EVALUATION OF THREE PLANT SPECIES FOR STORMWATER TREATMENT IN BIORETENTION BASINS

By

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ABSTRACT

EVALUATION OF THREE PLANT SPECIES FOR STORMWATER TREATMENT IN BIORETENTION BASINS

Stormwater frequently contains contaminants that pollute ground and surface waters. As water becomes an increasingly scarce commodity, groundwater recharge and preventing water pollution has been identified as a key aspect of sustainability. Recent research shows bioretention basins as an effective management practice to reduce pollutants of concern in stormwater including total suspended solids, oil and grease, heavy metals, pathogenic bacteria, and some forms of nutrients.

This study evaluates three different plant species for use in bioretention basins. Two native wetland species, *Carex comosa* and *Iris virginica* and one non native plant species, *Poa pratensis* were tested to evaluate stormwater treatment in bioretention basins. Five replicates of each species were planted in columns to simulate a bioretention and treated with synthetic stormwater. Stormwater leached from the columns was evaluated for nitrate, ammonia, total nitrogen, orthophosphate, and total phosphorus. It was determined that vegetation species is a significant predictor in determining nutrient treatment efficiency, plant tissue content and nitrate and phosphorus concentrations in the first 15.24 centimeters (six inches). Typically *Carex comosa* and *Iris virginica* vegetation tested showed a superior level of treatment with *Carex comosa* reducing nitrate nitrogen 96.3 percent and total phosphorus 83.7 percent over an unplanted Control. With the exception of phosphorus, vegetation species was not a significant indicator in the nutrient concentration of the bioretention soil mixture (depth 15 to 45 centimeters).

DEDICATION

I would like to dedicate this work to those who have shown
continued love and support throughout this process:
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Patricia
Trisha
Ashley
and Sawyer

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KEY TO SYMBOLS OR ABBREVIATIONS

Adj	adjusted
AL_PTN	Plant Tissue Aluminum
AL_G_PTN	Plant Tissue Aluminum (grams)
Ana	analyte
BMPs	Best Management Practices
B_PTN	Plant Tissue Boron
B_G_PTN	Plant Tissue Boron (grams)
CC	Carex comosa
Cd	Cadmium
cm	centimeter
cm^3/d	centimeters cubed per day
conf	confidence
Cu	copper
CU_PTN	Plant Tissue Copper
CU_G_PTN	Plant Tissue Copper (grams)
DI	deionized water
DW	dry weight
FE_PTN	Plant Tissue Iron
FE_G_PTN	Plant Tissue Iron (grams)
g	gram
GAC	Granular Activated Carbon
I	Iris virginica

in	inch
K_PTN	Plant Tissue Potassium
K_G_PTN	Plant Tissue Potassium (grams)
L	liter
LBray_P_B_PPM	Log Phosphorus Bioretention Soil (ppm)
LBray_P_T_PPM	Log Phosphorus Potting Soil (ppm)
LID	Low Impact Development
LTN_B_PPM	Log Total Nitrogen Bioretention Soil (ppm)
LTN_T_PPM	Log Total Nitrogen Potting Soil (ppm)
LTNH4_B_PPM	Log Ammonia Bioretention Soil (ppm)
LTNH4_T_PPM	Log Ammonia Potting Soil (ppm)
LNO3_mg_L	Log Nitrate Leached (mg)
LPO4_mg_L	Log Orthophosphate Leached (mg)
LSW_V_U_D	Log Stormwater Volume Utilized Daily
LTN_mg_L	Log Total Nitrogen Leached (mg)
LTNO3_B_PPM	Log Nitrate Bioretention Soil (ppm)
LTNO3_T_PPM	Log Nitrate Potting Soil (ppm)
LTP_mg_L	Log Total Phosphorus Leached (mg)
MDL	Method Detection Limit
mg	milligram
mg L	milligrams leached
MIVQU10	minimum variance quadratic unbiased estimation of the covariance parameters

mL	milliliter
ML	maximum likelihood
mmol	millimole
MN_PTN	Plant Tissue Manganese
MN_G_PTN	Plant Tissue Manganese (grams)
N_PTN	Plant Tissue Nitrogen
N_G_PTN	Plant Tissue Nitrogen (grams)
n.a.	not applicable
ND	non detect
NH4_mg_L	Ammonia leached (mg)
NT	New Poa pratensis
OT	Old Poa pratensis
P	phosphorus
P_PTN	Plant Tissue Phosphorus
P_G_PTN	Plant Tissue Phosphorus (grams)
Pb	lead
ppb	parts per billion (ug/L)
ppm	parts per million (mg/L)
psi	pounds per square inch
R^2	model fit
REML	residual maximum likelihood
Species_Ref	Species
st dev	standard deviation

SW_Ref	Stornwater Dosed
TN	total nitrogen
TP	total phosphorus
ug	microgram
VIF	variance inflation factor
Zc	zinc
ZN_PTN	Plant Tissue Zinc
ZN_G_PTN	Plant Tissue Zinc (grams)

CHAPTER ONE: INTRODUCTION

Stormwater runoff frequently contains contaminants that pollute ground and surface waters. These contaminants can include oil, pathogens, metals, organic nutrients, phosphorous and nitrogen [4-7]. As water becomes an increasingly scarce commodity, preventing water pollution and promoting groundwater recharge have been identified as key aspects of sustainability. Consequently, the USEPA has begun to impose regulations on stormwater quality, which demand that stormwater treatment devices are implemented. Stormwater treatment devices include dry extended detention basins, bioretention basins, constructed wetlands, infiltration trenches, wet/retention basins and sand filtration [8]. These technologies promote infiltration of stormwater for groundwater recharge as well as primary treatment of stormwater runoff.

Initial treatment of stormwater before it reaches bodies of water is one way to improve water quality. Multiple Best Management Practices (BMPs) have been identified to treat stormwater runoff. BMPs typically reduce the volume of stormwater or slow down its progress in urban areas to treat stormwater. This increases groundwater recharge, while decreasing pollution or reducing the demand on wastewater treatment plants [4, 9]. Brown and Hunt explains that bioretention basins address several key stormwater design criteria: hydrologic, water quality and aesthetic [10].

Bioretention basins reduce runoff volumes by retaining or pooling stormwater. Plants in the basin promote evapotranspiration of the water, while water is also filtered into the soil, improving water quality [4, 11][4][11]. Furthermore, bioretention basins treat runoff pollutants using adsorption, biological decomposition, filtration and sedimentation [12].

Although bioretention basins are a sustainable approach to urban stormwater management, design and maintenance relationships are still being investigated. Implementation of this technology will increase with additional research and development [2]. Numerous low impact development (LID) manuals have been developed detailing design, construction and uses of bioretention basins to facilitate adoption as a stormwater treatment technology. However, many of the design documentation is not based on sound research or scientific documentation [2]. Davis (2009) prioritized the following research topics to provide significant design tools for effective implementation of bioretention basins:

Fill media composition;

Fill media depth and configuration;

Drainage configuration;

Basin geometry;

Maximum bowl ponding depths;

Vegetation selection;

Maintenance recommendations and their relationship to pretreatment; and

Determining costs and benefits of alternative bioretention designs.

The Michigan LID manual provides recommendations on basin geometry, maximum bowl ponding depths, soil media mixture as well as native planting materials. Design recommendations were developed based on general stormwater management publications. The lack of specific technical guidance for Michigan is gradually becoming more available. In 2010 Carpenter published a study evaluating the bioretention soil mixture recommendation in the Michigan LID [3]. Research conducted in Australia by Read in 2008 evaluated twenty different vegetation species for pollutant removal in bioretention basins for stormwater treatment [13].

This study was developed to evaluate vegetation recommendations in the Michigan LID manual for treatment of stormwater in bioretention basins. The objective is to provide qualitative design data on vegetation selection in Michigan for stormwater treatment in bioretention basins by determining if stormwater treatment is influenced by vegetation selection. Improved understanding of vegetation selection will provide significant design tools to advance the efficiency and implementation of bioretention basins to treat stormwater in Michigan.

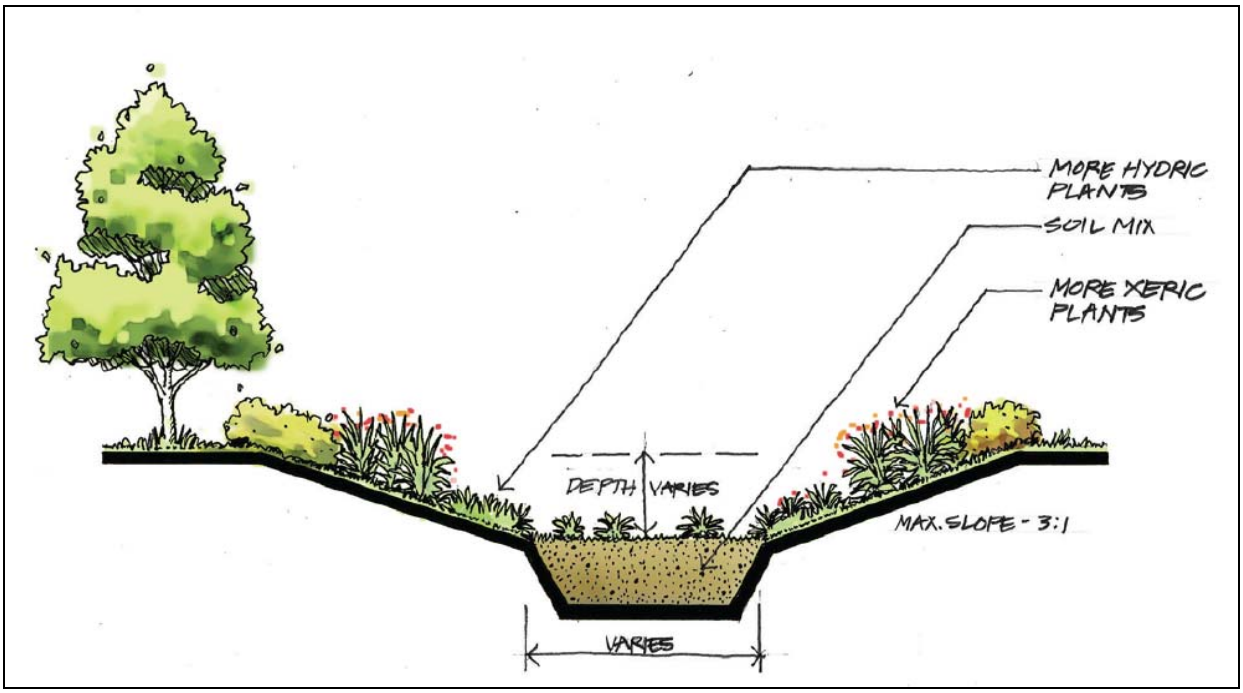
CHAPTER TWO: LITERATURE REVIEW

This section evaluates existing literature to maximize treatment of stormwater using bioretention basins. Recommendation guidelines describing bioretention basin use in the United States are abundant; however, the information presented in these documents is not often verified through scientific evaluation [2]. Broad statements regarding construction, types of plants and soils to use, treatment efficiencies and hydraulic performance have been made, and not all have been justified. Specific design parameters should be fully understood to improve future design of bioretention basins.

Bioretention Basin Background

Using bioretention basins to treat stormwater has been a key component to low impact development since the late 1990's. Bioretention basins are designed to treat runoff from urban areas prior to discharge into the environment. The available runoff area for treatment depends on bioretention soil infiltration properties, assuming a draw down of 24 to 48 hours. The Michigan LID manual suggests a maximum runoff area ratio of 5 to bioretention area of 1 with the runoff area not to exceed 1 acre. Bioretention basins are designed to pond water at a depth of 15 to 45 centimeters (6 to 18 inches) for infiltration over 48 hours. Vegetation is planted in and around the bioretention basins to uptake nutrients, improve infiltration, and develop appealing aesthetics of the bioretention basin. A typical rain garden schematic is shown below in Figure 2.1 and Figure 2.2.

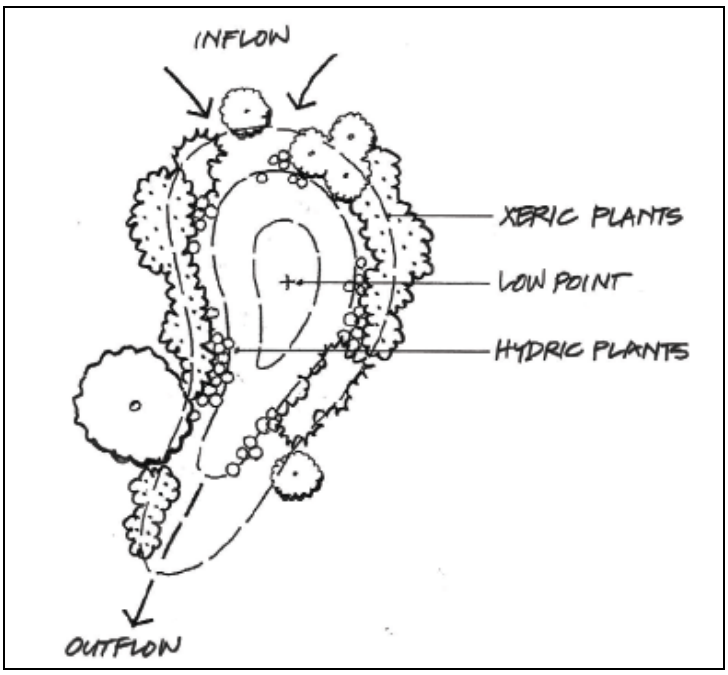
FIGURE 2.1. SCHEMATIC OF A TYPICAL BIORETENTION BASIN (PROFILE)



buildgreen.ufl.edu/Fact_sheet_Bioretention_Basins_Rain_Gardens.pdf

For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.

FIGURE 2.2. SCHEMATIC OF A TYPICAL BIORETENTION BASIN (PLAN)



buildgreen.ufl.edu/Fact_sheet_Bioretention_Basins_Rain_Gardens.pdf

Recent research shows bioretention basins are effective management tools that reduce most pollutants of concern in stormwater including total suspended solids, oil and grease, heavy metals, pathogenic bacteria, and some forms of nutrients[1]. Reported nutrient removal efficiencies are varied, specifically for nitrogen and phosphorus. Bioretention basins are limited in their effectiveness to treat nitrate nitrogen as it is soluble and will move downward as stormwater is filtered through the basin[14]. Phosphorus removal appears to be closely related to the type of media used in construction [15]. However, reported nitrogen removal rates from bioretention basins suggest that they are more effective at removing nitrogen than traditional stormwater BMPs [16]. The International Stormwater Best Management Practices Database (2008) reports mean total nitrogen concentrations of 1.4 and 2.1 mg/L for wet and dry ponds and 0.8 mg/L for bioretention ponds. Heavy metal treatment has been shown to be very effective and closely related to the type of media used in bioretention basins [12, 17, 18]. Most case studies

indicate that bioretention basins will achieve effective runoff retention and water quality treatment [19].

Vegetation

Vegetation used in bioretention basins is varied based the geographic location, land use functions and aesthetics. The Low Impact Development Center guidance documents suggest native plants are more effective than traditional landscaping plants including turf. Native plants are considered to be more tolerant of the climatic conditions, including wet and dry cycles than non native plants. The Michigan LID suggests native floodplain or wet meadow plant species including Cardinal Flower (*Lobelia cardinalis*), Blue Lobelia (*Lobellia siphilitica*), New England Aster (*Aster novae-angliae*) and Brown Fox Sedge (*Carex vulpinoidea*). Information on native vs. non native species selection can be important in assisting designers in vegetation species selection. Recent research conducted in Australia suggests that plant selection will significantly influence the effectiveness of nutrient removal efficiencies in bioretention basins [20]. Data on viability, reproduction and pest vulnerability of selected vegetation is also needed.

Species Selection

A recent study conducted in Melbourne, Australia demonstrated that two species, Carex apressa and Melaleuca ericiflolia were more effective at nitrogen removal [18]. Another study conducted by Read with Australian vegetation species showed significant variation in pollutant removal of nutrients per root mass, specifically in relation to nitrate and ammonia forms of nitrogen [13]. Plant traits including length of root, root diameter and mass have been shown to be effective in correlating N and P removal in stormwater [20, 21]. This information strongly suggests that species of plants with large root masses with thicker diameter roots and root hairs

are more effective at removing nitrogen and phosphorus in stormwater runoff in bioretention basins.

Native vs. Non Native

Vegetation species selection for use in bioretention basins is loosely related to research data. The majority of LID literature recommends the use of native vegetation in bioretention basins for stormwater treatment under the assumption that native plants will perform more efficiently based on their ability to thrive in the local ecosystem. Infiltration rates and soluble nutrient uptake have been tied to an increased in rooting depth [22]. However, the underlying assumption in these arguments is that native vegetation has a greater rooting depth than non native vegetation. Read conducted a study on native plants in Australia that supports increase nutrient uptake by native vegetation. However, a field study in North Carolina showed that nutrient removal of grass biofilters of Burmuda sod were as effective as bioretention basins planted with native vegetation [23]. Current research evaluating native and non native vegetation for stormwater treatment in bioretention basins for the state of Michigan is currently limited.

Hyperaccumulators

Hyperaccumulators are plants that demonstrate the ability to absorb contaminants in water, soil or both water and soil [24]. Information on heavy metal uptake is fairly substantial for phytoremediation of contaminated mining sites [25-27]. Information for bioretention basins on nutrient utilization (specifically nitrogen and phosphorus), heavy metals, and oil and grease from vegetation typically used in bioretention is unavailable at this time [2]. Vegetation selection for bioretention could be assumed from the abundance of vegetation data for waste treatment of contaminated soils. However, this could be a fatal flaw in design of bioretention basins because

plant species may not adapt well to bioretention basins and the wet/dry cycles or specific climatic conditions.

Bioretention Soil Media

Information on soil media used for bioretention cells is varied. Carpenter conducted a national review of bioretention design standards and reported that most regulatory agencies recommend a specific mix of sand (30 to 60 percent), compost (20-40 percent) and topsoil (20-30 percent) [3]. The LID Manual for Michigan suggests a composition of 20 to 30 percent compost; 20 to 30 percent top soil with a clay content of less than 12 percent; and 50 percent clean sand. Soil media in bioretention basins should be designed to maximize treatment efficiencies. It is important that the soil mix meet the needs of the selected vegetation and treat the pollutant of concern [2]. Recent research conducted by Carpenter evaluated two full scale bioretention basins using a soil mix of 20:30:50 compost, topsoil sand mix and 80:20 sand to topsoil mix [3]. He concluded that the 20:80 soil mixture exhibited better treatment efficiencies for large storm events for all pollutants of concern. However, the 80:20 soil mix experienced short circuiting that minimized treatment during smaller storm events that did not completely flood the bioretention cell[3].

Engineering Bioretention Soil Media to Increase Treatment

Significant amount of research has been conducted in the last two years aimed at supplying design recommendations to treat specific stormwater contaminants with soil media. Phosphorus removal has been considerably increased using granular activated carbon (GAC), limestone, iron humate and other fillers[28-30]. Phosphorus removal has been shown to be directly correlated to the amount of calcium and calcium oxides in the soil mixture [31].

Lucas completed a study in 2008 that evaluated different soil mixture types for bioretention treatment of total nitrogen and total phosphorus. Results for total nitrogen ranged from 18 percent to 51 percent in non-vegetated loam and gravel and 14, 33 and 56 percent from non-vegetated gravel, sand and loam for total phosphorus [32].

Blecken evaluated modifying the soil mixture to include an organic carbon source and flooded zone to enhance heavy metal removal [17]. The laboratory study determined that saturated zones and a cellulose carbon increased metal treatment.

Soil Infiltration and Ponding

Bioretention basin design standards typically suggest 15 to 45 centimeters (6 to 12 inches) for ponding depth and between 24 to 72 hour detention times [3]. These design standards have not been associated with improved efficiencies of pollutants of concern. Research conducted in Australia by Hatt evaluated the clogging potential of biofilter soil media [33]. Their laboratory findings indicate that the first five to 13 centimeters (two to five inches) of soil are the most effective at removing suspended solids and particulate pollutants. However, this upper section of the soil profile may become clogged and ineffective with time. Hatt suggested removing the first five to 13 centimeters (two to five inches) of soil every year and replacing it with clean media.

Producing wet and dry areas in the bioretention basin with a regulated outlet has shown to increase heavy metal treatment efficiencies as well as produce microclimates to enhance denitrification [17, 34].

Hydrologic Impacts

Low impact development (LID) management practices are emphasized in urban construction to minimize hydrologic impacts. Recommendations for siting and sizing

bioretention basins are readily available based on existing hydrologic engineering experience. However, treatment efficiencies of bioretention basins related to ponding volume and retention time in relation to vegetation species and soil media is not available [2].

Flood and Flow Duration Control

The hydrologic performance of two bioretention cells was tested by Davis et al. The bioretention cells averaged 49 percent and 58 percent reduction in peak flows for each cell [9]. Bioretention basins are designed to capture stormwater flows and slowly release the water, imitating undeveloped land behavior and reducing peak flows. The monitoring during this study revealed that flow peak reductions were, on average, reduced by a factor of two. Sansalone and Teng (2004 and 2005) had previously determined that bioretention basins achieve optimum performance for small storm events [35, 36]. Typically less than 1/4 of the input volume flowed out of the cells within 24 hours of the start of a storm, demonstrating that bioretention basins effectively manage stormwater to prevent flooding.

In a field study of three bioretention sites in North Carolina it was observed that the outflow to runoff ratio is higher during winter seasons, compared to spring, summer or fall. The difference in ratio suggests that the plants are likely using less water during winter months, potentially decreasing the three basins' performance [4].

Treatment Pathways

Bioretention basins treat stormwater through many pathways. Total suspended solids and particulates are trapped in the vegetated biomass and filtered through the soil profile. Soluble nutrients, including nitrogen and phosphorus, are utilized by plants and microbial population for growth. Heavy metals and other contaminants can be sorbed onto or interact with the soil media.

