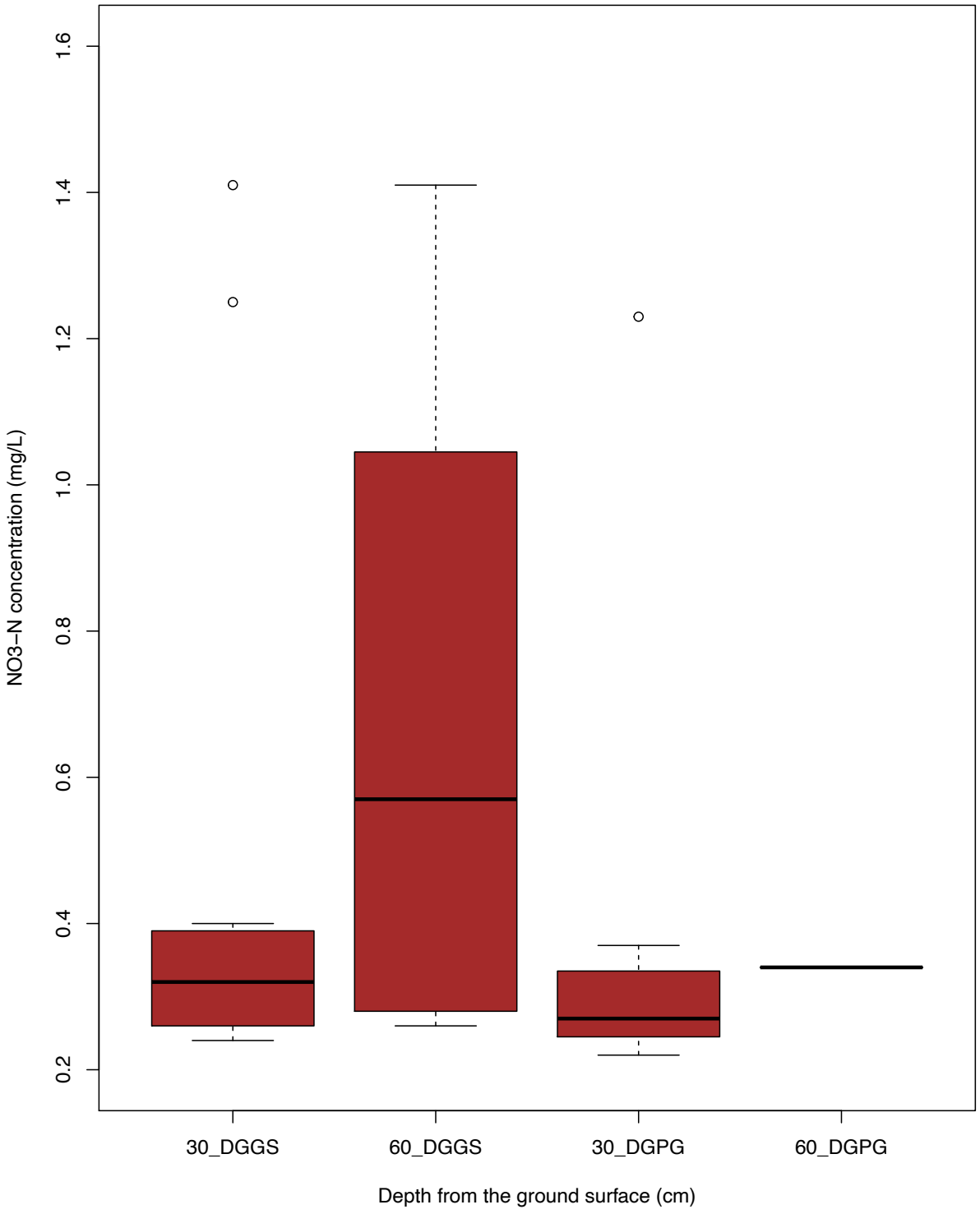


Figure B-4. NO_3^--N concentration in the vadose waters collected from lysimeters downgradient (DG) at 30 cm and 60 cm depths for the plots with plants (green) during growing season (GS) and post- growing season (PG). The ends of the boxes represent the 25th and 75th percentiles with the solid line at the median (50th percentiles); the error bars depict the 10th and 90th percentiles; the circle depict the outlier.