This section looks at the relevant literature on treatment pathways associated with bioretention basins.

Soil Treatment

Bioretention basins physically treat stormwater through filtration and sorption onto the soil particles. Depending on vegetation, soil media also provides an environment for soil microbes mostly around the rhizosphere [37, 38]. The soil microbial population can also provide treatment [39]. Total suspended solids and particulates are trapped and filtered through the soil profile during stormwater events. Soluble nutrients, including nitrogen and phosphorus, can be sorbed or precipitated onto soil particles based on the bioretention soil mix media. Davis completed a comprehensive analysis on technical information related to bioretention soil mix media and reported that bioretention basins performed similarly in treatment of particulates, metals, phosphorus and oil and grease regardless of the soil matrix mix [2]. These results indicate that soil media mixture will not alter treatment efficiencies for contaminants that are removed through filtration. Treatment effectiveness of heavy metals and nutrients, specifically dissolved phosphorus and nitrate nitrogen species, were closely related to the soil mix used in the bioretention basin [12, 40], supporting that treatment pathways for these contaminants do not rely on filtration through the soil media mix but on other treatment pathways (phytoremediation, soil sorption, precipitation, or microbial treatment).

Soil Filtration

Soil filtration has been shown to be effective in removing total suspended solids (> 96 percent), particulates, and oil and grease (>96 percent) [40]. Increase removal of soluble nutrients including nitrate nitrogen and dissolved phosphorus can be achieved through modifying the soil profile. Modifications can include the addition of saturated zones or increasing the clay

content or additional sorption media. The addition of a saturated zone has been shown to significantly decrease nitrate concentrations as well as heavy metal concentrations [17, 34]. Contaminants will also be sorbed or precipitate with the addition of clay or other material (lime, seashells, etc.) as previously discussed. However, modifications of the soil media to increase nutrient removal efficiencies can often decrease the infiltration rate of the bioretention basin. A decrease in the infiltration rate may not be desirable, reducing treatment time and allowing for anaerobic conditions.

Soil Sorption

Soil sorption of contaminants occurs when chemical compounds are sorbed onto the soil surface and become part of the soil matrix. The chemicals can be held tightly on the soil particle or may change form and be released dependent on pH, temperature or the chemical gradient in the soil solution. Sorption in soil is an equilibrium process that will change based on the physical environment. Ballantine reported that wetland phosphorus removal is increased by adding material to the soil matrix that will adsorb phosphorus [15]. Limestone, slag, seashells, shell-sand and tree bark were identified as appropriate filter materials to add to the soil media to remove phosphorus in a wetland. Additional research has been conducted specific to bioretention soil mixes modified with GAC, limestone, iron humate, red mud, etc [28-31, 41]. All soil amendments were chosen for their ability to sorb phosphorus and therefore increased phosphorus sorption. Design of bioretention basins in watersheds where phosphorus is a pollutant of concern should consider addition of soil amendments to increase phosphorus reduction in bioretention basins.

Soil Microbial Immobilization

Soil microbial populations are capable of utilizing and immobilizing stormwater contaminants in bioretention basins. Ammonia can be used as an electron donor to form nitrate, nitrate can be used as an electron donor (in the absence of oxygen) to form nitrogen gas, etc. However, evidence of treatment through soil microbial immobilization in bioretention basins has not been adequately studied. Lucas and Greenway completed a laboratory study that showed soil columns with vegetation performed better treating total nitrogen and total phosphorus than soil columns devoid of vegetation. Nutrient reduction was greater than nutrient uptake for both nitrogen and phosphorus suggesting other treatment processes are being utilized in bioretention basins [32]. While these processes can be attributed to vegetation treatment pathways, there is a significant relationship between microbial populations and the rhizosphere that also contributes to treatment.

Phytoremediation

Phytoremediation processes occurring in bioretention basins are complex due to the numerous interactions between phytoremediation and other physical, chemical, and biological processes. Treatment pathways include the plant utilization, stabilization, destruction (mass removal) and transfer of contaminants and provision of an environment for microorganisms to complete the same actions. Phytoremediation mechanisms are identified in Table 2.1 as described in the Phytotechnology Technical and Regulatory Guidance [42].

TABLE 2.1 SUMMARY OF PHYTOTECHNOLOGY MECHANISMS [42]

Mechanism	Description	Remediation Method
Phytosequestration	The ability of plants to sequester certain contaminants in the rhizosphere through exudation of photochemical and on the root through transport proteins and cellular processes	Containment
Rhizodegradation	Exuded phytochemicals can enhance microbial biodegradation of contaminants in the rhizosphere	Remediation by destruction
Phytohydraulics	The ability of plants to capture and evaporate water off the plant and take up and transpire water through the plant	Containment by controlling hydrology
Phytoextraction	The ability of plants to take up contaminants into the plant with the transpiration stream	Remediation by removal of plants
Phytodegradation	The ability of plants to take up and break down contaminants in the transpiration stream through internal enzymatic activity and photosynthetic oxidation/reduction	Remediation by destruction
Phytovolatilization	The ability of plants to take up, translocate, and subsequently transpire volatile contaminants in the transpiration stream	Remediation by removal through plants

Phytoextraction and phytosequestration are the two main phytoremediation mechanisms utilized in bioretention basins to treat phosphorus and metals.

Plant Utilization

Vegetation will utilize available nutrient contaminants (nitrogen and phosphorus) in storm water runoff for plant growth. Other contaminants may also be metabolized into different forms and stored in the plant tissue (phytometabolism) or released through the leaves (phytovolatilization).

Phosphorus uptake in plants has been linked to root mass and growth in many studies [43]. The quantity of root hairs found on the plants rooting system can significantly extend the surface area available for phosphorus uptake [44]. Phosphorus in the soil mixture is transported to roots through diffusion. Therefore, plant root systems including the size and number of fine root hairs and large root mass will affect the plants ability to obtain phosphorus [45]. Rooting

system differences in vegetation will affect the ability of the plant to uptake phosphorus [46]. In addition, temperature plays an important role in plant root growth [47] as warmer temperatures were shown to increase root growth. A recent study conducted on 35 wetland plants determined that total phosphorus removal was greater for thick root plants (those with roots greater than 1 mm) when compared to fibrous rooted plants [21]. Studies on agronomic species have also indicated that certain species can accumulate high concentrations of phosphorus in their plant tissues. Sharma conducted laboratory research to evaluate legume, vegetable and herb crops for increased phosphorus uptake. He reported that sunflowers, cucumber and yellow squash accumulated phosphorus in their shoots with cucumber and yellow squash reporting over 1 percent of total phosphorus [24].

Plant Assimilation

Plant assimilation is another treatment pathway that is utilized in phytoremediation. Contaminants are taken up with water and stored in plant tissues (phytoextraction). Evidence of stormwater contaminant treatment through plant assimilation in bioretention cells has not been adequately studied. However, one can assume that plant assimilation of stormwater contaminants reported through traditional phytoremediation would be applicable to bioretention technology. Mercury and methyl mercury have been shown to preferentially assimilate in roots of *E. crassipes* (water hyacinth) [48], while jack bean showed increased uptake of copper in roots, including transferring into the shoots [49].

Plant Immobilization

Plant immobilization (phytosequestration) occurs when chemical compounds released by the plant immobilize contaminants in the bioretention soil media, thereby reducing transfer through the environment. Evidence of stormwater treatment through plant immobilization in

bioretention basins has not been adequately studied. However, as with plant assimilation, one can assume that plant immobilization of stormwater contaminants reported through traditional phytoremediation would be applicable to bioretention technology.

Hydraulic Effects on Treatment

Treatment pathways discussed above can be enhanced or minimized based on the hydraulic design of bioretention basins. Concerns with minimum ponding time and maximum infiltration times are typically discussed in LID manuals but not in context with maximizing treatment of pollutants of concern in specific watersheds. Over infiltration can lead to contaminating groundwater and has been noted as a potentially harmful impact of bioretention basins [50-52]. However, bioretention basins have also been shown to clean contaminated groundwater in shallow areas during dry periods [50]. In addition, bioretention basins allow sedimentation to take place, which decreases the threat of groundwater contamination [51, 52].

A key function of bioretention basins is to improve effluent water quality. Urban runoff contaminants include metals, nutrients—phosphorous and nitrogen—bacteria and total suspended solids. This section will discuss reported treatment efficiencies of bioretention basins for nutrients, total suspended solids and metals.

Nutrient Removal

Total nitrogen and total phosphorus load reductions in bioretention basins for laboratory and pilot scale projects were compiled and reported by Davis [2]. Load reductions for total nitrogen are shown to be between 30 and 95 percent [2]. Data on the amount and type of vegetation in the bioretention basins was not evaluated. Blecken reported that cold temperatures influenced the ability of bioretention basins to treat nitrogen runoff. In fact, nitrate nitrogen was actually produced in the columns and leached through the soil profile [53]. Nitrate nitrogen

concentrations increased with an increase in temperature (from 2 to 20° C) but were still observed at 2° C. Lucas determined that there was an increase in nitrate nitrogen retention (up to 50 percent) in bioretention systems constructed with longer retention times during the winter months [54]. Recent research has linked nitrogen treatment efficiencies to plant selection. Read's data indicates that *Carex appressa*, *Juncus anabilis*, and *Juncus flavidus* were more effective in reducing nitrogen concentrations than other plant species tested [20].

Total phosphorus load reductions were varied from a net gain to 99 percent load reduction. Davis formulated a theory that this range was mainly due to the amount of phosphorus in the soil media used in bioretention construction [2]. Data on the type of soil media used in the bioretention basins for each analysis was not evaluated.

Suspended Solids

Treatment efficiencies of total suspended solids in bioretention basins are historically high. The major treatment pathway is through trapping particles as they filter through the vegetation and soil media. Fletch found in a laboratory study that total suspended solids were reduced by 96 percent [55]. Total suspended solid load reductions in bioretention basins for laboratory and pilot scale projects were compiled and reported by Davis [2]. Davis reported that traditional efficiencies are approximately 95 percent with a few results reported around 55 percent mass removal. Stormwater with heavy total suspended solids contamination is prone to block or plug the filter media, requiring routine maintenance including raking and topsoil removal.

Metals

Metals, present on roads from automobile exhaust, wearing of tires and brakes and from salts used for de-icing in winter, are common stormwater pollutants [56]. Removal of metals by

bioretention basins is attributed primarily to sedimentation and filtration [57]. There is a significant correlation between total suspended solid removal and heavy metal removal [2].

Vegetation can also contribute to the removal of dissolved metals in bioretention basins. Plants can immobilize metals in their rhizosphere. For example, arbuscular mycorrhizal plants, including lettuce, immobilized cadmium in the rhizosphere [58]. Introduction of vegetation increases the sorption lifespan of the soil if a rhizosphere can be developed [32]. In addition to immobilization many plants, known as hyperaccumulators, are capable of accumulating high concentrations of metals from soils into their biomass. Eupatorium capillifolium (dog fennel) can accumulate 12.3 – 16.4 mg of Cd per kg of above-ground plant biomass when grown in soils containing 1.9 mg/kg Cd indicating that the metal concentration was 25 times greater in above-ground biomass than in the soil [42]. Accumulation of cadmium by roots of four emergent wetland species varied from 0.6 mg/kg for *Baumea juncea* to 2835 mg/kg for *Juncus subsecundus* [59]. Translocation from roots to shoots also varied, resulting in shoot concentrations ranging 0.1 mg/kg for *S. validus* to 272 mg/kg for *J. subsecudus*. Phytoextraction and hyperaccumulation has also been observed for copper, lead, and zinc [42].

Summary

The use of bioretention basins to treat stormwater runoff has increased in popularity over the last ten years. There is a striking lack of technical performance evaluation used to create many design guides and regulations [2]. Scientifically substantiated information on how to locate, design and maximize effective treatment for site specific pollutants of concern is becoming more available. Recent research indicates that the vegetation used in bioretention basins will have a discernible effect on treatment of nutrients in bioretention basin. Further research is required to provide technical design information for stormwater treatment using

bioretention basins within specific geographic areas. Design objectives need to be fully understood to ensure the sustainability of bioretention basins.

Bioretention basins have been shown to manage stormwater runoff sustainably by using natural processes for treatment. Natural treatment processes typically have a lower carbon footprint than traditional wastewater treatment mechanisms. Modifications of the hydrologic regime of watersheds in relation to water reuse and retention in times of drought using bioretention basins have not been considered. While many aspects of bioretention basin design and treatment pathways have yet to be studied adequately to make design recommendations to maximize treatment efficiency, bioretention basins have been shown to effectively treat stormwater runoff and offer a sustainable method of stormwater treatment.

CHAPTER THREE: MATERIAL AND METHODS

This study was developed to evaluate vegetation recommendations in the Michigan LID manual for treatment of stormwater in bioretention basins. *Carex comosa*, *Iris virginica* and *Poa pratensis* vegetation species were evaluated in a column experiment to simulate treatment of stormwater in a bioretention basin to provide design data on vegetation selection in Michigan for stormwater treatment in bioretention basins. The objective was to determine if stormwater treatment is influenced by vegetation selection in bioretention basins.

Experimental Design and Establishment

Five plant species were chosen based on the Low Impact Development (LID) Manual for Michigan [60] and available native plant species from JFNew (http://www.cardnojfnew.com/Nursery.aspx). Plant species and the recommended planting zone based on the design water depth of the bioretention basin are shown in Table 3.1.

TABLE 3.1 PLANT SPECIES USED IN EXPERIMENT AND RECOMMENDED PLANTING DEPTH (CENTIMETERS (INCHES) IN RELATION TO WATER LEVEL)

Plant Species Common Name	Botanical Name	-10 to -5 (-4 to -2)	-5 to 0 (-2 to 0)	0 to 5 (0 to 2)	5 to 10 (2 to 4)	N/R1
Blue Flag Iris	Iris virginica	X	X	X	X	
Bristly Sedge	Carex comosa		X	X	X	
Cardinal Flower	Lobelia cardinalis			X	X	
Great Blue Lobelia	Lobelia siphilitica			X	X	
Kentucky Blue Grass	Poa pratensis					X

N/R = Not Recommended

Native plants, *Iris virginica, Carex comosa, Lobelia cardinalis* and *Lobelia siphilitica*, were ordered from JFNew. Native plants were shipped from JFNew in quart containers and

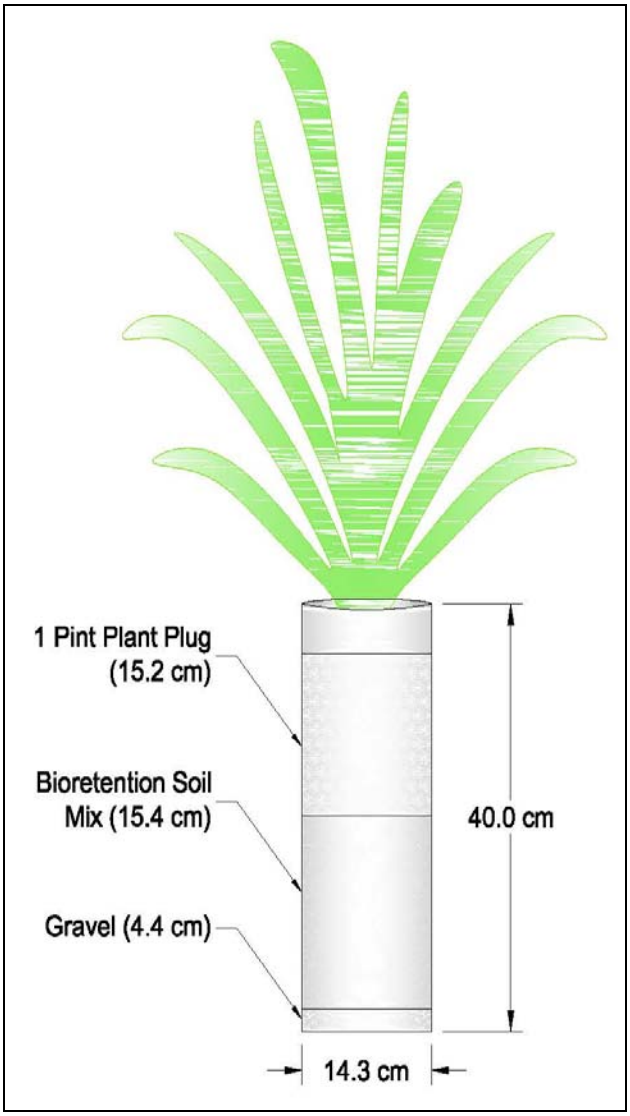
planted in columns on August 19, 2010. *Poa pratensis* (Kentucky Blue Grass) was obtained from the MSU Turf Grass Science Department and planted on August 25, 2010.

Bioretention soil media was prepared as recommended by the LID Manual for Michigan with 50 percent sand, 20 percent top soil and 30 percent compost (by volume). Sand and top soils were obtained from the MSU landscaping services. Soil was classified as a sandy loam soil with 12.1 percent clay. Compost, obtained from Schafer's Inc. Landscape Supplies, consisted of yard waste with no animal manures or other byproducts (including food waste). Sand, topsoil and compost were measured using a five gallon bucket and spread on a concrete slab. Mixing was completed using rakes and flat head shovels until the bioretention soil media was uniformly mixed. Bioretention soil media was then stored in a 50 gallon rubber trash can with a lid until column construction. Columns were constructed within 7 days of combining the bioretention soil media.

Columns were constructed from 14.3 centimeters (5.63 inches) diameter PVC pipe. Column height is 40.0 centimeters (15.75 inches). Cheese cloth and 0.63 centimeters (0.25 inches) fiberglass screen were placed on the bottom of each column and attached with a 15.24 centimeters (6 inches) hose clamp. Gravel was placed in the bottom of the columns (4.4 centimeters (1.8 inches)) followed by 15.2 centimeters (6 inches) of bioretention soil media. Bioretention soil media was compacted in three lifts using a pestle roughly 50 times each lift. Native plant plugs were taken from 1 pint containers and placed directly above the bioretention soil media with roughly 5.1 centimeters (2.0 inches) of column above the native plant. Plant plugs were compacted around the edges of the column by hand to minimize damage to the root system. On overflow spigot was placed on the columns 2.5 centimeters (1.0 inches) from the top. Column construction for the *Poa pratensis* was modified with the addition of 1 pint of potting

soil placed on top of the soil media mix followed by the grass plug to simulate soil media conditions in the native plant columns. Potting soil used was the same potting soil used by JFNew, Promix-BX obtained from Home Harvest Garden Supply, 4870 Dawn Ave East Lansing, MI. Plant column construction is shown in Figure 3.1.

FIGURE 3.1 PLANT COLUMN DIAGRAM

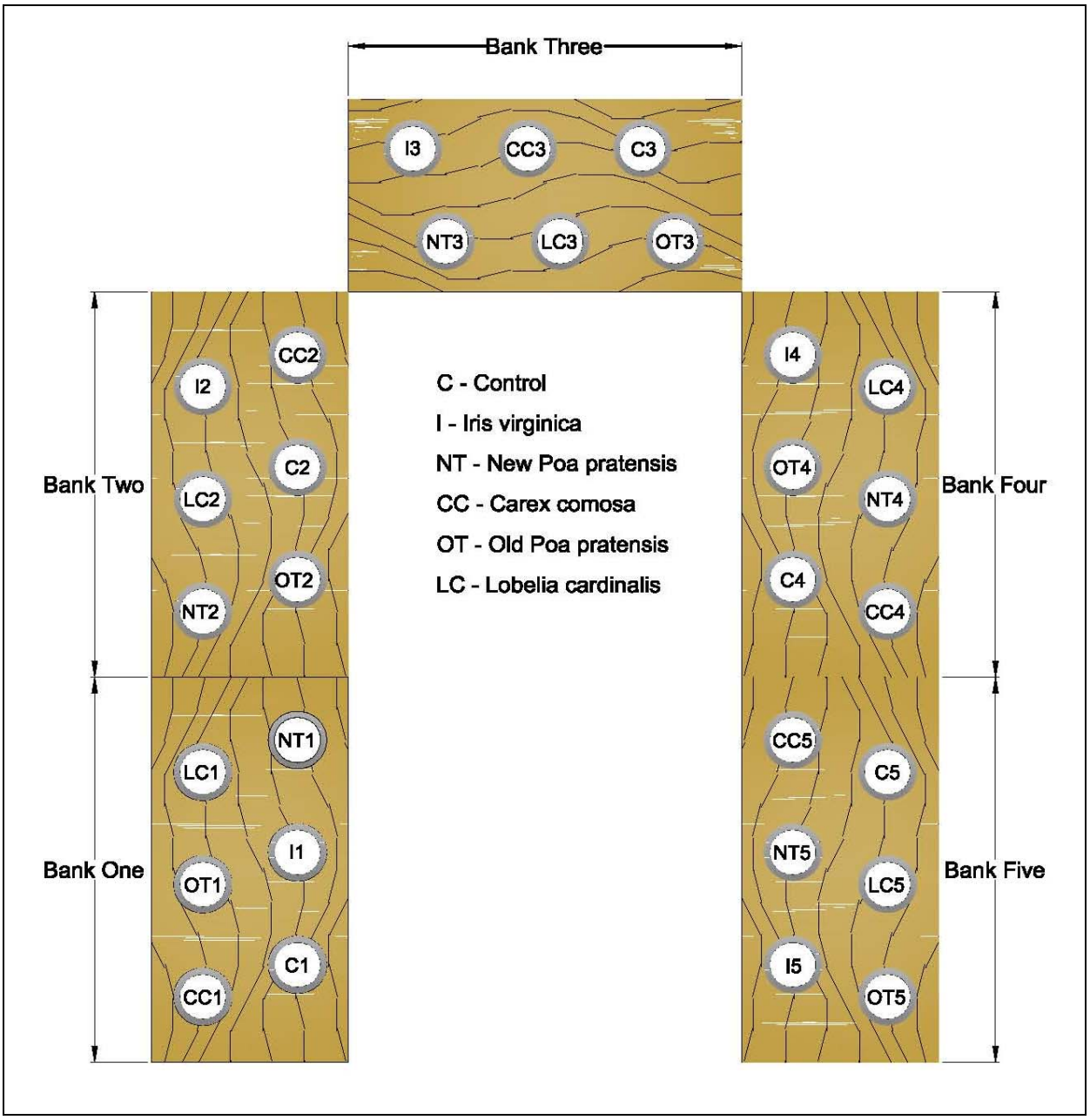


Columns were placed on metal shelving with six columns on each shelf, shown in Figure 3.2. Plants were randomly placed on the metal shelves. Three banks of florescent lights were placed above each metal shelf. Lights were activated by an automatic timer with 16 hours of light and 8 hours of dark. Plants were irrigated every three to five days until testing started.

An irrigation system was constructed using 1.3 centimeters (½ inch) Teflon tubing and plastic connectors. Each bank was set up on a main line for irrigation. Teflon tubing went from the main line to the top of each column. Water was supplied through the potable water system to

the laboratory. Water flow into the columns was regulated using plastic clamps at each column so each column in a bank was irrigated with the same volume of water. Water was supplied by a 50 gallon plastic barrel that was filled with a hose from the laboratory spigot when needed. A small water fountain pump was placed in the barrel and connected to each of the main lines. Teflon tubing was also used to connect the overflow spigot on each column to a floor drain in the center of the metal shelving. Teflon tubes were secured along the metal shelving with plastic zip ties as needed.

FIGURE 3.2 PLANT COLUMN LAYOUT



Plant Pests and Stress

Infestation of aphids and spider mites were identified in September 2010 and a pyrethrin based insecticide was applied. The insecticide was applied as needed for four weeks. At that time other methods were employed to control pests including spraying dilute alcohol (1:10) and soap solution (1:10) and biological control using ladybugs (Coccinellidae). Within three weeks of

aphid identification, four of five *Lobelia siphilitica* and one of five *Lobelia cardinalis* had died. These two species showed preferential contamination of green aphids. Alcohol treatment appeared to burn the leaves of *Lobelia cardinalis* and was subsequently not used. Black aphids showed preferential infestation to *Carex comosa*, while the spider mites targeted *Iris virginica*. By the time of testing in April 2011 all planting of *Lobelia siphilitica* had died and three of five *Lobelia cardinalis*. *Poa pratensis* did not respond well to the drip irrigation and consequentially had died or was not considered a "healthy" species. For the purposes of this thesis "healthy" is considered maintaining biological function or actively growing. Columns were tested as noted by Old *Poa pratensis*. New cutting of *Poa pratensis* were planted on March 4, 2011 by replacing the *Lobelia siphilitica* columns. New planting of turf grass are noted by New *Poa pratensis*.

Stormwater Generation

Stormwater was prepared the day of dosing with deionized water (DI) in two 5 gallon carboys. 12 L of stormwater was prepared in each carboy and applied to the columns. The order of stormwater application to each column was modified for each testing event as well as the source of the stormwater (depending on the first or second carboy). Synthetic stormwater was produced using the chemicals and concentrations shown in Table 3.2. Heavy metals were patterned after a Blecken study [17] while nutrients were patterned after a Lucas and Greenway study [32].

TABLE 3.2 CHEMICAL CHARACTERISTICS OF SYNTHETIC STORMWATER

Synthetic Stormwater		Stock Concentration	Stormwater Stock Addition	Stormwater Concentration
Pollutant	Chemical	(g/L)	(uL per L SW)	(mg/L)
Ortho-Phosphate	Potassium Phosphate	7.97	1000	7.97
Ortho-Phosphate	Potassium Phosphate	7.97	100	0.79
Total Dissolved Phosphorus				0.79 or 7.97
Ammonia	Ammonium Chloride	4.12	100	0.41
Nitrogen Oxides	Potassium Nitrate	8.69	102	0.97
Org. Nitrogen	Nicotinic Acid	6.62	365	3.47
Total Dissolved Nitrogen				4.86
Cadmium	Cadmium Nitrate	0.26	10	0.003
Copper	Copper Sulphate	54.4	10	0.544
Lead	Lead Nitrate	15.0	10	0.150
Zinc	Zinc Chloride	57.7	10	0.578
Total Metals				1.27

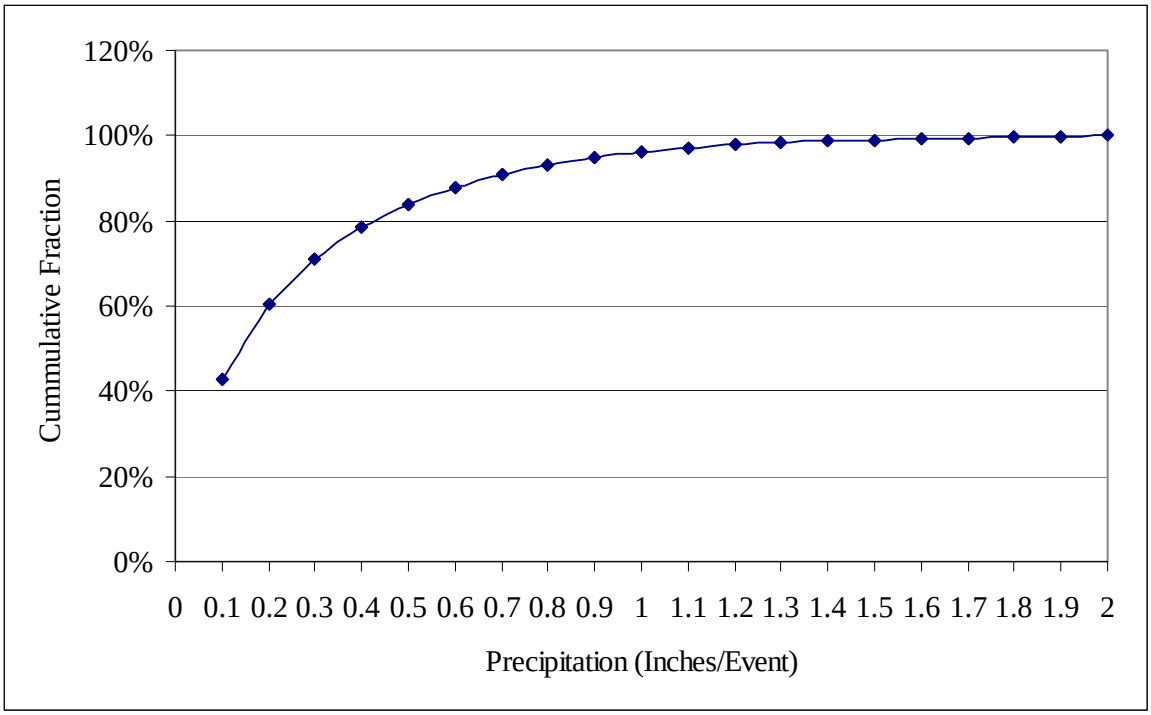
Four testing events were completed with a high level of orthophosphate (7.97 mg/L) and then six testing events were completed with low levels of orthophosphate (0.79 mg/L). Higher levels of phosphorus were used to help saturate adsorption sites in the potting soil and bioretention soil. The phosphorus concentration was then minimized to meet synthetic stormwater suggested values [32]. All other chemical concentrations were kept the same.

Stormwater Sample Preparation

Daily precipitation data for Owosso, MI was obtained from the National Climatic Data Center from 1896 to 2009. Based on the daily precipitation data, the mean storm event occurring 50 percent of the time is 0.381 centimeters (0.15 inches)s in Owosso, MI shown in Figure 3.3.

The cumulative fraction of storm event occurring for precipitation events of 0.635 centimeters (0.25 inches) is 65 percent, and 78 percent for precipitation events of 0.99 centimeters (0.39 inches). This data also includes winter storm events.

FIGURE 3.3 CENTRAL MICHIGAN STORMWATER EVENTS



The LID Manual for Michigan suggests sizing bioretention basins at a maximum 5:1 ratio not to exceed 1 acre, meaning the area of the bioretention basin should be a minimum of 16.7 percent of the area that collects stormwater and drains to the bioretention basin. The Michigan LID manual suggests treating a minimum of 1.27 centimeters (0.5 inches) of runoff from the site to account for first flush and up to 1 inch of water over the runoff area for a water quality design criteria. However, stormwater volume dosed in this experiment varied from 500 ml to 800 ml, corresponding to stormwater events between 0.635 centimeters (0.25 inches) and 0.99 centimeters (0.39 inches). This volume was chosen to evaluate roughly 65 percent of the stormwater events in Owosso, Michigan, assuming a 5:1 design ratio. Larger stormwater events

were not addressed in this study. Stormwater was weighed and applied to each column as shown in Table 3.3.

TABLE 3.3 DATE OF TESTING AND STORMWATER DOSAGE

Date	Stormwater Dose (mL)
4/1/2011	750
4/8/2011	500
4/15/2011	500
4/21/2011	500
4/29/2011	500
5/6/2011	650
5/12/2011	800
5/15/2011	650
6/7/2011	800
6/13/2011	800

Leachate was collected from the bottom of each column four hours after the initial application. Leachate was then weighed and processed for analysis. All samples (including stormwater samples from each carboy) were analyzed for ammonia, nitrate, total nitrate, phosphate, total phosphorus, and transition metals.

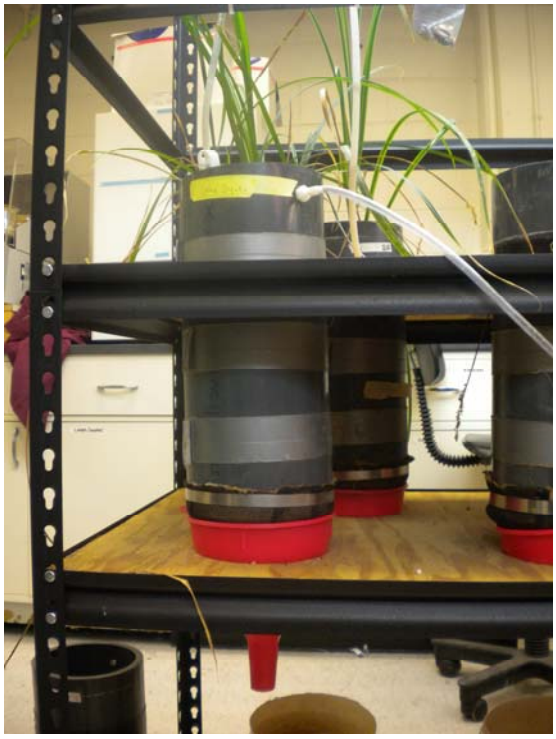
Hydraulic Permeability Testing

Hydraulic permeability testing was conducted on Bank 1 and Bank 4 columns. Bank 1 was tested on 6/14/2011 while Bank 4 was tested on 6/17/2011. Testing was conducted following ASTM D 2434- 68 with the exception that air removal was not conducted by saturating the sample form the bottom up. This process, designed to saturate all soil voids, is very unlikely to occur during operation of a bioretention basin. The purpose of the hydraulic

permeability testing is to determine whether plant species affect the soil permeability in bioretention basins. It was therefore determined that full saturation of the soil was not needed as it is not applicable to functioning bioretention basins.

Water was applied to the columns using the irrigation system. Columns were saturated 2.5 centimeters (1.0 inch) above the soil level. Excess water applied to the columns overflowed through the spigot located 2.5 centimeters (1.0 inch) below the top of the column (see Figure 3.4). Columns were saturated for 30 minutes prior to testing. Buckets were placed under the columns to gather leached water. Water was collected five times in three minute intervals and weighed to obtain a representative sample.

FIGURE 3.4. HYDRAULIC PERMEABILITY SET UP



Coefficient of permeability was determined using Darcy's Law and the seepage rate. Both the coefficient of permeability and seepage rate are presented in the Results section.

Biomass Sample Preparation

Plants were harvested on June 17th and June 21st 2011. Plants were gently manipulated from the columns and separated into leaves and stems (referred to as shoots), roots in potting soil mix and roots in bioretention soil media (Figures 3.5 through 3.10). Leaves and stems were placed in a brown paper bag and weighed to determine wet weight. Roots were gently removed from the potting soil media mix and the bioretention soil media by gently shaking and raking through the media. Roots were then placed in a one gallon plastic bucket filled with water and gently washed. Roots and the associated media were filtered through a 200 um screen and placed in a brown paper bag and weighed to determine wet weight. Separated plant matter (roots and shoots) were dried at 105°C for 24 hours and weighed again to determine dry weight. Dried roots and shoots from each plant were combined into a 1 pint plastic bag and taken to the MSU soils laboratory for plant tissue analysis. Soil samples were taken from the potting soil mix and the bioretention soil media and taken to the MSU soils laboratory for analysis.

FIGURE 3.5 COLUMN DECONSTRUCTION

FIGURE 3.6 COLUMN DECONSTRUCTION

FIGURE 3.7 BIORETENTION SOIL MIX AND POTTING SOIL SEPARATION

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FIGURE 3.8 BIORETENTION SOIL MIX AND POTTING SOIL SEPARATION

FIGURE 3.9 ROOT SEPARATION FOR *CAREX COMOSA*

FIGURE 3.10 ROOT SEPARATION FOR *IRIS VIRGINICA*

Stormwater Sample Analysis

All samples were filtered with a .45 um syringe filter prior to analysis using ion chromatography in a Dionex ICS-5000. Table 3.4 shows the analytical methods used for each analysis and the respective holding times.

TABLE 3.4 LABORATORY ANALYTICAL METHODS, PRESERVATIVE AND HOLDING TIME

Laboratory Analysis	Analytical Method(s)1	Preservative	Unit of Measure	Holding Time
Total ammonia as N	SM 4500-NH3 / EPA 350.1	None	mg/l	24 hours
Nitrate-nitrite nitrogen	SM 4500 NO3 / EPA 353.2	None	mg/l	48 hours
Total nitrogen (TN)	SM 4500-N	K2S2O8, pH>10	mg/l	28 days
Ortho phosphorus (P)	SM 4500- P / EPA 351.2	None	mg/l	48 hours
Total phosphorus (TP)	SM 4500-P / EPA 365.4	K2S2O8, pH>10	mg/l	28 days
Transition Metals		H2SO4, pH<2	mg/l	6 months

NOTES:

1. EPA Test Methods for Evaluating Solid Waste Physical/Chemical Methods (SW-846)—Third Edition, September 1986; Final Update IV, January 2008

A Dionex ICS-5000 was used to analyze samples for nitrate, ammonia, total nitrogen, orthophosphate and total phosphate. Two milliliters of sample was placed in either polystyrene or glass sample vials and injected by AS-AP Autosampler. Nitrate, total nitrogen, orthophosphate, and total phosphorus were separated using an IonPac AS22 Carbonate Eluent Anion-Exchange Column. Total nitrogen and total phosphorus were digested using potassium persulfate ($K_2S_2O_8$) in accordance with Standard Methods for the Examination of Water and Wastewater. Ammonia was separated using an IonPac CS 12 column using metanesulfonic eluent. Transition metals were separated using an IonPac CS5A Transition Metal Column.

Cation and Anion Program

A 100 ml volume flush was utilized prior to each sample. The minimum and maximum pressure limit on the ICS-5000 was 200 and 2900 psi. Maximum flow rate was limited to 6.00 ml/min2. Temperature in the column compartment was regulated between 30 and 35 ºC. Sample injection into the column was 250 uL for anions and 25 uL for cations. A concentrator column was used to analyze anions. Eluent for the anion column consisted of 4.5 mmol carbonate and 1.4 mmol bicarbonate. Total flow rate was 1.2 ml/min. The cation column utilized metanesulfonic eluent at a total flow rate of 1.0 ml/min. Total run time for the anion column was 15 minutes while the total run time for the cation column was 12 minutes.

Anion quantification was performed using linear point to point calibration of 15 calibration levels, 10 lower level calibration levels and 5 high range calibration levels. Cation quantification was performed using linear point to point calibration of 8 calibration levels. Table 3.5 shows the calibration concentrations and Figures 3.11 through 3.15 illustrate the calibration curves for nitrate, phosphate, total nitrogen and total phosphorus. Regression correlation coefficients and standard error for each curve is also shown. Retention time for nitrate varied from 6.5 to 8 minutes and phosphorus from 7 to 10 minutes based on sample pH and how clean the column was. Retention time for ammonia was consistently around 4.8 minutes.

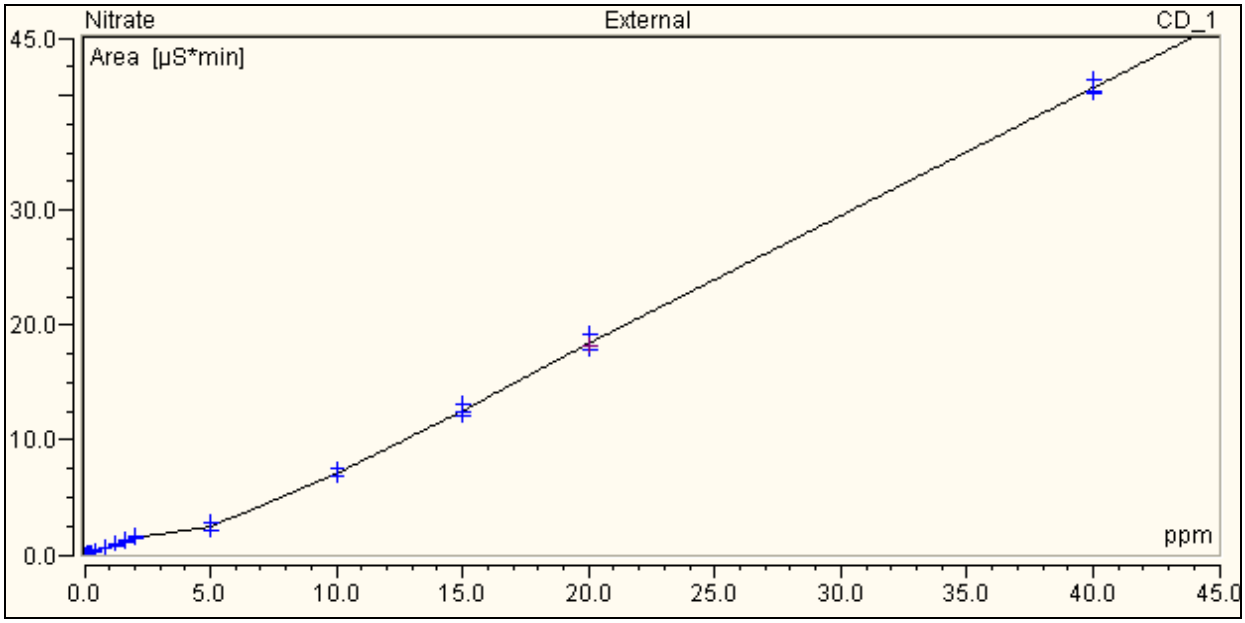
TABLE 3.5. CALIBRATION STANDARD CURVE FOR ANIONS AND CATIONS

Standard	Nitrate mg/l	Phosphate mg/l	Ammonia mg/l	Total Nitrogen mg/l	Total Phosphorus mg/l
1	0.008	0.012	0.04	0.08	0.12
2	0.04	0.06	0.1	0.16	0.24
3	0.08	0.12	0.4	0.28	0.42
4	0.16	0.24	1	0.4	0.6
5	0.28	0.42	4	0.8	1.2
6	0.4	0.6	10	1.2	1.8
7	0.8	1.2	20	1.6	2.4
8	1.2	1.8	30	2	3
9	1.6	2.4		5	7.5
10	2	3		10	15
11	5	7.5		15	22.5
12	10	15		20	30
13	15	22.5		40	60
14	20	30		0	0
15	40	60		0	0
R^2	99.51	99.38	98.15	99.34	99.30
St. Dev.	4.40	3.99	9.98	9.95	13.91

R^2 is the coefficient of determination

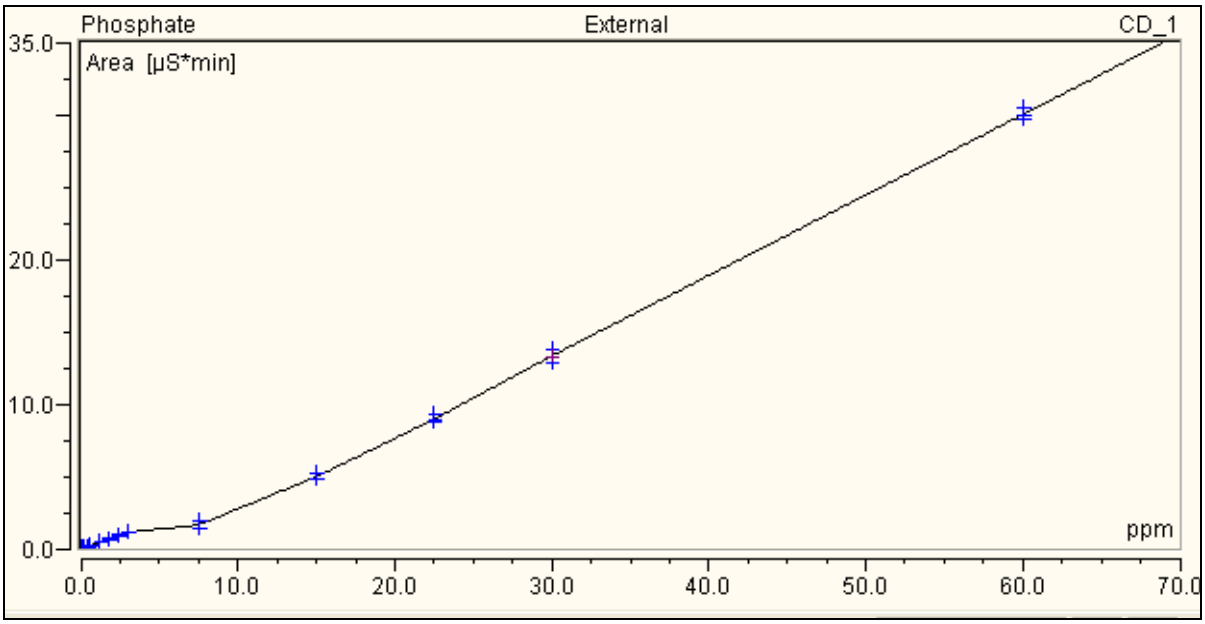
St. Dev is the standard deviation

FIGURE 3.11. NITRATE CALIBRATION CURVE



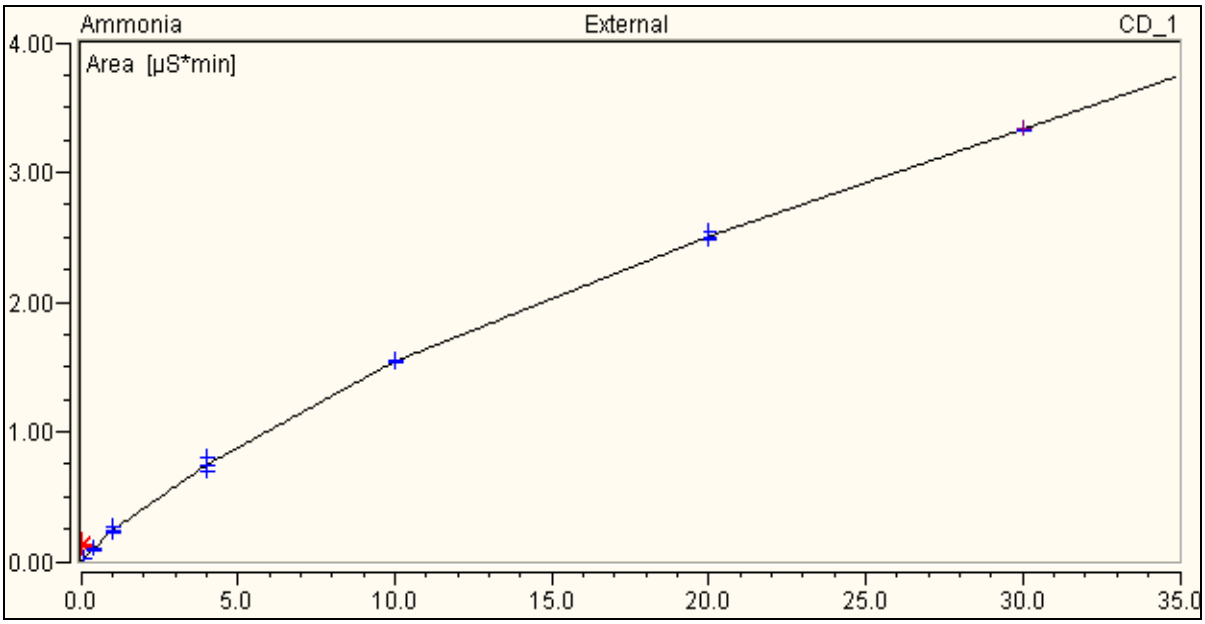
*Red asterisk indicates a data point that was not used in the calibration.