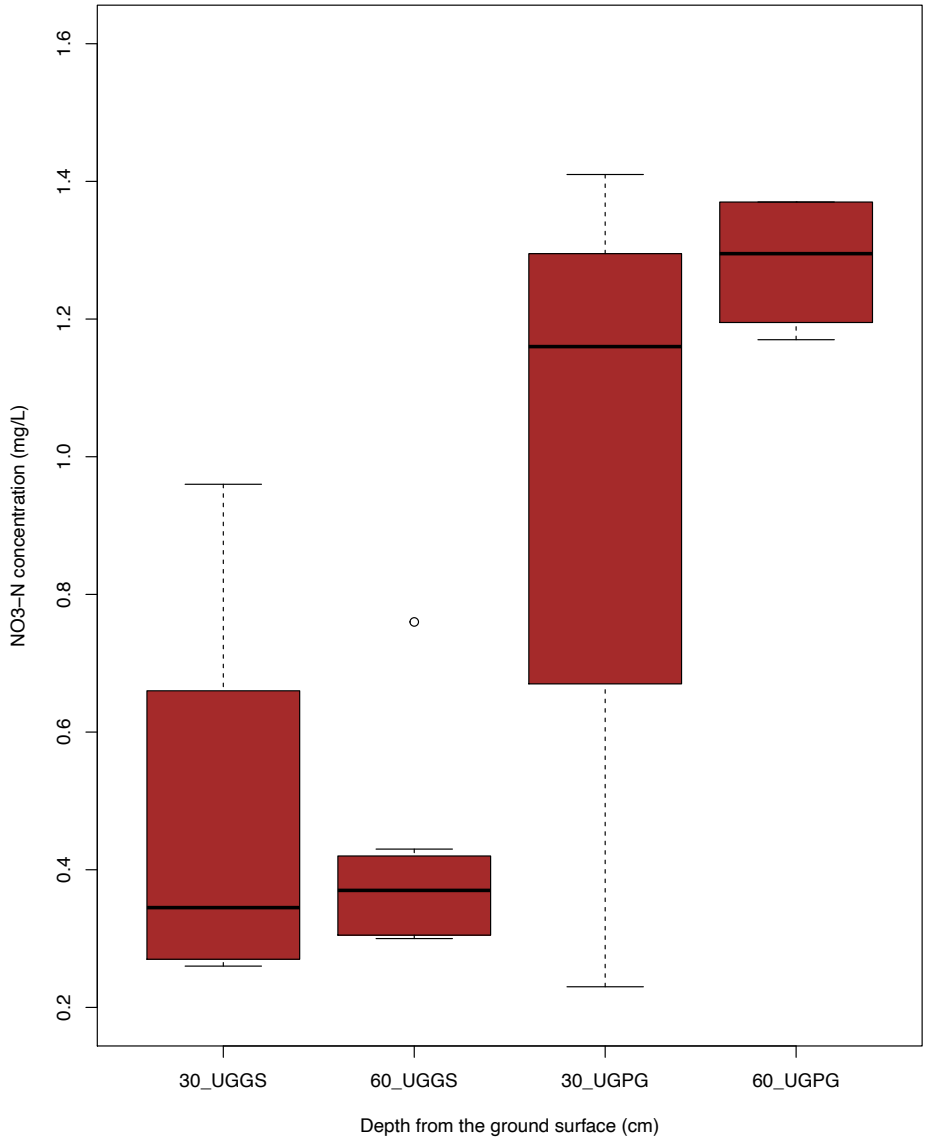


Figure B-5. NO_3^--N concentration in the vadose waters collected from lysimeters upgradient (UG) at 30 cm and 60 cm depths for the barren plots (red) during growing season (GS) and post-growing season (PG). The ends of the boxes represent the 25th and 75th percentiles with the solid line at the median (50th percentiles); the error bars depict the 10th and 90th percentiles; the circle depict the outlier.