FIGURE 3.12. PHOSPHATE CALIBRATION CURVE



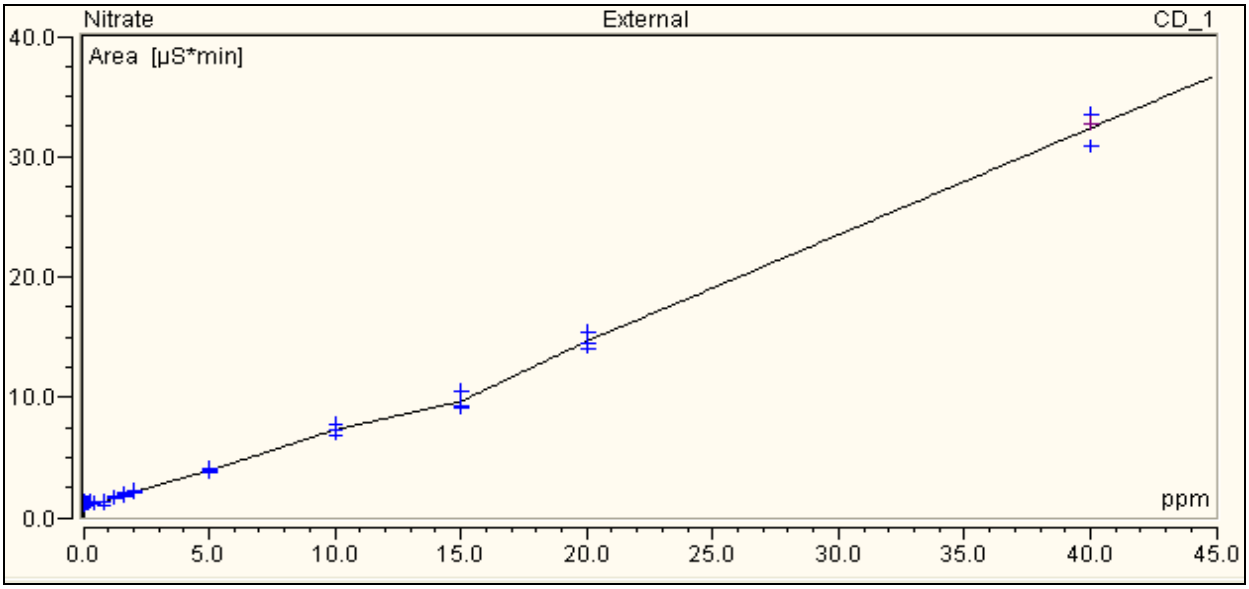
*Red asterisk indicates a data point that was not used in the calibration.

FIGURE 3.13. AMMONIA CALIBRATION CURVE



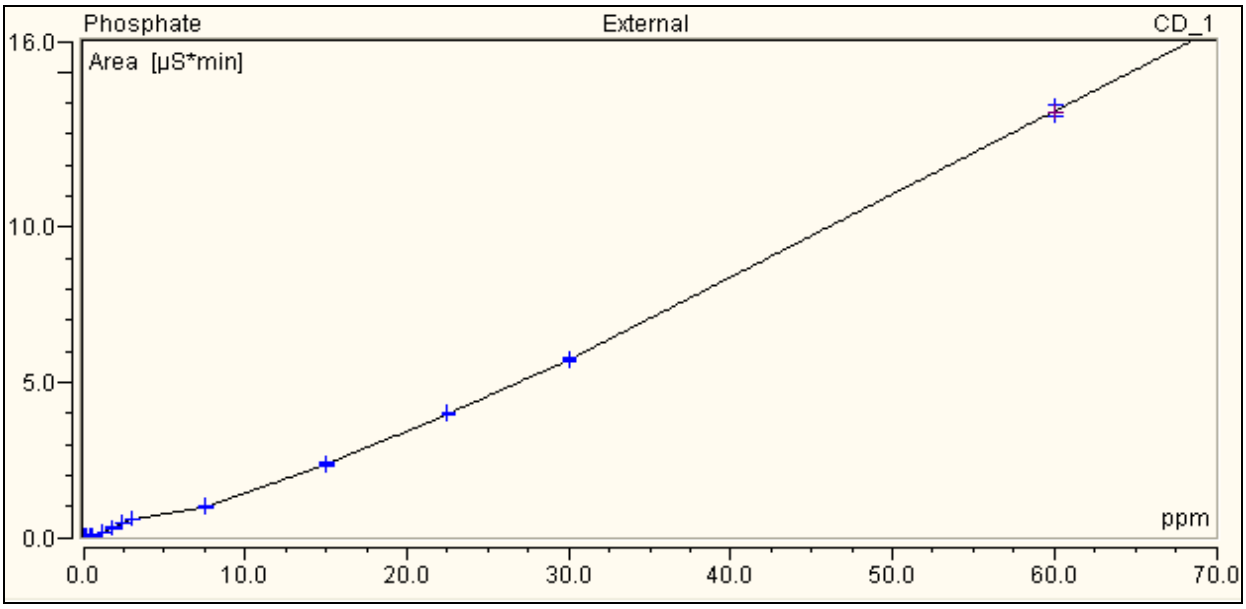
*Red asterisk indicates a data point that was not used in the calibration.

FIGURE 3.14. TOTAL NITROGEN CALIBRATION CURVE



*Red asterisk indicates a data point that was not used in the calibration.

FIGURE 3.15 TOTAL PHOSPHORUS CALIBRATION CURVE



*Red asterisk indicates a data point that was not used in the calibration.

Transition Metal Program

A 250 ml volume flush was utilized prior to each sample. The minimum and maximum pressure limit on the ICS-5000 was 200 and 3000 psi. Maximum flow rate was limited to 6.00 ml/min. Syringe speed was set at 4 and the unit was not required to wait for temperature to reach equilibrium. Temperature in the column compartment was regulated at 30º C. A concentrator column was used to analyze transition metals. MetPac PDCA eluent consists of pyridine-2, 6-cidarboxylic acid that is used as a complexing agent to separate transition metals. Final concentrations of transition metals were analyzed using UV_VIS of wavelength 530 nm. Total flow rate of the transition metals column was 1.2 ml/min.

Calibration Curve for Transition Metals

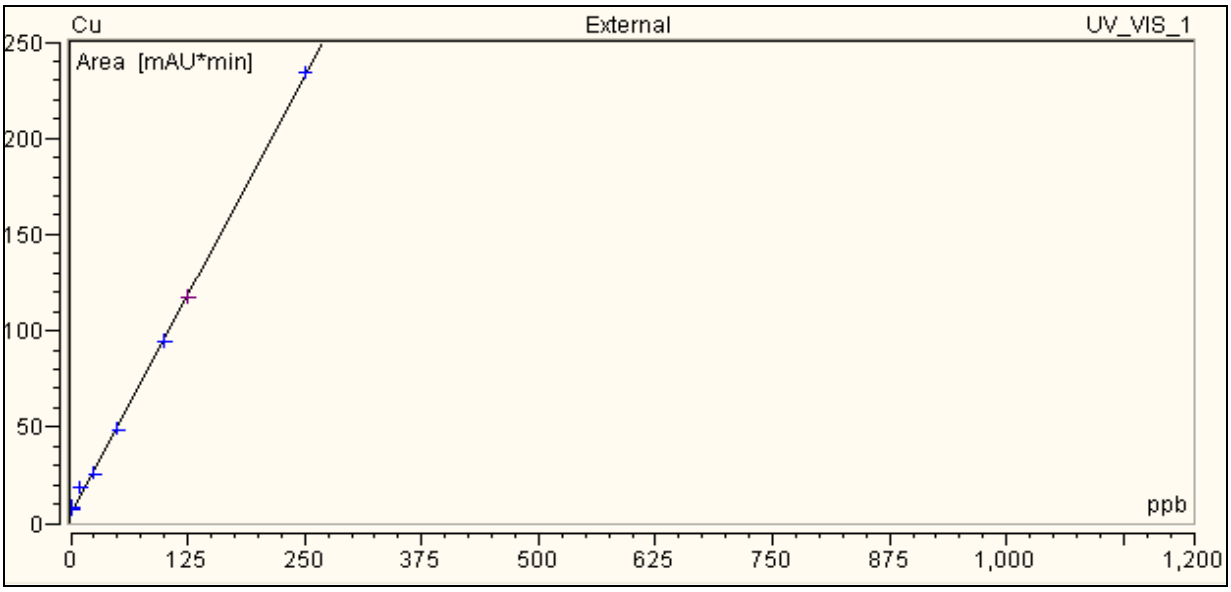
Quantification was performed using linear calibration of 7 calibration levels. Regression correlation coefficient and standard error for each curve is shown in Table 3.6. Calibration

curves are shown in Figures 3.16 through 3.19. Retention time for copper was at 6.64 min., nickel was 7.57 min., zinc was 8.413 min, and cadmium was 10.253 min.

TABLE 3.6. CALIBRATION STANDARD CURVE FOR TRANSITION METALS

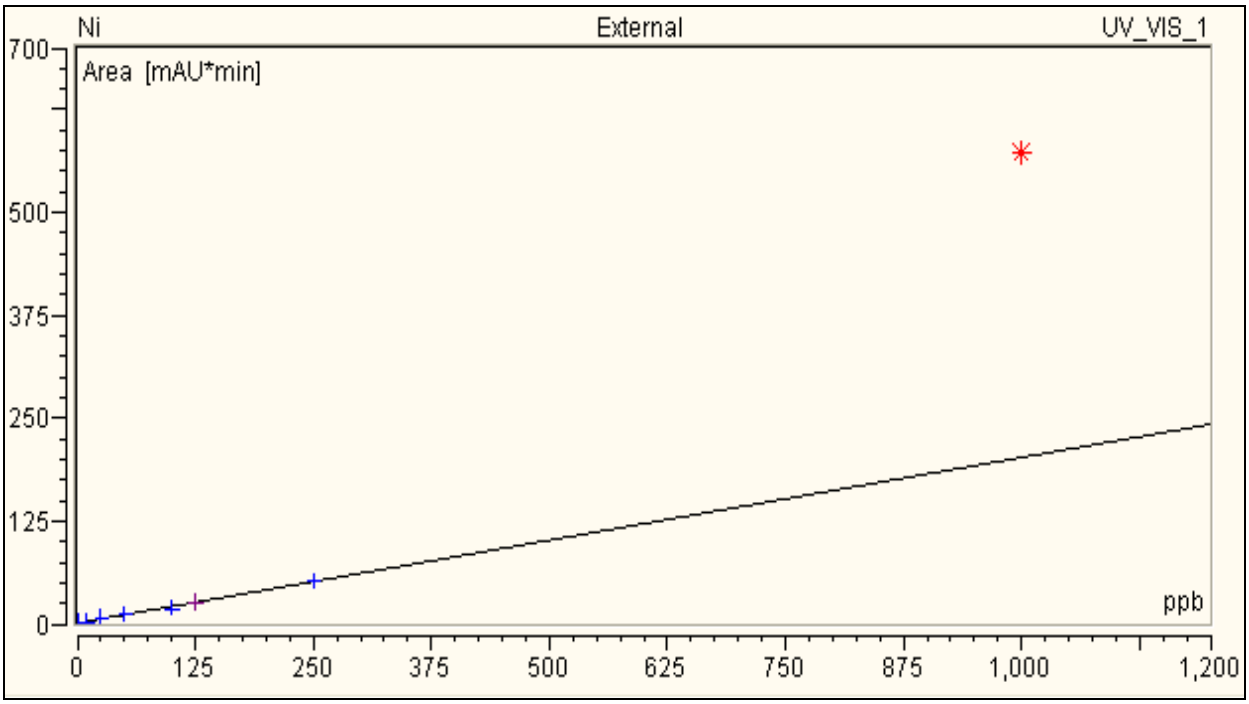
Standard	Copper mg/l	Nickel mg/l	Zinc mg/l	Cadmium mg/l
1	0.1	0.1	0.1	0.1
2	0.5	0.5	0.5	0.5
3	1	1	1	1
4	5	5	5	5
5	10	10	10	10
6	20	20	20	20
7	25	25	25	25
Correlation Coefficient	99.93	99.99	99.99	99.99
Relative Standard Deviation	5.57	0.97	1.22	3.13

FIGURE 3.16 COPPER CALIBRATION CURVE



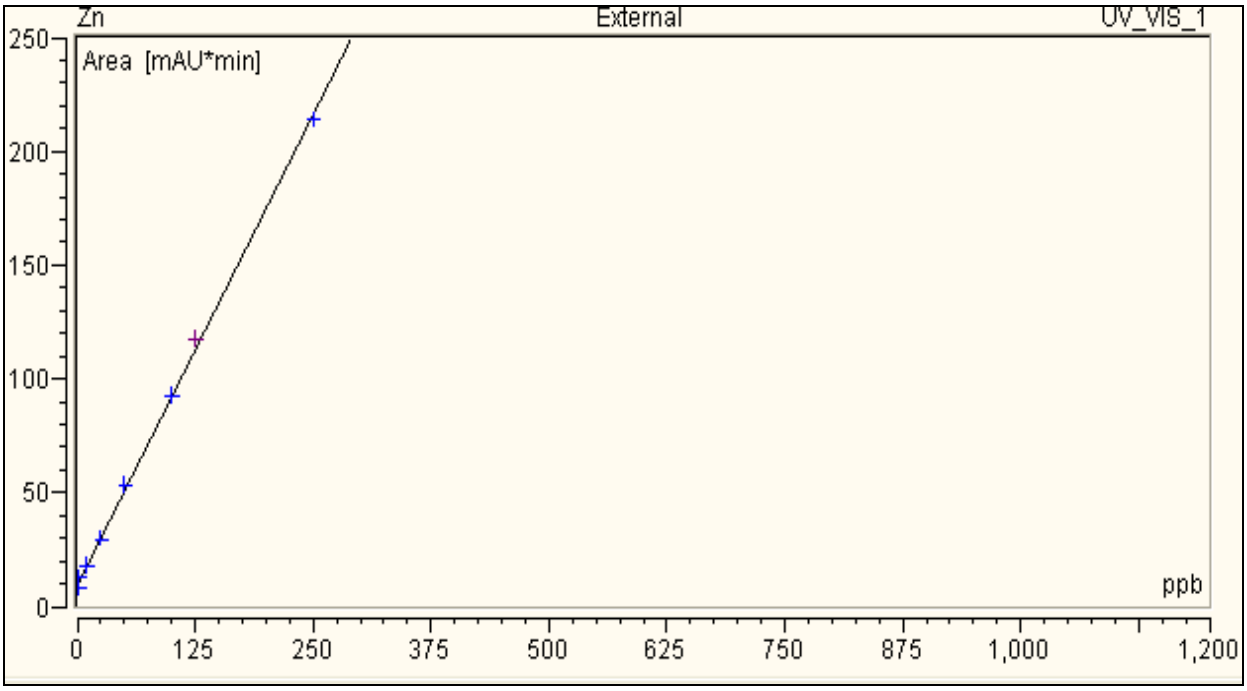
*Red asterisk indicates a data point that was not used in the calibration.

FIGURE 3.17 NICKEL CALIBRATION CURVE



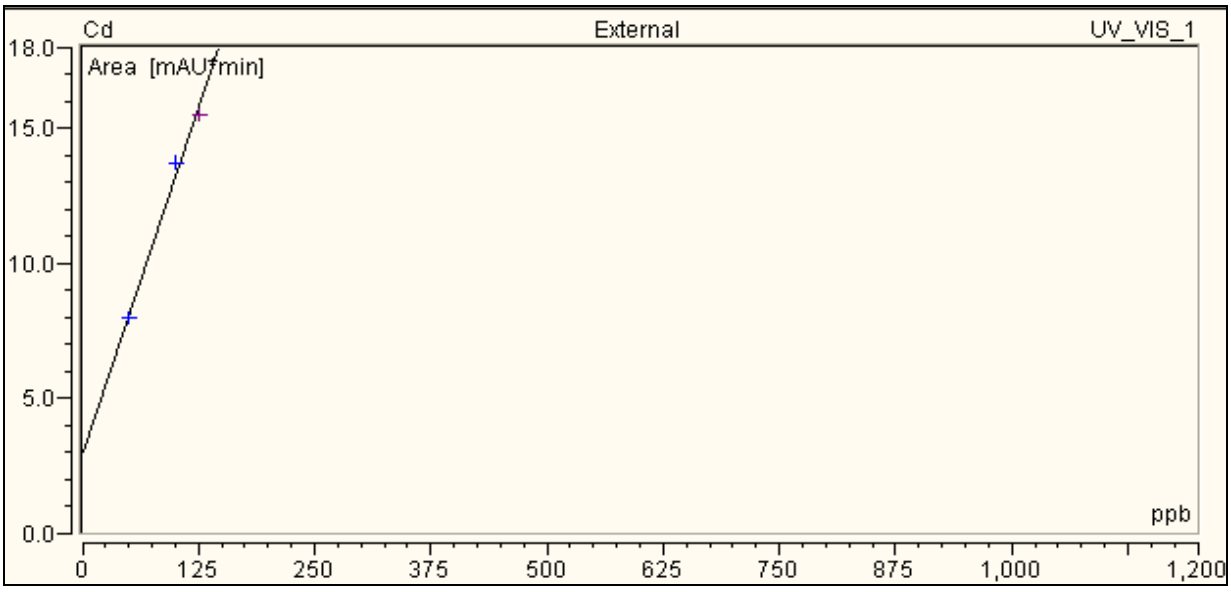
*Red asterisk indicates a data point that was not used in the calibration.

FIGURE 3.18 ZINC CALIBRATION CURVE



*Red asterisk indicates a data point that was not used in the calibration.

FIGURE 3.19 CADMIUM CALIBRATION CURVE



*Red asterisk indicates a data point that was not used in the calibration.

Method Detection Limits (MDL) and Non Detect Limits

The MDL is defined as the minimum concentration of a substance that can be measured and reported with 95 percent confidence that the analyte concentration is greater than zero. Non detects were assumed to equal 0.5 MDL. The constituent standards and pollutant concentrations are presented in Table 3.7.

TABLE 3.7. METHOD DETECTION LIMITS AND NON DETECT VALUES

	MDL	ND
Target Parameter	MDL (mg/L)	ND (mg/L)
Nitrate Nitrogen	0.01	0.0045
Ammonia Nitrogen	0.10	0.05
Total Nitrogen	0.25	0.5
Orthophosphate	0.06	0.03
Total phosphate	0.37	0.18
Copper	0.10	0.05
Nickel	0.10	0.05
Zinc	0.10	0.05
Cadmium	0.10	0.05

Data Analysis

Data Summary

All dependent variables were analyzed for normal distribution using residual analysis from the model (shown in Appendix C). If the data was considered not normal, it was log transformed and analyzed again. At this time, the residual analyses were compared against the log transformed residual analysis to determine the best approximation to normality. Wastewater was not leached through column CC 5 on 4/29/11 and 5/12/11 creating missing data points for that column for two data sets. Missing data is discussed further in Data Analysis Steps. The raw

plant tissue data was not transformed due to the limited number of samples (one for each column).

Categorical and Numerical Data

Four independent variables (species, total dry weight, stormwater volume applied, and time) were analyzed in relation to the dependant variables collected. Of the four independent variables, species and stormwater volume applied were treated as nominal variables while total dry weight, and time were evaluated as ratio variables. The difference in stormwater volume dosed (500 to 800 mL) was not sufficient to extrapolate beyond the experiment and was therefore chosen to be considered as categorical data.

Collinearity

The two independent variables of species and total dry weight infer multicollinearity as one would assume that the total dry weight of a plant might be correlated with the species to some degree. The variance inflation factor (VIF) was calculated between species and total dry weight and was determined to be 0.16. Generally, VIF values less than 0.1 indicate that the correlation between variables is excessive and one of them should be removed. However, due to excessive errors in the model when using both dry weight and species, the collinearity was determined to be too great. Therefore, species was selected to represent both species and total dry weight because the experiment was designed around evaluating vegetation species for treatment of stormwater in bioretention basins. It is also a more practical independent variable that can easily be assessed in the field.

Influence

Individual columns were analyzed using Cook's D to determine undue influence to the overall effect of the model. A Cook's D of greater than 1.0 was considered for removal of the data set. However, values of Cook's D were never greater than 1.0 for all data sets analyzed.

Covariate ratio statistics were also evaluated to measure the change in the determinant of the covariance matrix of the fixed-effect parameter estimates by deleting the column. Columns with a covariate ratio of greater than 1.0 were evaluated to determine if deleting that column would improve the precision of the fixed effect parameter estimates. Based on the analysis, no raw data was removed from the data set. Influence data is found in Appendix D.

Data Analysis Steps

Statistical analysis was performed using SAS. The Center for Statistical Training and Consulting was contacted to assist in the statistical evaluation of the experiment. Initial data was evaluated using a longitudinal study of the dependent variable to determine the effects of time. A significant trend was not found for the values as time progressed. David Reyes-Gastelum suggested using a mixed linear model to analyze data in SAS. A linear mixed model obtains an estimate of the correlation between variables when multiple measurements are available on each of the variables of interest by grouping data to evaluate difference in groups vs. individual data points. The linear mixed model is capable of using both random and fixed variables, adjusting for missing data and a utilizing a wide variety of covariance structures for random effects and repeated effects, completing a robust analysis.

Linear Mixed Model Assumptions

Assumptions for using a linear mixed model include normally distributed data and that the means of the data are linear and parallel. Three different methods were used to evaluate

model results including residual (restricted) maximum likelihood (REML), maximum likelihood (ML) and minimum variance quadratic unbiased estimation of the covariance parameters (MIVQUI0). All three methods were evaluated using the nitrate and orthophosphate data to determine that the maximum likelihood method showed the best correlation of the data and was therefore used for all statistical evaluation. The differences in correlation values between REML and ML methods are between 1 and 3 percent. MIVQUI0 correlation values were extremely low and not relevant. Therefore, two of the three methods exhibit similar response in the data.

Model Fit (R^2)

The ability of the independent variables to predict the model was determined by summing the intercept and residual estimates for the covariance parameters for the model with the independent variables (Cm) and without the independent variables (C). The following equation was used to determine the R^2 value.

$$R^2 = \left(\frac{(C - Cm)}{C} \right) \qquad \text{Eq. 1}$$

This value indicates how much of the variability in the model was predicted by the independent variables.

Model Development

Nutrient data (concentration leached (mg) and mass leached (mg L)) was analyzed using the linear mixed model assuming zero predictors, one predictor, two predictors, etc. through all four independent variables. The associated R^2 values are shown in Table 3.8

TABLE 3.8. VARIANCE PREDICTED BY INDEPENDENT VARIABLES

Nutrient	Stormwater	Total Dry Weight	Species	Time	All
NH3 ppm	4.28%	0.00%	0.00%	1.87%	2.18%
NO3 ppm	0.28%	8.79%	21.25%	-0.15%	29.12%
PO4 ppm	1.54%	34.85%	40.82%	3.48%	45.77%
TN ppm	5.93%	1.50%	12.96%	4.58%	22.00%
TP ppm	2.82%	12.09%	13.43%	1.23%	17.91%
NH3 mg L	57.05%	6.71%	6.04%	-356.38%	67.79%
NO3 mg L	2.69%	17.23%	26.29%	0.13%	34.24%
PO4 mg L	5.10%	31.95%	42.60%	0.77%	49.38%
TN mg L	22.43%	8.28%	22.42%	21.29%	44.40%
TP mg L	10.48%	17.80%	21.90%	3.86%	33.66%

ppm = concentration (mg/L)
mg L = mass (in mg) leached

Species was the overall highest predictor of variability followed by total dry weight, stormwater and time. Individual analysis of nutrient data over time for each column was not significant so the independent variable of time was eliminated from the model in future analysis. Nitrate and orthophosphate data (concentration leached (ppm) and mass leached (mg L)) were analyzed using the linear mixed model with species, then species and total dry weight, and finally species, total dry weight and stormwater applied. Species predicted 26.3 percent of the variability in the model for nitrate and 42.6 percent of the variability for orthophosphate. The addition of total dry weight increased the predicted variability by 4.32 percent for nitrate and -0.26 percent for orthophosphate. The addition of stormwater volume increased the prediction 0.94 percent for nitrate and 1.95 percent for orthophosphate.

The difference between the R^2 values of mass leached and concentration were calculated and shown in Table 3.9. Ammonia data is highly variable, most likely due to non detect values for all samples and is therefore not considered in this analysis.

TABLE 3.9. DIFFERENCE IN R^2 FROM MASS (MG L) AND CONCENTRATION (PPM)

	NO3	PO4	TN	TP
Stormwater				
ppm	0.28%	1.54%	5.93%	2.82%
mg L	2.69%	5.10%	22.43%	10.48%
Difference	2.41%	3.56%	16.50%	7.65%
Total Dry Weight				
ppm	8.79%	34.85%	1.50%	12.09%
mg L	17.23%	31.95%	8.28%	17.80%
Difference	8.44%	-2.89%	6.78%	5.71%
Species				
ppm	21.25%	40.82%	12.96%	13.43%
mg L	26.29%	42.60%	22.42%	21.90%
Difference	5.03%	1.78%	9.46%	8.47%
Time				
ppm	-0.15%	3.48%	4.58%	1.23%
mg L	0.13%	0.77%	21.29%	3.86%
Difference	0.28%	-2.71%	16.70%	2.63%
All Variables				
ppm	29.12%	22.00%	22.00%	17.91%
mg L	34.24%	44.40%	44.40%	33.66%
Difference	5.12%	22.40%	22.40%	15.76%

Overall, mass leached is a better indicator of the variability in the model with the exception of orthophosphate in relation to total dry weight. Therefore, the remaining model analysis was evaluated with mass leached.

Nitrate and orthophosphate data (ppm and mg L) were analyzed using a linear mixed model with root dry weight (Root DW), total dry weight (Total DW), vegetation dry weight

(Veg DW) and percent dry weight (% DW) to determine the best predictor of variability in the data. The associated R^2 values are shown in Table 3.10.

TABLE 3.10. VARIANCE PREDICTED BY DRY WEIGHT

Independent Variable	NO3 mg L	PO4 mg L
Root DW	38.70%	53.40%
Total DW	38.47%	53.42%
Veg DW	36.05%	53.00%
% DW	34.32%	53.81%

Overall, the variance explained by Root DW, Total DW, Veg DW and % DW is very similar. While Root DW predicted mg of nitrate leached 0.23 percent better than Total DW, and % DW predicted mg of orthophosphate leached 0.41 percent better that Total DW, Total DW was the best overall predictor for nitrate and orthophosphate data. Therefore, it was used as the independent variable in the model.

Two different concentrations of phosphorus were dosed during the experiment. Three datasets were analyzed with Species, Total DW and Stormwater Applied as variables to determine if the data should be analyzed separately. The first data set was modified to include only the high concentration of phosphorus (7.97 mg/L). The second data set included only the low concentration of phosphorus (0.79 mg/L) and the third data set included all values of phosphorus. The associated R^2 values are shown in Table 3.11.

TABLE 3.11. VARIANCE PREDICTED BY DIFFERENT P CONCENTRATIONS

Dependent Variable	PO4 mg L	TP mg L
High Concentration P	62.46%	30.46%
Low Concentration P	49.44%	41.21%
All Concentration P	53.42%	36.26%

The dataset with only the high concentrations of phosphorus showed the highest R^2 value for orthophosphate while the dataset with the lowest concentrations of phosphorus showed the highest R^2 value for total phosphorus. It was determined to use all concentrations of phosphorus in the model to strike a balance between orthophosphate and total phosphorus predictors.

Final Model

A linear mixed model was used to evaluate the raw data. Model results were analyzed using the maximum likelihood method. Data was grouped by each column and the intercept was a random variable. Independent variables were established as species and stormwater applied for all nutrient data. Least means squared was completed with an alpha of 0.5 and using Tukey/Kramer adjustment. Plant tissue and soil data was analyzed using a linear model with the independent variable Species with an alpha of 0.5 and a Tukey adjustment to the least means squared. Independent variable for soil data were Species with Tukey adjustment to the least means squared. The model and least means squared adjustment for each dependent variable is shown in Table 3.12.

TABLE 3.12. MODEL CHARACTERISTICS FOR DEPENDENT VARIABLES

Dependent Variable	Model	LMS Adjustment
Nutrient Data	Mixed - Species, Stormwater Applied	Tukey/Kramer
Plant Tissue Data	Linear - Species	Tukey
Soil Data	Linear - Species	Tukey

Data is reported in this thesis as the model average with a 95 percent confidence interval. Statistical parameters for independent variables determined by the model will be reported with the F value and the probability that the mean is greater than the F value reported. Least squares means was used to analyze each vegetation group with an alpha value of 0.05 using a Tukey/Kramer correction factor for multiple comparisons. The least squares means data is reported with the t-statistic and the associated p-value.

QA/QC Data

Quality assurance samples were analyzed with each run on the IC. One blank was run with two sample duplicates, two standard samples and two matrix spikes. Average QA data is shown in Table 3.13. Duplicate and standard sample percentages indicate the variance of the sample. Matrix spike percentages indicate the percent recovered.

TABLE 3.13 NUTRIENT QA QC DATA

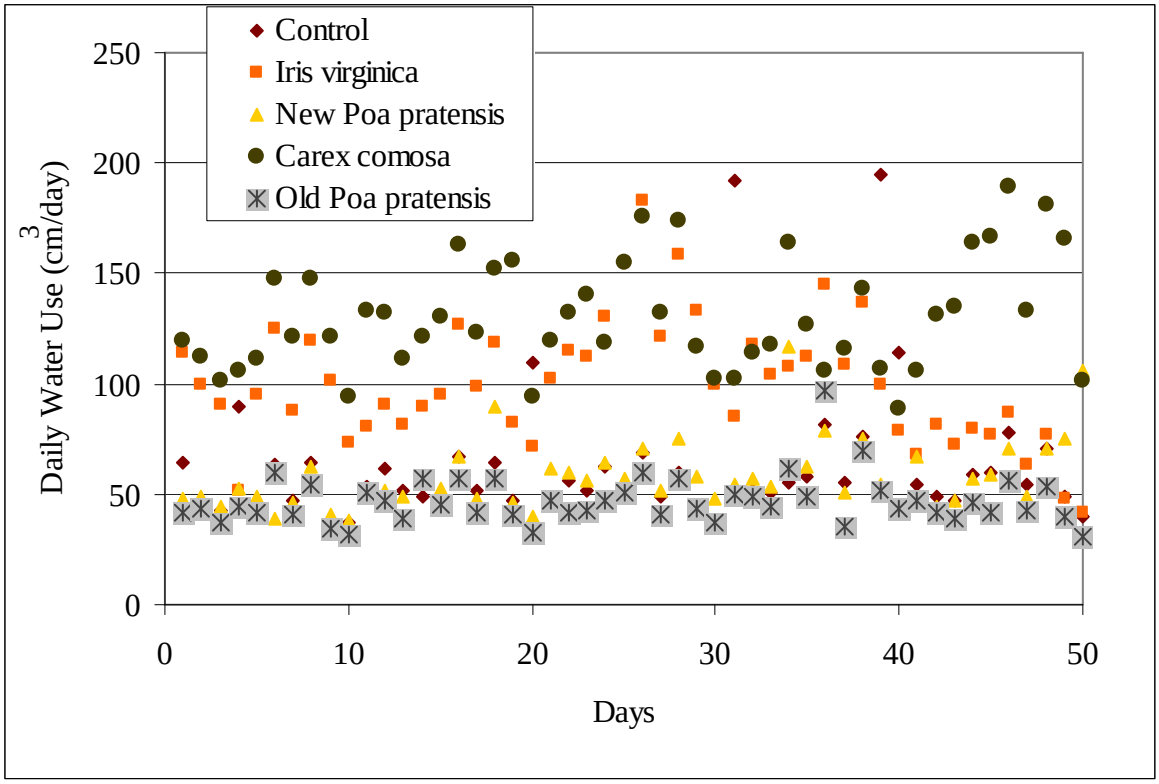
	NO3	PO4	NH4	TN	TP
Blank	7/10 ND	8/10 ND	6/6 ND	7/9 ND	8/9 ND
Duplicate A	16.01%	22.78%	0.83%	39.31%	52.44%
Duplicate B	12.79%	14.26%	0.83%	56.81%	51.76%
Standard A	18.47%	44.84%	8.00%	46.12%	69.76%
Standard B	37.89%	33.65%	13.48%	24.64%	70.92%
Matrix Spike A	-495.40%	65.49%	75.01%	-754.19%	-2.52%
Matrix Spike B	-442.48%	173.40%	61.28%	-632.48%	74.51%

CHAPTER FOUR: RESULTS

Water Use

Daily water use was calculated by subtracting the volume of leachate from the stormwater applied and dividing by the number of days between irrigation and stormwater application. Geometric mean water use did not change significantly during the duration of the experiment (P value 0.1258), shown in Figure 4.1.

FIGURE 4.1 GEOMETRIC MEAN DAILY WATER USE VS. TIME



Vegetation species and the amount of storm water dosed were significant predictors for water use in the mixed linear model, shown in Table 4.1. The covariance parameter estimate

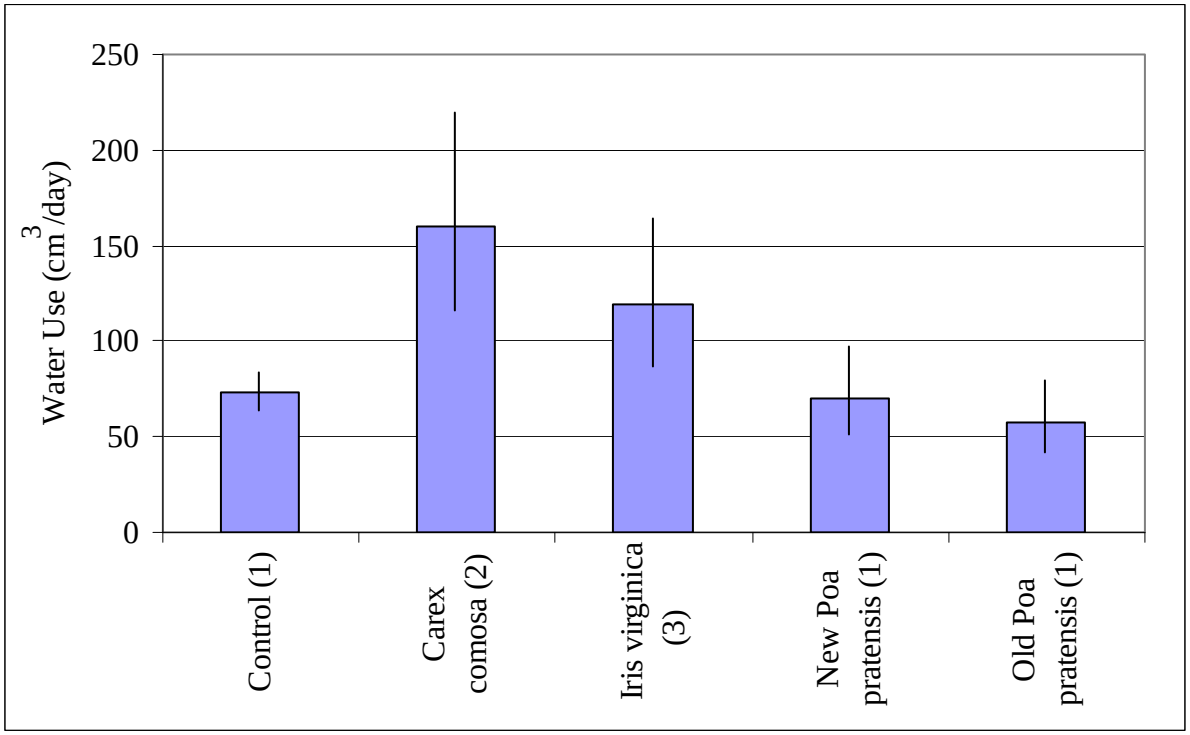
explained 73.9 percent (R^2) of the variation in the model. All stormwater volumes dosed were significantly different than the Control volume of 650 ml.

TABLE 4.1 TEST OF FIXED EFFECTS FOR DAILY WATER USE

Tests of Fixed Effects	F value	Pr>F
Species	45.43	<0.0001
Stormwater Applied	40.23	<0.0001

Carex comosa showed the highest water use (159.6 [115.92, 219.84] cm^3/day) followed by *Iris virginica* (119.4 [86.68, 164.4] cm^3/d). *Poa pratensis*, both Old and New had lower daily water use (57.4 [41.6, 79.0] cm^3/d; 70.5 [51.2, 97.0] cm^3/d) than the Control (72.9 [63.5, 83.6] cm^3/d). Statistical analyses of the fixed effects for daily water use are shown in Table 4.2. The geometric mean daily water use is shown graphically in Figure 4.2.

FIGURE 4.2 GEOMETRIC MEAN DAILY WATER USE



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.2 SOLUTION FOR FIXED EFFECTS FOR DAILY WATER USE

Species Parameters	Estimate cm^3/day	Standard Error	Pr > | t |
Control	72.9	1.07	<.0001
Carex comosa	159.6	1.09	<.0001
Iris virginica	119.4	1.09	<.0001
New Poa pratensis	70.5	1.09	0.7050
Old Poa pratensis	57.4	1.09	0.0121

*Control is the reference category

Stormwater Applied Parameters**	Estimate cm^3/day	Standard Error	Pr > | t |
500 ml	57.1	1.03	<0.0001
650 ml	72.9	1.07	<0.0001
800 ml	53.9	1.03	<0.0001

** 650 ml is the reference category

Carex comosa and *Iris virginica* were significantly different from each other as well as from the Control and New and Old *Poa pratensis*. There was not a significant difference between the Control and New *Poa pratensis*. However, there was a difference between the Control and Old *Poa pratensis* at a 0.1 significant level, shown in Table 4.3.

TABLE 4.3 DIFFERENCES OF LEAST SQUARES MEANS FOR DAILY WATER USE

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	3.3	0.0031	Tukey-Kramer	0.0234
Carex comosa	New Poa pratensis	9.2	<.0001	Tukey-Kramer	<.0001
Carex comosa	Old Poa pratensis	11.5	<.0001	Tukey-Kramer	<.0001
Carex comosa	Control	8.8	<.0001	Tukey-Kramer	<.0001
Iris virginica	New Poa pratensis	5.9	<.0001	Tukey-Kramer	<.0001
Iris virginica	Old Poa pratensis	8.3	<.0001	Tukey-Kramer	<.0001
Iris virginica	Control	5.6	<.0001	Tukey-Kramer	<.0001
New Poa pratensis	Old Poa pratensis	2.3	0.0287	Tukey-Kramer	0.1715
New Poa pratensis	Control	-0.38	0.7050	Tukey-Kramer	0.9951
Old Poa pratensis	Control	-2.7	0.0121	Tukey-Kramer	0.0817

Seepage Rate of Columns

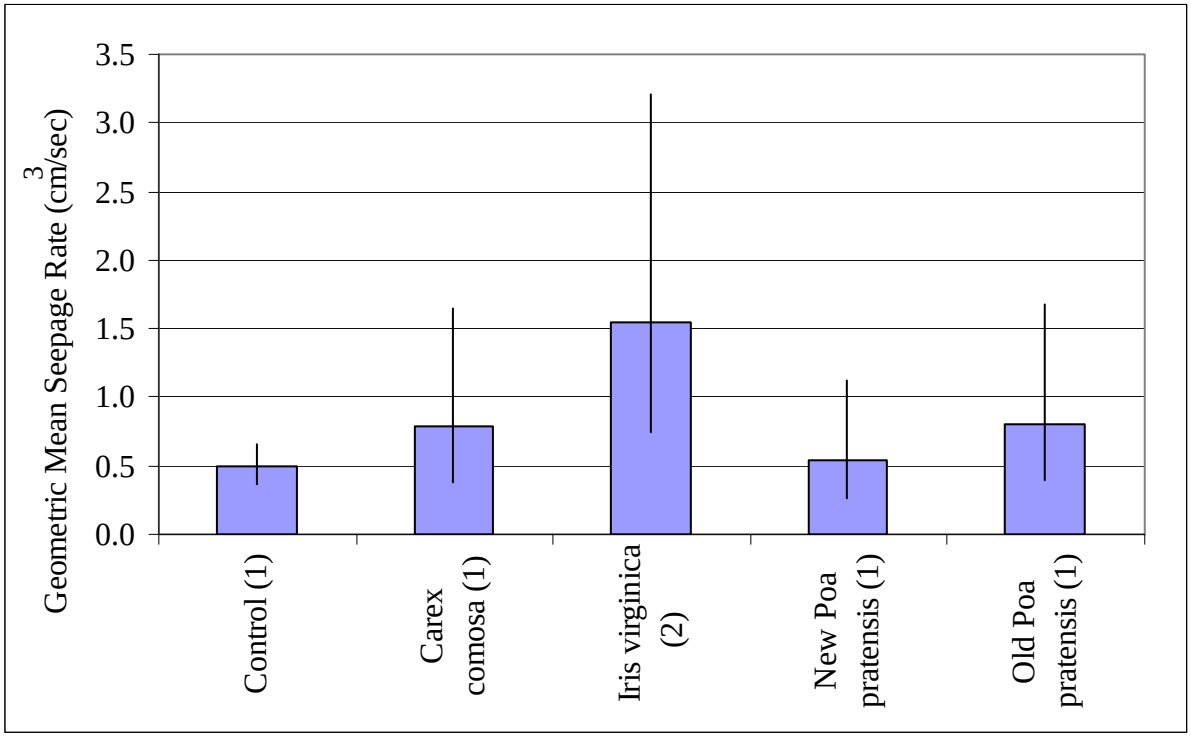
Seepage testing was completed on columns in the first and fourth banks to obtain two samples from each species. Both seepage rate and the coefficient of permeability were determined. The seepage rate will be presented with the knowledge that the coefficient of permeability is 35 percent of the seepage rate (centimeter/min). Vegetation species was a significant predictor using a mixed linear model, shown in Table 4.4. The covariance parameter estimate explained 74.6 percent (R^2) of the variation in the model.