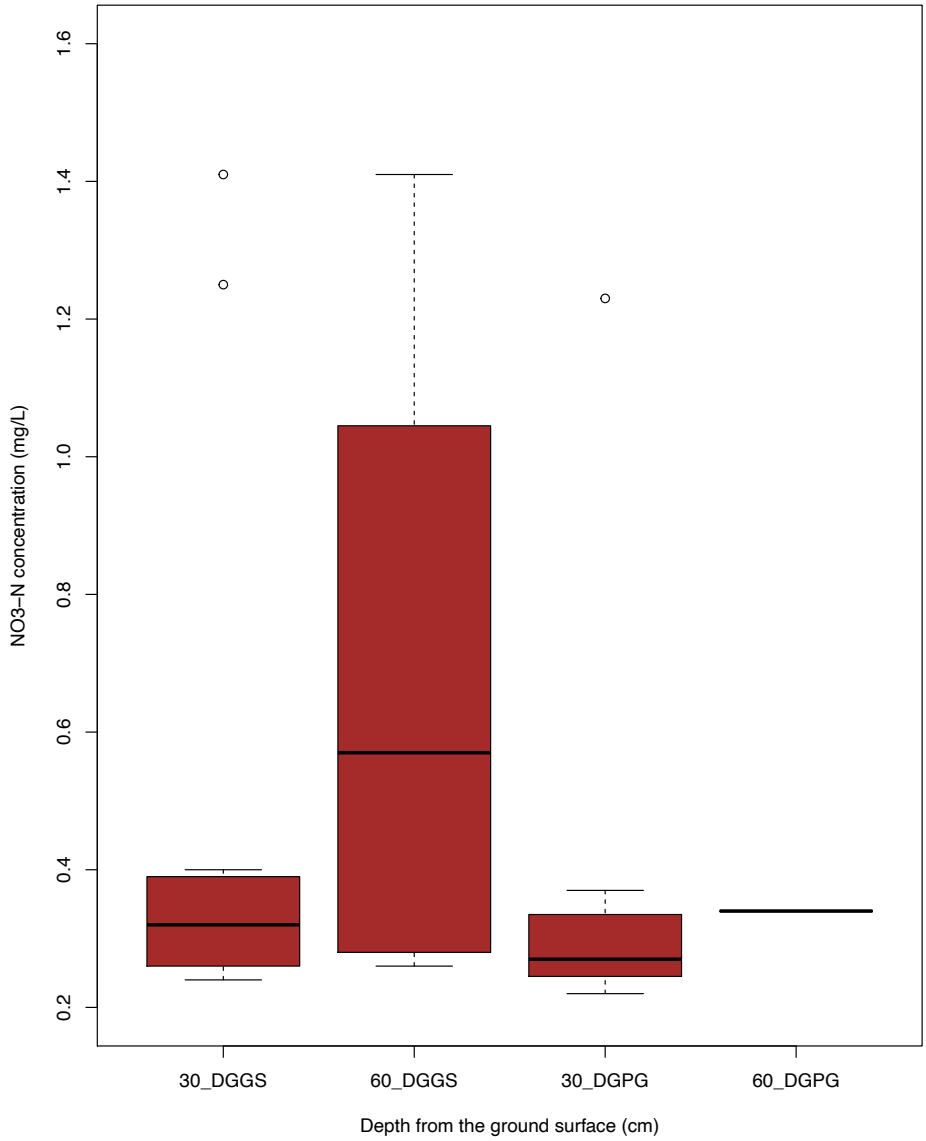


Figure B-6. NO_3^--N concentration in the vadose waters collected from lysimeters downgradient (DG) at 30 cm and 60 cm depths for the barren plots (red) during growing season (GS) and post-growing season (PG). The ends of the boxes represent the 25th and 75th percentiles with the solid line at the median (50th percentiles); the error bars depict the 10th and 90th percentiles; the circles depict the outliers.

APPENDIX C: BIOMASS DATA

Table C

Biomass data of plants collected from the plot with plants

Season	Sample ID	Wet weight (gm^{-2})	Dry weight (gm^{-2})
Peak of	1A	572.25	260.62
growing	1B	669.22	302.37
(August)	1C	537.13	232.78
Post-	2A	397.34	219.92
growing	2B	199.13	111.40
(October)	2C	393.88	201.56

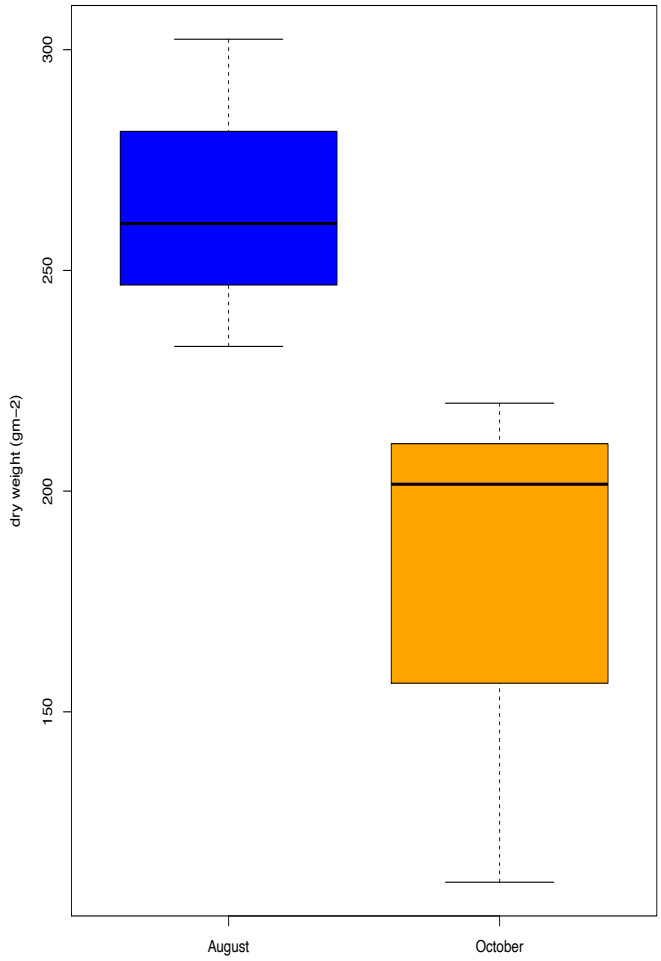


Figure C-1. Biomass of plants collected from the plot with plants as grams per squared meter during the peak of the growing season (blue) and post- growing season (yellow). The ends of the boxes represent the 25th and 75th percentiles with the solid line at the median (50th percentiles); the error bars depict the 10th and 90th percentiles; the circles depict the outliers.