TABLE 4.4 TEST OF FIXED EFFECTS FOR SEEPAGE RATE

Tests of Fixed Effects	F value	Pr>F
Species	11	0.0011

Columns planted in *Iris virginica* had the highest geometric mean seepage rate and the largest variability (1.54 [0.74, 3.2] cm^3/s). Statistical analysis of the fixed effects for geometric mean seepage rate is shown in Table 4.5. The geometric mean seepage rate is shown graphically in Figure 4.3.

FIGURE 4.3 SEEPAGE RATE BY VEGETATION SPECIES



(#) Different number indicate significance at a 0.05 level
Error bars indicate 95 percent confidence limit

TABLE 4.5 GEOMETRIC MEAN SEEPATE RATE SOLUTION FOR FIXED EFFECTS

Species Parameters	Estimate cm^3/s	Standard Error	Pr > | t |
Control	0.49	1.14	0.0004
Carex comosa	0.79	1.21	0.0314
Iris virginica	1.54	1.21	0.0001
New Poa pratensis	0.54	1.21	0.6202
Old Poa pratensis	0.81	1.21	0.0272

*Control is the reference category

Iris virginica was shown to be significantly different from all other columns. There was not a significant difference between the Control, New *Poa pratensis*, Old *Poa pratensis*, and *Carex comosa*, shown in Table 4.6.

TABLE 4.6 DIFFERENCES OF LEAST SQUARES MEANS FOR GEOMETRIC MEAN SEEPAGE RATE

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	-3.46	0.0061	Tukey-Kramer	0.0386
Carex comosa	New Poa pratensis	1.99	0.0747	Tukey-Kramer	0.3363
Carex comosa	Old Poa pratensis	-0.09	0.9338	Tukey-Kramer	1.0000
Carex comosa	Control	2.5	0.0314	Tukey-Kramer	0.1663
Iris virginica	New Poa pratensis	5.45	0.0003	Tukey-Kramer	0.0020
Iris virginica	Old Poa pratensis	3.37	0.0071	Tukey-Kramer	0.0440
Iris virginica	Control	5.96	0.0001	Tukey-Kramer	0.0010
New Poa pratensis	Old Poa pratensis	-2.07	0.0648	Tukey-Kramer	0.3012
New Poa pratensis	Control	0.51	0.6202	Tukey-Kramer	0.9843
Old Poa pratensis	Control	2.59	0.0272	Tukey-Kramer	0.1468

Nutrient Results

Leachate collected from the bottom of the columns was weighed to determine the volume of leachate and then analyzed as discussed in Chapter Three to determine the concentration of ammonia, nitrate, total nitrogen, orthophosphate and total phosphorus. Data in this section will be reported as concentration of nutrient in the leachate and the mass of nutrient leached. Mass of leached nutrients was determined by taking the concentration of the nutrient found in the leachate and multiplying it by the volume of simulated stormwater that was leached.

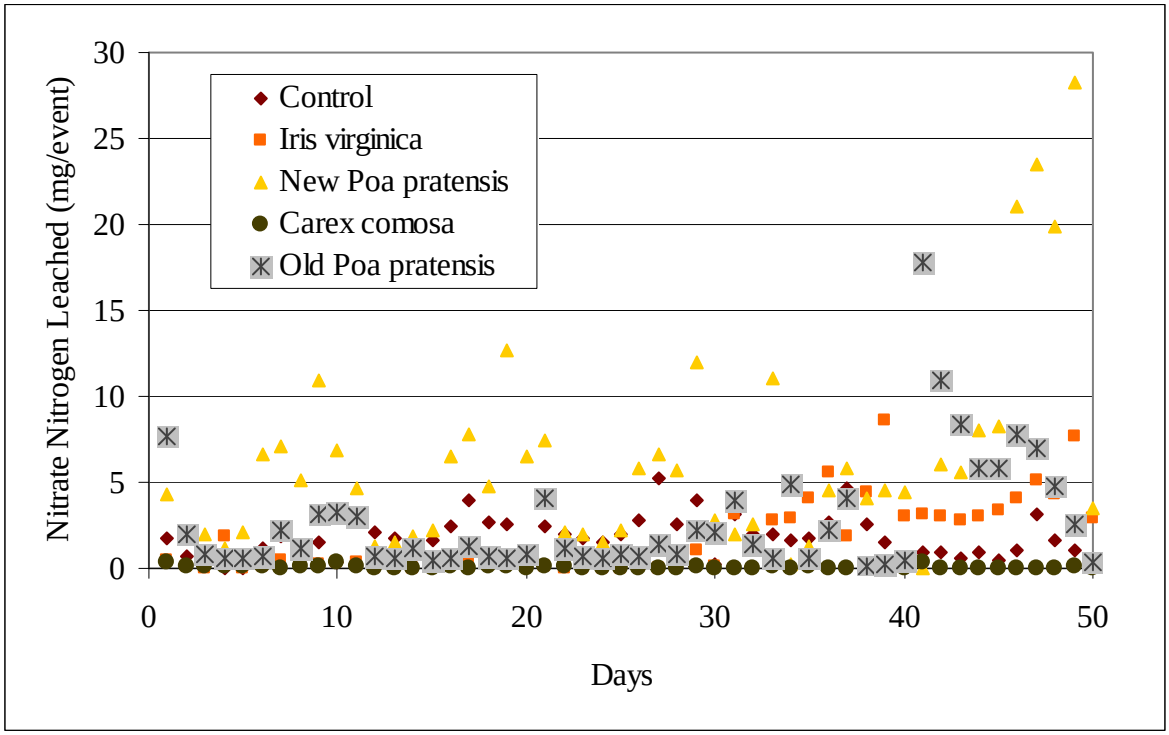
Ammonia Nitrogen Results

The minimum detection limit for ammonia is 0.1 ppm as discussed in Section 3.6.1. Ammonia concentrations in all samples with the exception of column C2 (0.17 ppm) on 4/21/2011 were determined to be non-detects.

Nitrate Nitrogen Results

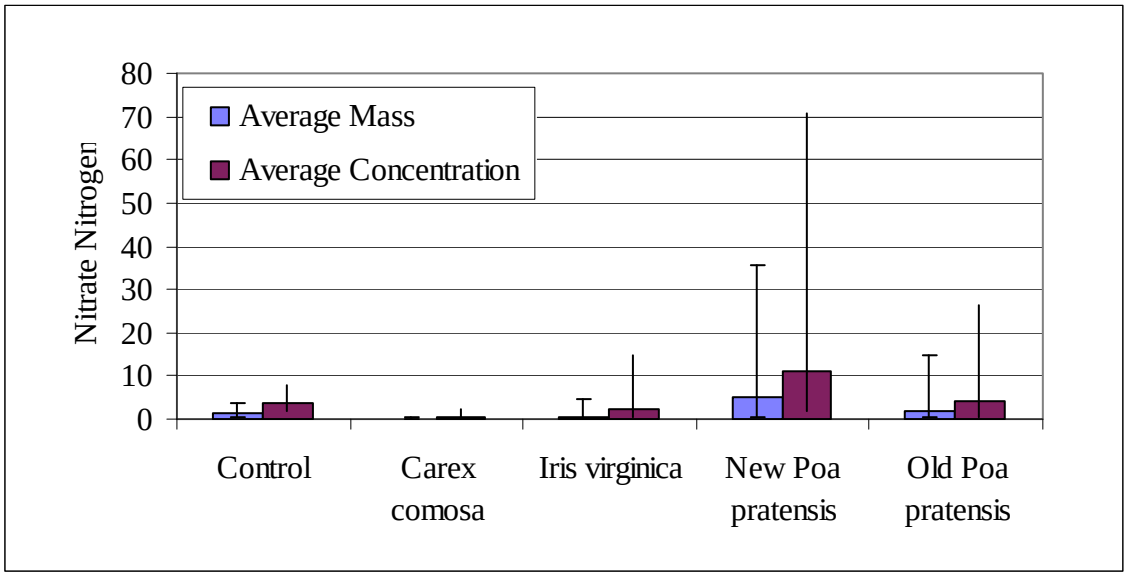
Nitrate nitrogen leached (mg per event) did not change significantly during the duration of the experiment (P value 0.0809), shown in Figure 4.4. While time was significant predicting nitrate nitrogen leached at a 0.1 significance level, the model only explained 0.4 percent of the variability (R^2). This loose correlation may be attributed to the degradation of New *Poa pratensis* columns towards the end of the study. Columns NT1, NT3 and NT5 had significant reductions in plant matter from the beginning of the study. However, the correlation between the results and time was determined to be insignificant due to the low R^2 value.

FIGURE 4.4 MASS NITRATE NITROGEN LEACHED VS. TIME



The concentration of nitrate leached is compared against the mass of nitrate leached for each species below in Figure 4.5. The Control and *Iris virginica* and Old *Poa pratensis* showed similar nitrate concentrations in the leachate.

FIGURE 4.5 MASS NITRATE NITROGEN LEACHED VS. CONCENTRATION NITRATE NITROGEN LEACHED



New *Poa pratensis* showed the highest nitrate concentration as well as the highest mass of nitrate leached while *Carex comosa* was significantly lower that all other columns. However, there is a significant correlation in the concentration of nitrate leached vs. the mass of nitrate leached ($R^2 = 0.97$). Therefore, the remaining analysis is completed using the mass of nitrate leached.

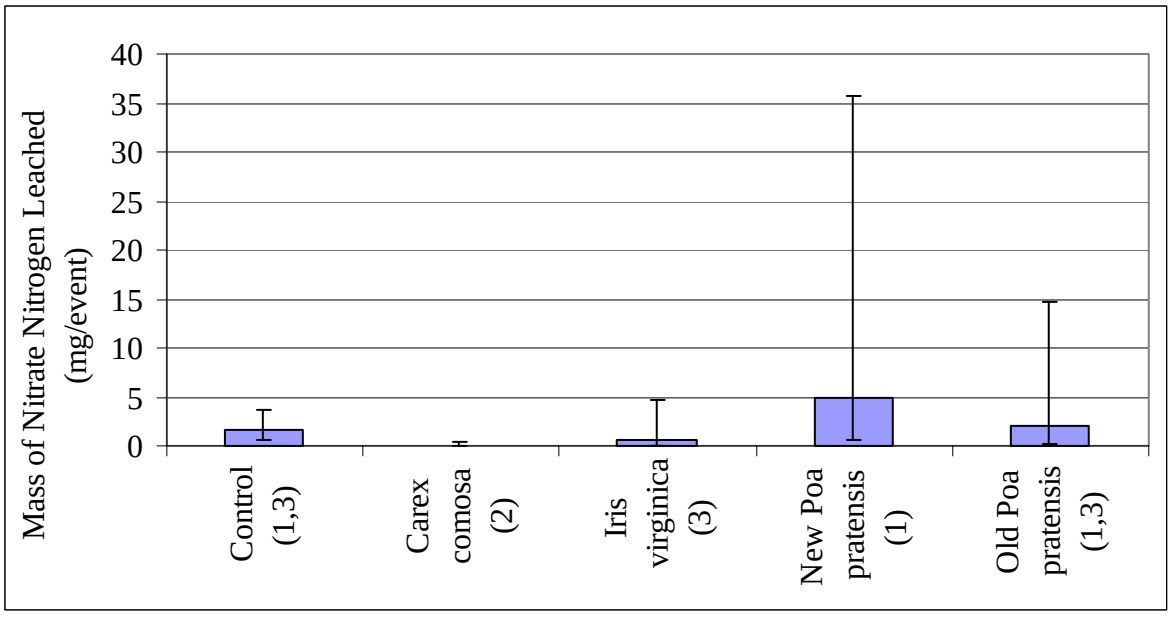
Vegetation species and the amount of storm water dosed were significant predictors using a mixed linear model, shown in Table 4.7. The covariance parameter estimate explained 57.5 percent (R^2) of the variation in the model. The lower stormwater volume dosed (500 ml) is significantly different than the Control volume of 650 ml and the higher stormwater volume dosed (800 ml).

TABLE 4.7 TEST OF FIXED EFFECTS FOR MASS OF NITRATE LEACHED

Tests of Fixed Effects	F value	Pr>F
Species	19.41	<0.0001
Stormwater Applied	12.05	<0.0001

Carex comosa showed lowest nitrate nitrogen mass leached (0.05 [0.01, 0.38] mg/event) followed by *Iris virginica* (0.64 [0.09, 4.7] mg/event). *Poa pratensis*, both Old and New had higher nitrate nitrogen mass leached (2.0 [0.27, 14.8] mg/event; 4.85 [0.66, 35.8] mg/event) than the Control (1.5 [0.67, 3.6] mg/event). Statistical analysis of the fixed effects for mass of nitrate nitrogen leached is shown in Table 4.8. The geometric mean nitrate nitrogen leached is shown graphically in Figure 4.6.

FIGURE 4.6 GEOMETRIC MEAN MASS OF NITRATE NITROGEN LEACHED PER EVENT



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.8 SOLUTION FOR FIXED EFFECTS FOR NITRATE NITROGEN

	Estimate		
Species Parameters	mg	Standard Error	Pr > | t |
Control	1.5	1.5	0.3033
Carex comosa	0.05	1.75	<.0001
Iris virginica	0.64	1.74	0.123
New Poa pratensis	4.9	1.74	0.0505
Old Poa pratensis	2.0	1.74	0.6450
*Control is the reference category			
	Estimate		
Stormwater Applied Parameters**	mg	Standard Error	Pr > | t |
500 ml	0.8	1.2	0.004
650 ml	1.6	1.5	0.3033
800 ml	1.6	1.2	0.9209
** 650 ml is the reference category			

Carex comosa was shown to be significantly different from all other columns as well as *Iris virginica* from New *Poa pratensis*. There was not a significant difference between the Control and New *Poa pratensis*, Old *Poa pratensis*, or *Iris virginica*, shown in Table 4.9.

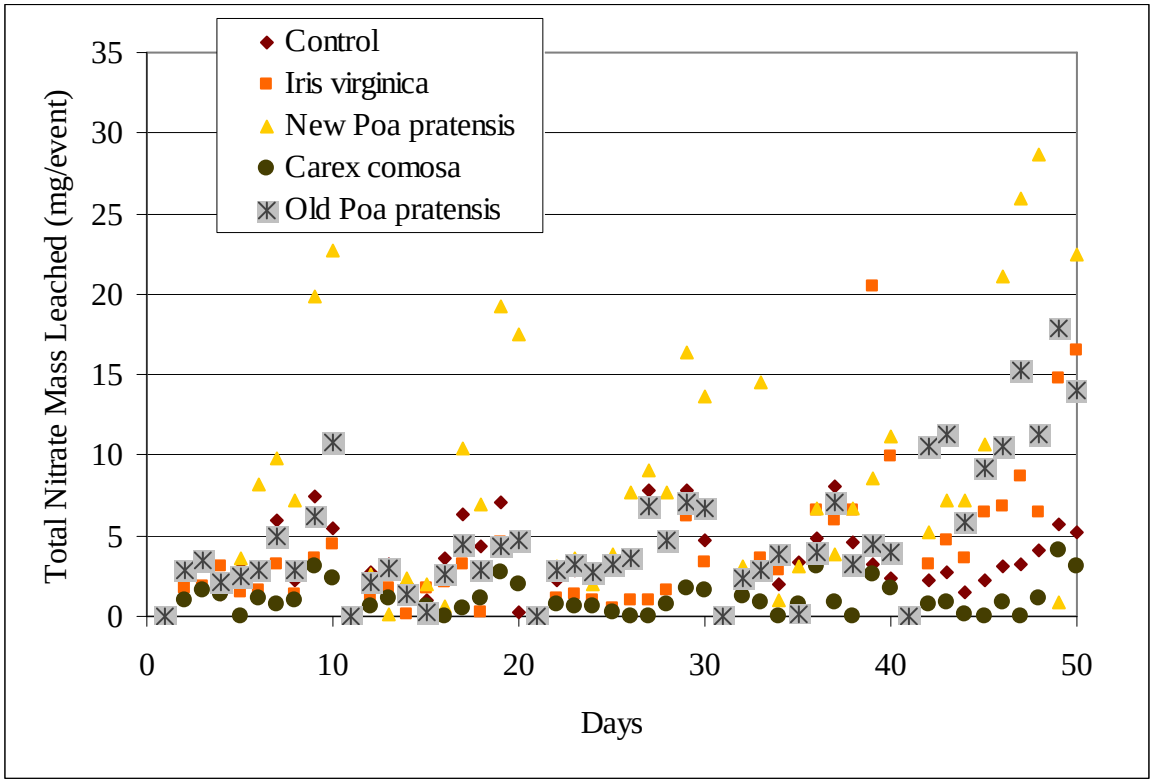
TABLE 4.9 DIFFERENCES OF LEAST SQUARES MEANS FOR NITRATE NITROGEN

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	-4.5	0.0001	Tukey-Kramer	0.0011
Carex comosa	New Poa pratensis	-8.2	<.0001	Tukey-Kramer	<.0001
Carex comosa	Old Poa pratensis	-6.6	<.0001	Tukey-Kramer	<.0001
Carex comosa	Control	-6.1	<.0001	Tukey-Kramer	<.0001
Iris virginica	New Poa pratensis	-3.7	0.0012	Tukey-Kramer	0.0096
Iris virginica	Old Poa pratensis	-2.1	0.0497	Tukey-Kramer	0.2671
Iris virginica	Control	-1.6	0.1230	Tukey-Kramer	0.5133
New Poa pratensis	Old Poa pratensis	1.6	0.1247	Tukey-Kramer	0.5179
New Poa pratensis	Control	2.1	0.0505	Tukey-Kramer	0.2704
Old Poa pratensis	Control	0.47	0.6450	Tukey-Kramer	0.9897

Total Nitrogen Results

Total nitrogen leached (mg per event) did change significantly during the experiment (P value 0.0243), shown in Figure 4.7. While time was significant, the model only explained 2.6 percent of the variability (R^2). This loose correlation may be attributed to the increase in total nitrogen trend shown in Old *Poa pratensis* columns and to a lesser extent *Iris virginica* columns towards the end of the study. The variability of the data from the New *Poa pratensis* columns (due to the degradation of specific columns discussed in Plant Tissue Results) also contributed to the significant P value. However, time was not included in the model due to the low R^2 value.

FIGURE 4.7 TOTAL NITROGEN MASS LEACHED VS. TIME



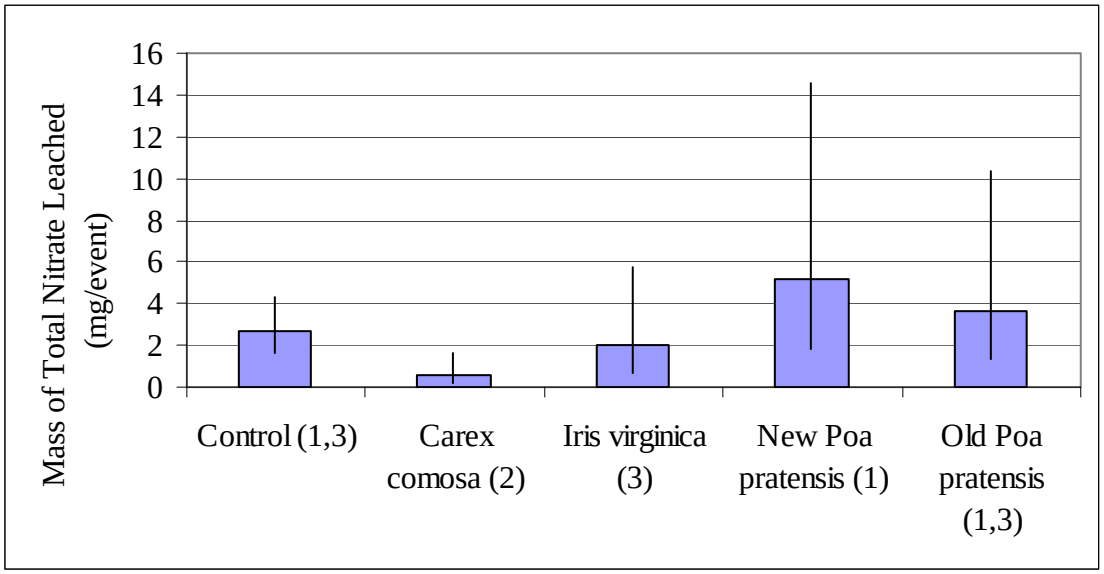
Vegetation species and the amount of storm water dosed were significant predictors using a mixed linear model, shown in Table 4.10. However, the covariance parameter estimate explained 2.6 percent (R^2) of the variation in the model. The higher stormwater volume dosed (800 ml) is significantly different than the Control volume of 650 ml and the lower stormwater volume dosed (500 ml). However, the lower stormwater volume dosed (500 ml) was different from the Control at the 0.1 level.

TABLE 4.10 TEST OF FIXED EFFECTS FOR MASS OF TOTAL NITROGEN LEACHED

Tests of Fixed Effects	F value	Pr>F
Species	18.83	<0.0001
Stormwater Applied	21.20	<0.0001

Carex comosa showed lowest total nitrogen mass leached (0.57 [0.20, 1.6] mg/event) followed by *Iris virginica* (2.0 [0.72, 5.7] mg/event). *Poa pratensis*, both Old and New had higher total nitrogen mass leached (3.7 [1.3, 10.4] mg/event; 5.1 [1.8, 14.5] mg/event) than the Control (2.7 [1.7, 4.3] mg/event). Statistical analysis of the fixed effects for total nitrogen leached is shown in Table 4.11. The geometric mean total nitrogen leached is shown graphically in Figure 4.8.

FIGURE 4.8 GEOMETRIC MEAN MASS OF TOTAL NITROGEN LEACHED PER EVENT



(#) Different number indicate significance at a 0.05 level
Error bars indicate 95 percent confidence limit

TABLE 4.11 SOLUTION FOR FIXED EFFECTS FOR TOTAL NITROGEN

	Estimate		
Species Parameters	mg	Standard Error	Pr > | t |
Control	2.7	1.3	0.001
Carex comosa	0.57	1.3	<.0001
Iris virginica	2.0	1.3	0.3203
New Poa pratensis	5.1	1.3	0.0247
Old Poa pratensis	3.7	1.3	0.2575
*Control is the reference category			
	Estimate		
Stormwater Applied Parameters**	mg	Standard Error	Pr > | t |
500 ml	1.9	1.2	0.0701
650 ml	2.7	1.6	0.001
800 ml	5.8	8.3	0.0003
** 650 ml is the reference category			

Carex comosa was shown to be significantly different from all other columns as well as *Iris virginica* from New *Poa pratensis*. There was not a significant difference between the Control and New *Poa pratensis*, Old *Poa pratensis*, or *Iris virginica*, shown in Table 4.12.

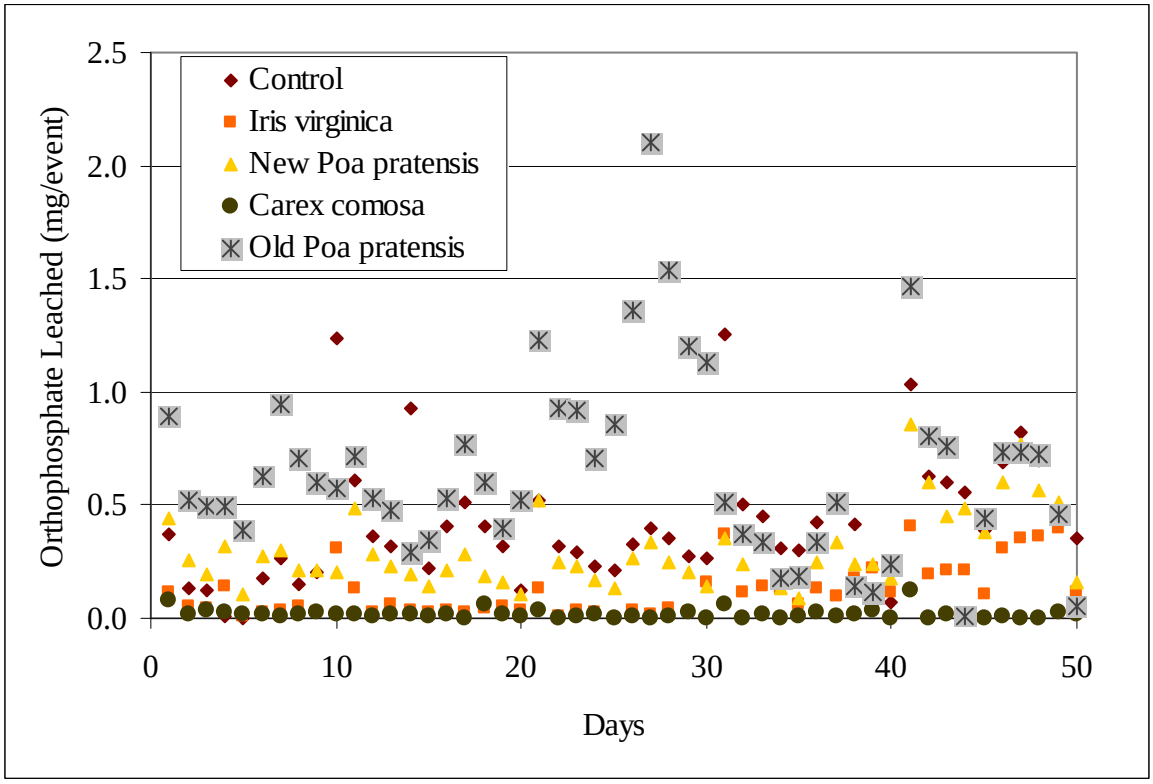
TABLE 4.12 DIFFERENCES OF LEAST SQUARES MEANS FOR TOTAL NITROGEN

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	-4.64	<.0001	Tukey-Kramer	0.0008
Carex comosa	New Poa pratensis	-8.02	<.0001	Tukey-Kramer	<.0001
Carex comosa	Old Poa pratensis	-6.80	<.0001	Tukey-Kramer	<.0001
Carex comosa	Control	-5.65	<.0001	Tukey-Kramer	<.0001
Iris virginica	New Poa pratensis	-3.41	0.0023	Tukey-Kramer	0.0173
Iris virginica	Old Poa pratensis	-2.17	0.0396	Tukey-Kramer	0.2224
Iris virginica	Control	-1.01	0.3203	Tukey-Kramer	0.8465
New Poa pratensis	Old Poa pratensis	1.23	0.2292	Tukey-Kramer	0.7327
New Poa pratensis	Control	2.39	0.0247	Tukey-Kramer	0.1505
Old Poa pratensis	Control	0.47	0.2575	Tukey-Kramer	0.7738

Orthophosphate Results

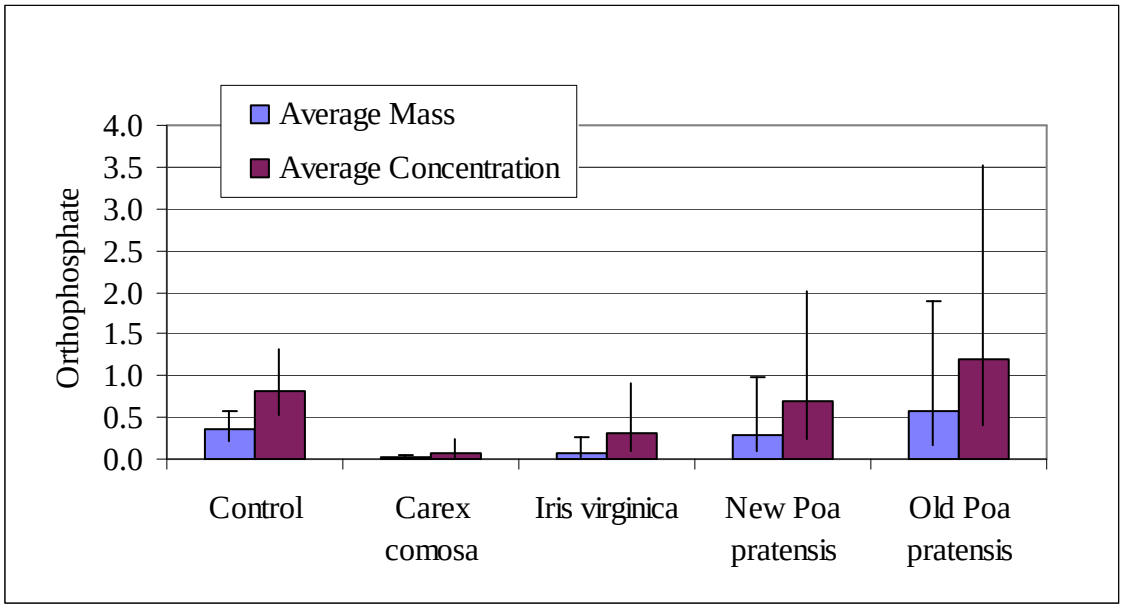
Time was a significant predictor based on orthophosphate leached (mg per event - P value <0.0001). However, the model only explained 3.9 percent of the variability (R^2). Therefore, it was determined to be insignificant, shown in Figure 4.9.

FIGURE 4.9 MASS ORTHOPHOSPHATE LEACHED VS. TIME



The concentration of orthophosphate leached is compared against the mass of orthophosphate leached for each species below in Figure 4.10. The concentration of orthophosphate leached was lower for native vegetation. *Carex comosa*, *Iris virginica*, and New *Poa pratensis* had lower concentrations of orthophosphate leached than the Control. Old *Poa pratensis* showed an increase in concentration of orthophosphate leached.

FIGURE 4.10 MASS ORTHOPHOSPHATE LEACHED VS. CONCENTRATION ORTHOPHOSPHATE LEACHED



There is a significant correlation in the concentration of orthophosphate leached vs. the mass of orthophosphate leached (R^2 = 99.2). Therefore, the remaining analysis is completed using the mass of orthophosphate leached.

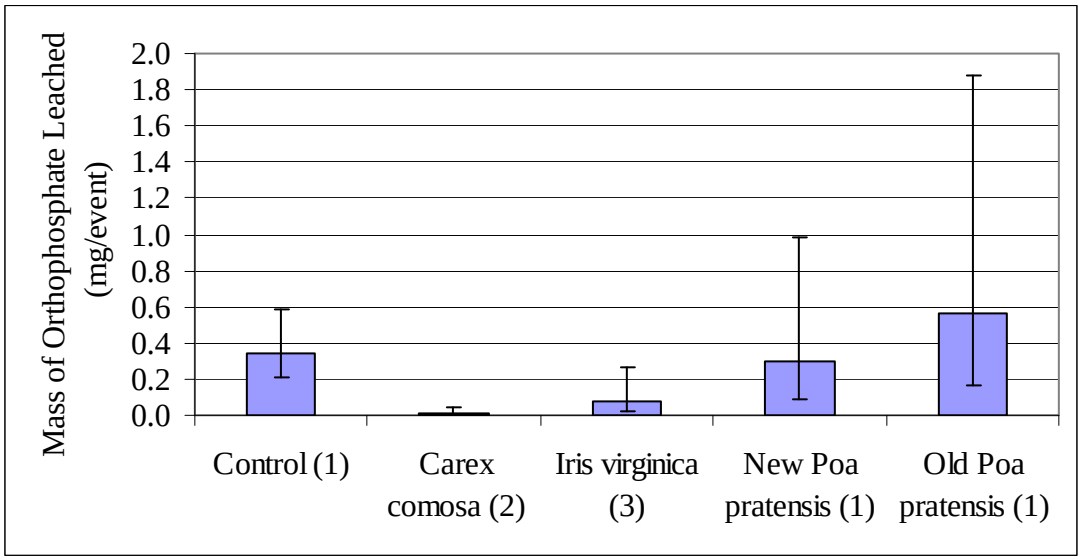
Vegetation species and the amount of storm water dosed were significant predictors using a mixed linear model, shown in Table 4.13. The covariance parameter estimate explained 47.4 percent (R^2) of the variation in the model. The lower stormwater volume dosed (500 ml) is significantly different than the Control volume of 650 ml and the higher stormwater volume dosed (800 ml).

TABLE 4.13 TEST OF FIXED EFFECTS FOR MASS OF ORTHOPHOSPHATE LEACHED

Tests of Fixed Effects	F value	Pr>F
Species	40.76	<0.0001
Stormwater Applied	11.30	<0.0001

Carex comosa showed lowest orthophosphate mass leached (0.01 [0.00, 0.04] mg/event) followed by *Iris virginica* (0.08 [0.02, 0.27] mg/event). New *Poa pratensis* showed a lower orthophosphate leached (0.29 [0.09, 0.98] mg/event) than the Control (0.35 [0.21, 0.58] mg/event). Old Poa pratensis had a higher orthophosphate mass leached than the Control (0.56 [0.17, 1.9] mg/event). Statistical analysis of the fixed effects for orthophosphate mass leached is shown in Table 4.14. The geometric mean orthophosphate mass leached is shown graphically in Figure 4.11.

FIGURE 4.11 GEOMETRIC MEAN MASS OF ORTHOPHOSPHATE LEACHED PER EVENT



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.14 SOLUTION FOR FIXED EFFECTS FOR ORTHOPHOSPHATE

	Estimate		
Species Parameters	mg	Standard Error	Pr > | t |
Control	0.35	1.3	0.0002
Carex comosa	0.01	1.4	<.0001
Iris virginica	0.08	1.4	0.0002
New Poa pratensis	0.29	1.4	0.6166
Old Poa pratensis	0.56	1.4	0.1578
*Control is the reference category			
	Estimate		
Stormwater Applied Parameters**	mg	Standard Error	Pr > | t |
500 ml	0.23	1.1	0.0034
650 ml	0.35	1.3	0.0002
800 ml	0.39	1.1	0.4094
** 650 ml is the reference category			

Carex comosa and *Iris virginica* is significantly different from all other columns. There was not a significant difference between the Control, New *Poa pratensis*, and Old *Poa pratensis*, shown in Table 4.15.

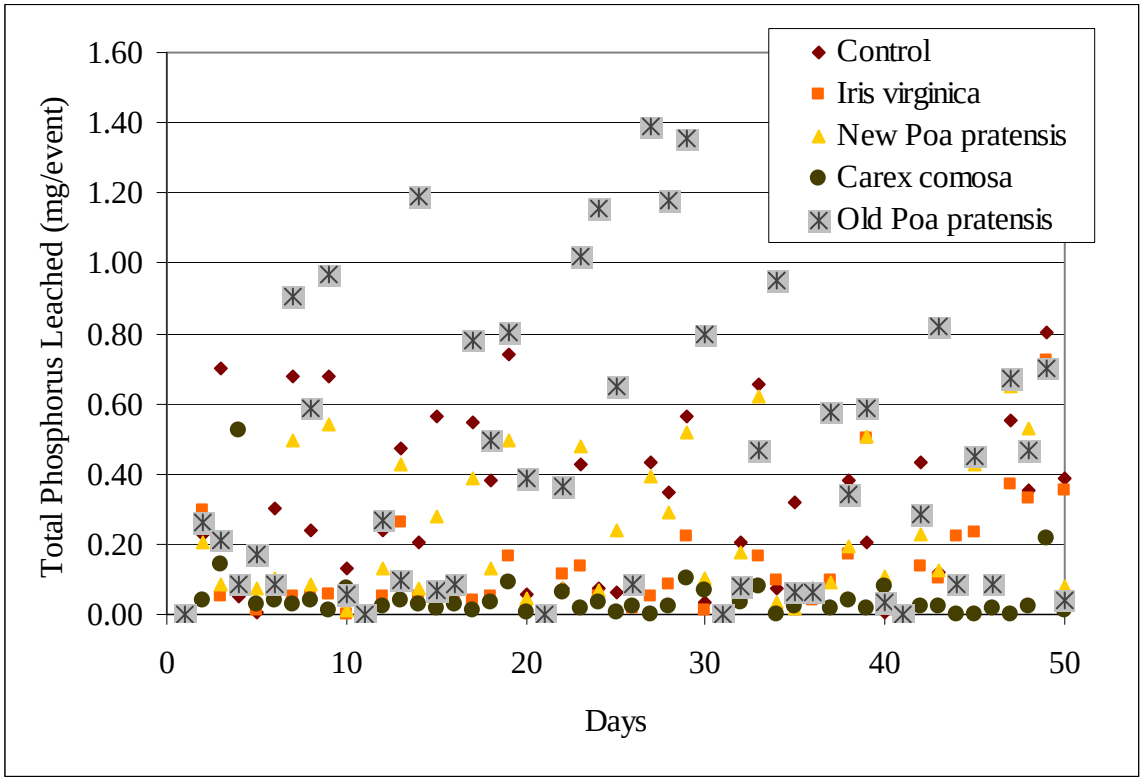
TABLE 4.15 DIFFERENCES OF LEAST SQUARES MEANS FOR ORTHOPHOSPHATE

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	-5.39	<.0001	Tukey-Kramer	0.0001
Carex comosa	New Poa pratensis	-9.24	<.0001	Tukey-Kramer	<.0001
Carex comosa	Old Poa pratensis	-11.20	<.0001	Tukey-Kramer	<.0001
Carex comosa	Control	-9.75	<.0001	Tukey-Kramer	<.0001
Iris virginica	New Poa pratensis	-3.87	0.0007	Tukey-Kramer	0.0057
Iris virginica	Old Poa pratensis	-5.83	<.0001	Tukey-Kramer	<.0001
Iris virginica	Control	-4.38	0.0002	Tukey-Kramer	0.0016
New Poa pratensis	Old Poa pratensis	-1.96	0.0609	Tukey-Kramer	0.3121
New Poa pratensis	Control	-0.51	0.6166	Tukey-Kramer	0.9859
Old Poa pratensis	Control	1.46	0.1578	Tukey-Kramer	0.5988

Total Phosphorus Results

Total phosphorus leached (mg per event) did not change significantly during the duration of the experiment (P value 0.8024), shown in Figure 4.12. The model with time as a predictor explained 0.02 percent of the variability (R^2). Therefore, it was determined to be insignificant.

FIGURE 4.12 MASS TOTAL PHOSPHORUS LEACHED VS. TIME



Vegetation species was a significant predictor using a mixed linear model, shown in Table 4.16. The covariance parameter estimate explained 36.9 percent (R^2) of the variation in the model. Stormwater dosed was not a significant predictor in determining the mass of total phosphorous leached.

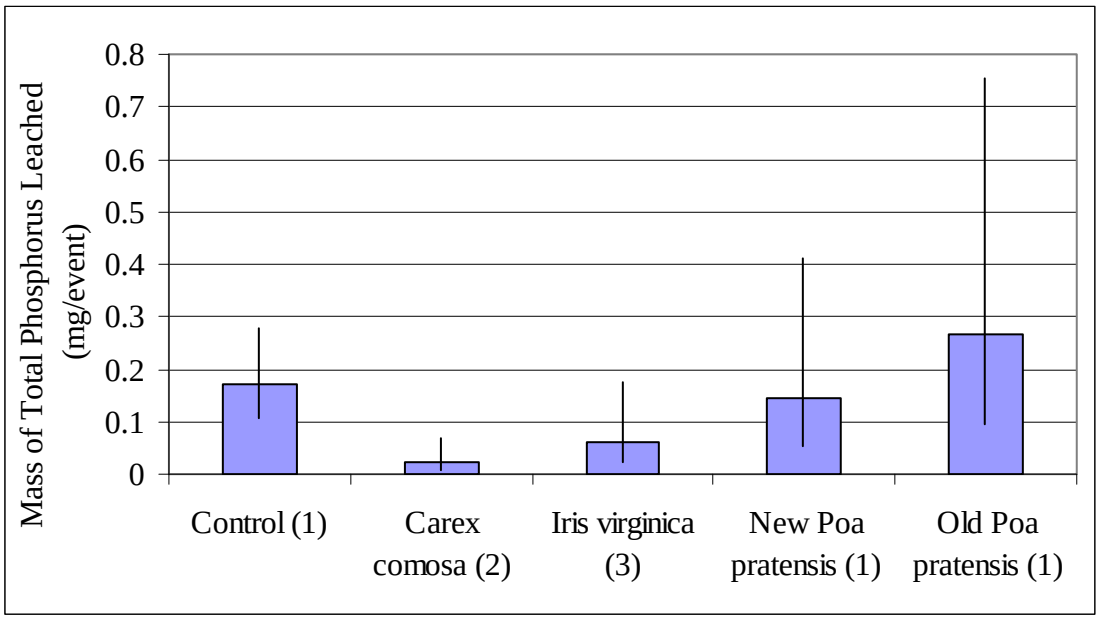
TABLE 4.16 TEST OF FIXED EFFECTS FOR MASS OF TOTAL PHOSPHORUS LEACHED

Tests of Fixed Effects	F value	Pr>F
Species	24.48	<0.0001
Stormwater Applied	1.26	0.2864

Carex comosa showed lowest total phosphorus mass leached (0.02 [0.01, 0.07] mg/event) followed by *Iris virginica* (0.06 [0.02, 0.18] mg/event). New *Poa pratensis* showed a

lower total phosphorus leached (0.15 [0.05, 0.41] mg/event) than the Control (0.17 [0.11, 0.28] mg/event). Old *Poa pratensis* had a higher total phosphorus mass leached than the Control (0.27 [0.09, 0.76] mg/event). Statistical analysis of the fixed effects for total phosphorus mass leached is shown in Table 4.17. The geometric mean orthophosphorus mass leached is shown graphically in Figure 4.13.

FIGURE 4.13 GEOMETRIC MEAN MASS OF TOTAL PHOSPHORUS LEACHED PER EVENT



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.17 SOLUTION FOR FIXED EFFECTS FOR TOTAL PHOSPHORUS

	Estimate		
Species Parameters	mg	Standard Error	Pr > | t |
Control	0.17	1.3	<.0001
Carex comosa	0.02	1.3	<.0001
Iris virginica	0.06	1.3	0.0009
New Poa pratensis	0.15	1.3	0.5368
Old Poa pratensis	0.27	1.3	0.1224
*Control is the reference category			
	Estimate		
Stormwater Applied Parameters**	mg	Standard Error	Pr > | t |
500 ml	0.19	1.2	0.7053
650 ml	0.17	1.3	<.0001
800 ml	0.23	1.2	0.1528
** 650 ml is the reference category			

Carex comosa and *Iris virginica* is significantly different from all other columns. There was not a significant difference between the Control, New *Poa pratensis*, and Old *Poa pratensis*, shown in Table 4.18.

TABLE 4.18 DIFFERENCES OF LEAST SQUARES MEANS FOR TOTAL PHOSPHORUS

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	-3.50	0.0017	Tukey-Kramer	0.0138
Carex comosa	New Poa pratensis	-6.61	<.0001	Tukey-Kramer	<.0001
Carex comosa	Old Poa pratensis	-8.81	<.0001	Tukey-Kramer	<.0001
Carex comosa	Control	-7.23	<.0001	Tukey-Kramer	<.0001
Iris virginica	New Poa pratensis	-3.13	0.0044	Tukey-Kramer	0.0323
Iris virginica	Old Poa pratensis	-5.36	<.0001	Tukey-Kramer	0.0001
Iris virginica	Control	-3.76	0.0009	Tukey-Kramer	0.0074
New Poa pratensis	Old Poa pratensis	-2.23	0.0354	Tukey-Kramer	0.2032
New Poa pratensis	Control	-0.63	0.5368	Tukey-Kramer	0.9694
Old Poa pratensis	Control	1.60	0.1224	Tukey-Kramer	0.5115

Transition Metal Results

Transition Metals were below detection limits in all samples analyzed. The concentration in the stormwater was very low (in the ppb range) and dosed in relatively small amounts (500 to 800 mL). Bioretention basins have historically been very efficient at removing transition metals through filtering in the bioretention soil media.

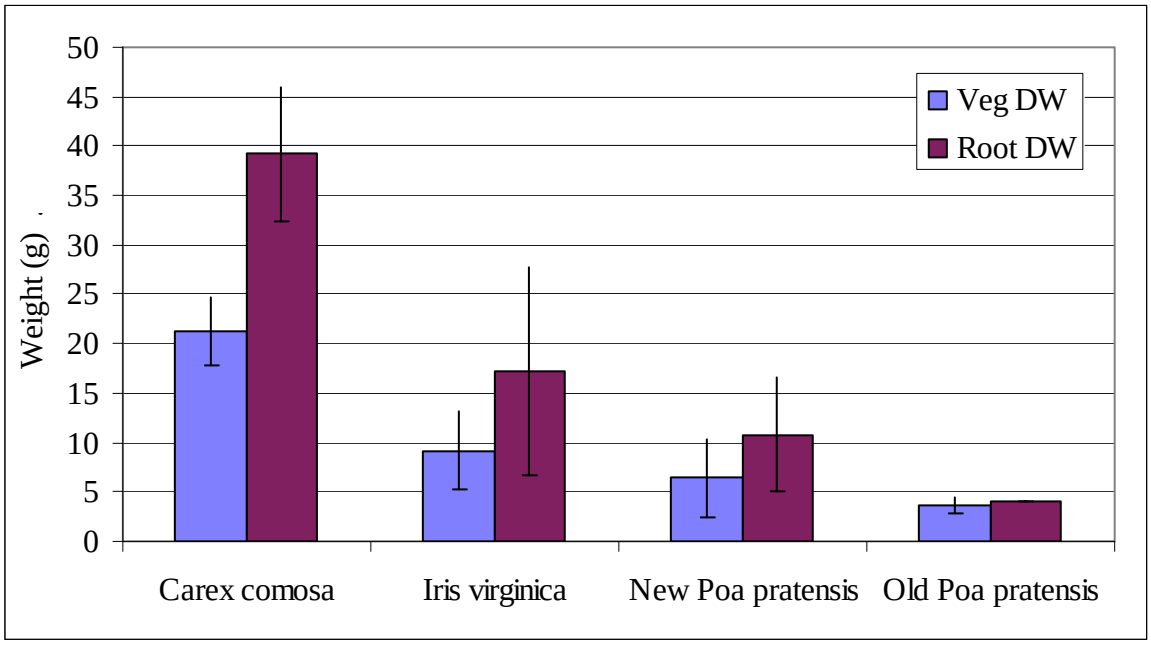
Plant Tissue Results

Vegetation Characteristics

Carex comosa and *Iris virginica* vegetation had a higher vegetation mass as well as root mass (dry weight) than *Poa pratensis* vegetation. *Carex comosa* had the highest vegetation mass of 21.2 [17.8, 24.6] g grams dry weight, followed by *Iris virginica* at 9.2 [5.2, 13.2] grams. New *Poa pratensis* and Old *Poa pratensis* showed roughly 25 percent of the vegetation mass of *Carex comosa* and *Iris virginica* vegetation (6.4 [2.4, 10.4] g and 3.6 [2.8, 4.4] grams).

Carex comosa had the highest root mass of 39.2 [32.5, 45.9] g grams dry weight, followed by *Iris virginica* at 17.2 [6.2, 27.7] grams. New *Poa pratensis* and Old *Poa pratensis* showed roughly 25 percent of the root mass of the *Carex comosa* and *Iris virginica* vegetation (10.8 [5.0, 16.6] grams and 4.0 [0.0 to 8.0] grams). Vegetation and root mass for each species is shown in Figure 4.14.

FIGURE 4.14 AVERAGE VEGETATION AND ROOT DRY MASS BY SPECIES



Error bars indicate 95 percent confidence limit

Nitrogen Results

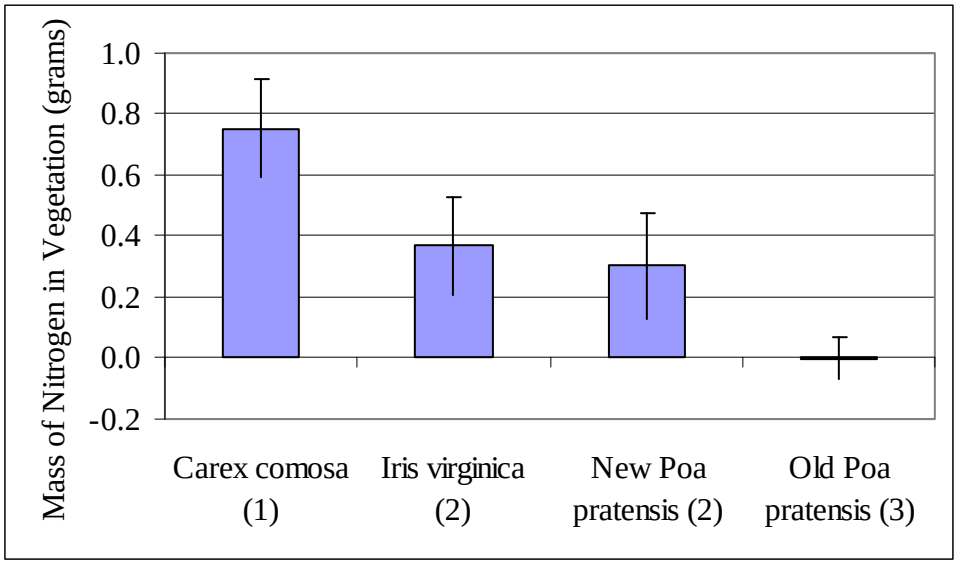
Species was a significant predictor in determining the percent of total nitrogen in vegetation using a linear model, shown in Table 4.19. The covariance parameter estimate explained 92.9 percent (R^2) of the variation in the model.

TABLE 4.19 TEST OF FIXED EFFECTS FOR MASS OF TOTAL NITROGEN IN VEGETATION

Tests of Fixed Effects	F value	Pr>F
Species	78.87	<0.0001

Carex comosa showed the highest nitrogen mass (0.75 [0.59, 0.91] grams) followed by *Iris virginica* (0.37 [0.21, 0.53] grams) and new *Poa pratensis* (0.30 [0.13, 0.48] grams). Old *Poa pratensis* had the lowest nitrogen mass due to the dead and decaying plant matter (0.09 [0.03, 0.16] grams). Statistical analysis of the fixed effects for nitrogen mass in vegetation is shown in Table 4.20. The mean nitrogen mass in vegetation is shown graphically in Figure 4.15.

FIGURE 4.15 MEAN MASS OF NITROGEN IN VEGETATION



(#) Different number indicate significance at a 0.05 level
Error bars indicate 95 percent confidence limit

TABLE 4.20 SOLUTION FOR FIXED EFFECTS FOR MASS NITROGEN IN VEGETATION

	Estimate		
Species Parameters	mg	Standard Error	Pr > | t |
Carex comosa	0.75	0.04	<.0001
Iris virginica	0.37	0.04	<.0001
New Poa pratensis	0.30	0.05	0.0009
Old Poa pratensis	0.09	0.03	0.0098

*Old *Poa pratensis* is the reference category

Carex comosa and Old *Poa pratensis* are significantly different from all other columns. There was not a significant difference between *Iris virginica* and New *Poa pratensis*, shown in Table 4.21.

TABLE 4.21 DIFFERENCES OF LEAST SQUARES MEANS FOR MASS OF NITORGEN IN VEGETATION

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	8.81	<.0001	Tukey-Kramer	<.0001
Carex comosa	New Poa pratensis	8.91	<.0001	Tukey-Kramer	<.0001
Carex comosa	Old Poa pratensis	15.14	<.0001	Tukey-Kramer	<.0001
Iris virginica	New Poa pratensis	1.28	0.2197	Tukey-Kramer	0.5867
Iris virginica	Old Poa pratensis	6.33	<.0001	Tukey-Kramer	<.0001
New Poa pratensis	Old Poa pratensis	4.20	0.0009	Tukey-Kramer	0.0044

Phosphorus Results

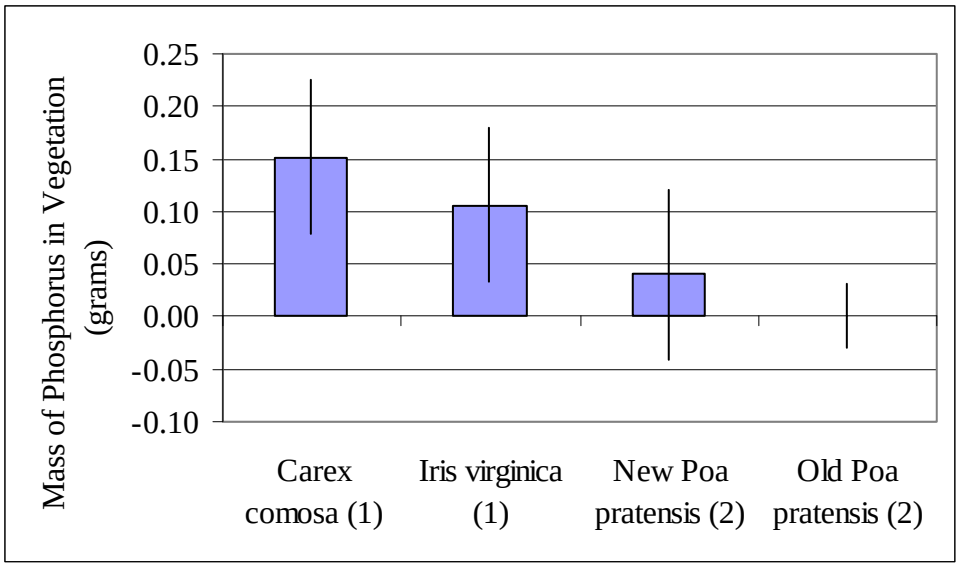
Species was a significant predictor in determining the percent of phosphorus in vegetation using a linear model, shown in Table 4.22. The covariance parameter estimate explained 74.0 percent (R^2) of the variation in the model.

TABLE 4.22 TEST OF FIXED EFFECTS FOR MASS OF PHOSPHORUS IN VEGETATION

Tests of Fixed Effects	F value	Pr>F
Species	17.09	<0.0001

Carex comosa showed the highest phosphorus mass (0.15 [0.08, 0.23] grams) followed by *Iris virginica* (0.11 [0.03, 0.78] grams) and New *Poa pratensis* (0.04 [0.00, 0.12] grams). Old *Poa pratensis* had the lowest phosphorus mass due to the dead and decaying plant matter (0.02 [0.00, 0.05] grams). Statistical analysis of the fixed effects for phosphorus mass in vegetation is shown in Table 4.23. The mean phosphorus mass in vegetation is shown graphically in Figure 4.16.

FIGURE 4.16 MEAN MASS OF PHOSPHORUS IN VEGETATION



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.23 SOLUTION FOR FIXED EFFECTS FOR MASS PHOSPHORUS IN VEGETATION

Species Parameters	Estimate mg	Standard Error	Pr > | t |
Carex comosa	0.15	0.02	<.0001
Iris virginica	0.11	0.02	0.0008
New Poa pratensis	0.04	0.02	0.4036
Old Poa pratensis	0.02	0.01	0.1814

*Old *Poa pratensis* is the reference category

Carex comosa and *Iris virginica* are not significantly different from each other but are significantly different from all other columns. There was not a significant difference between Old *Poa pratensis* and New *Poa pratensis*, shown in Table 4.24.

TABLE 4.24 DIFFERENCES OF LEAST SQUARES MEANS FOR MASS OF PHOSPHORUS IN VEGETATION

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	2.29	0.0383	Tukey-Kramer	0.1483
Carex comosa	New Poa pratensis	4.82	0.0003	Tukey-Kramer	0.0014
Carex comosa	Old Poa pratensis	6.56	<.0001	Tukey-Kramer	<.0001
Iris virginica	New Poa pratensis	2.84	0.0131	Tukey-Kramer	0.0562
Iris virginica	Old Poa pratensis	4.28	0.0008	Tukey-Kramer	0.0038
New Poa pratensis	Old Poa pratensis	0.86	0.4036	Tukey-Kramer	0.8244

Potassium Results

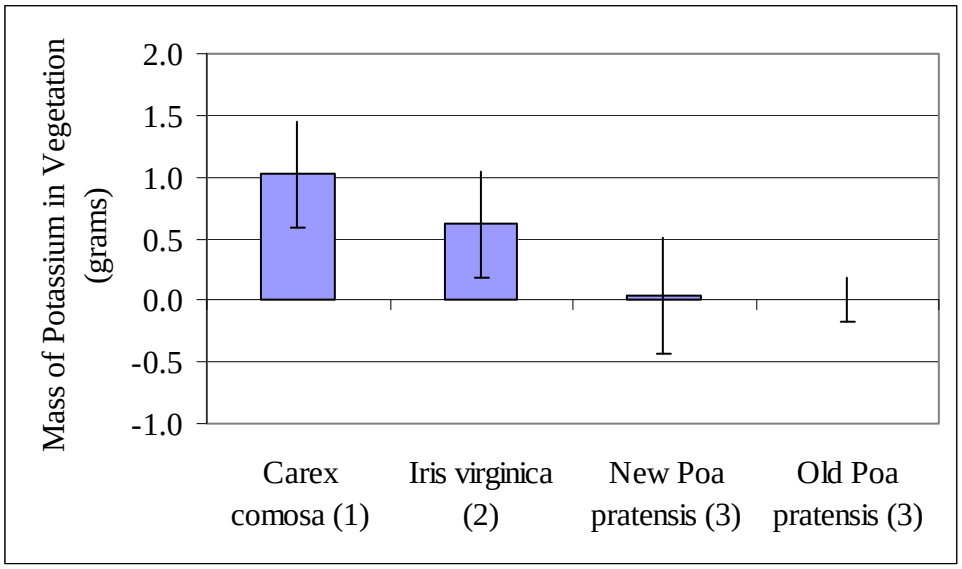
Species was a significant predictor in determining the percent of potassium in vegetation using a linear model, shown in Table 4.25. The covariance parameter estimate explained 84.0 percent (R^2) of the variation in the model.

TABLE 4.25 TEST OF FIXED EFFECTS FOR MASS OF POTASSIUM IN VEGETATION

Tests of Fixed Effects	F value	Pr>F
Species	31.40	<0.0001

Carex comosa showed the highest potassium mass (1.0 [0.60, 1.5] grams) followed by *Iris virginica* (0.62 [0.19, 1.0] grams) and new *Poa pratensis* (0.04 [0.00, 0.50] grams). Old *Poa pratensis* had the lowest potassium mass due to the dead and decaying plant matter (0.02 [0.00,0.20] grams). Statistical analysis of the fixed effects for potassium mass in vegetation is shown in Table 4.26. The mean potassium mass in vegetation is shown graphically in Figure 4.17.

FIGURE 4.17 MEAN MASS OF POTASSIUM IN VEGETATION



(#) Different number indicate significance at a 0.05 level
Error bars indicate 95 percent confidence limit

TABLE 4.26 SOLUTION FOR FIXED EFFECTS FOR MASS POTASSIUM IN VEGETATION

Species Parameters	Estimate mg	Standard Error	Pr > | t |
Carex comosa	1.0	0.12	<.0001
Iris virginica	0.62	0.12	0.0002
New Poa pratensis	0.04	0.14	0.8923
Old Poa pratensis	0.02	0.08	0.8312

*Old *Poa pratensis* is the reference category

Carex comosa and *Iris virginica* are significantly different from all other columns. There was not a significant difference between Old *Poa pratensis* and New *Poa pratensis*, shown in Table 4.27.

TABLE 4.27 DIFFERENCES OF LEAST SQUARES MEANS FOR MASS OF POTASSIUM IN VEGETATION

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	3.50	0.0036	Tukey-Kramer	0.0166
Carex comosa	New Poa pratensis	7.31	<.0001	Tukey-Kramer	<.0001
Carex comosa	Old Poa pratensis	8.60	<.0001	Tukey-Kramer	<.0001
Iris virginica	New Poa pratensis	4.28	0.0008	Tukey-Kramer	0.0038
Iris virginica	Old Poa pratensis	5.10	0.0002	Tukey-Kramer	0.0008
New Poa pratensis	Old Poa pratensis	0.14	0.8923	Tukey-Kramer	0.9990

Aluminum Results

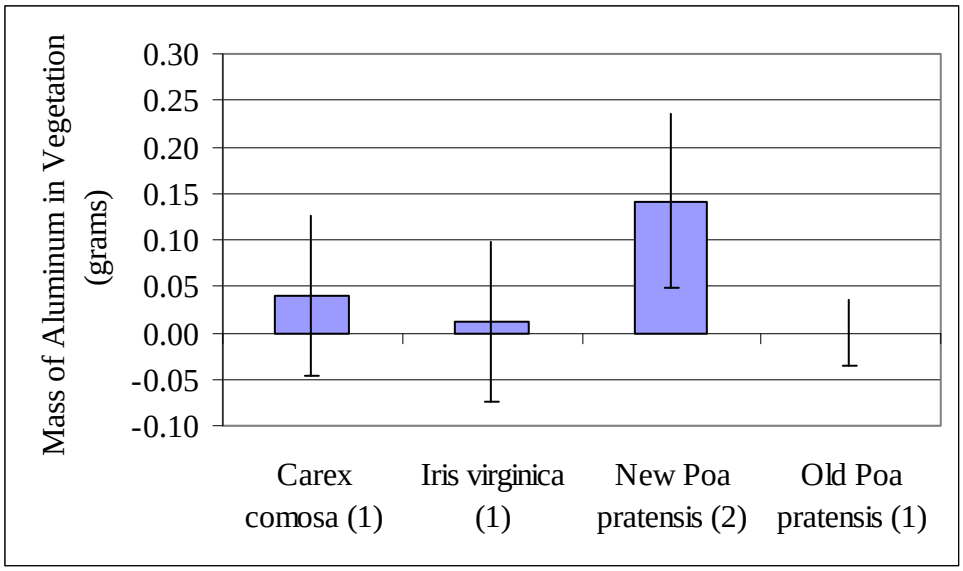
Species was a significant predictor in determining the percent of aluminum in vegetation using a linear model, shown in Table 4.28. The covariance parameter estimate explained 84.0 percent (R^2) of the variation in the model.

TABLE 4.28 TEST OF FIXED EFFECTS FOR MASS OF ALUMINUM IN VEGETATION

Tests of Fixed Effects	F value	Pr>F
Species	9.65	0.0010

New *Poa pratensis* showed the highest aluminum mass (0.14 [0.05, 0.24] grams) followed by *Carex comosa* (0.04 [0.00, 0.13] grams) and *Iris virginica* (0.01 [0.00, 0.10] grams). Old *Poa pratensis* had the lowest aluminum mass due to the dead and decaying plant matter (0.01 [0.00, 0.05] grams). Statistical analysis of the fixed effects for aluminum mass in vegetation is shown in Table 4.29. The mean aluminum mass in vegetation is shown graphically in Figure 4.18.

FIGURE 4.18 MEAN MASS OF ALUMINUM IN VEGETATION



(#) Different number indicate significance at a 0.05 level
Error bars indicate 95 percent confidence limit

TABLE 4.29 SOLUTION FOR FIXED EFFECTS FOR MASS ALUMINUM IN VEGETATION

	Estimate		
Species Parameters	mg	Standard Error	Pr > | t |
Carex comosa	0.04	0.02	0.1943
Iris virginica	0.01	0.02	0.8823
New Poa pratensis	0.14	0.03	0.0002
Old Poa pratensis	0.01	0.01	0.6344

*Old *Poa pratensis* is the reference category

New *Poa pratensis* is significantly different from all other columns. There was not a significant difference between Old *Poa pratensis, Carex comosa* and *Iris virginica,* shown in Table 4.30.

TABLE 4.30 DIFFERENCES OF LEAST SQUARES MEANS FOR MASS OF ALUMINUM IN VEGETATION

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	1.21	0.2454	Tukey-Kramer	0.6294
Carex comosa	New Poa pratensis	-3.73	0.0022	Tukey-Kramer	0.0106
Carex comosa	Old Poa pratensis	1.36	0.1943	Tukey-Kramer	0.5408
Iris virginica	New Poa pratensis	-4.78	0.0003	Tukey-Kramer	0.0015
Iris virginica	Old Poa pratensis	0.15	0.8823	Tukey-Kramer	0.9987
New Poa pratensis	Old Poa pratensis	4.91	0.0002	Tukey-Kramer	0.0012

Boron Results

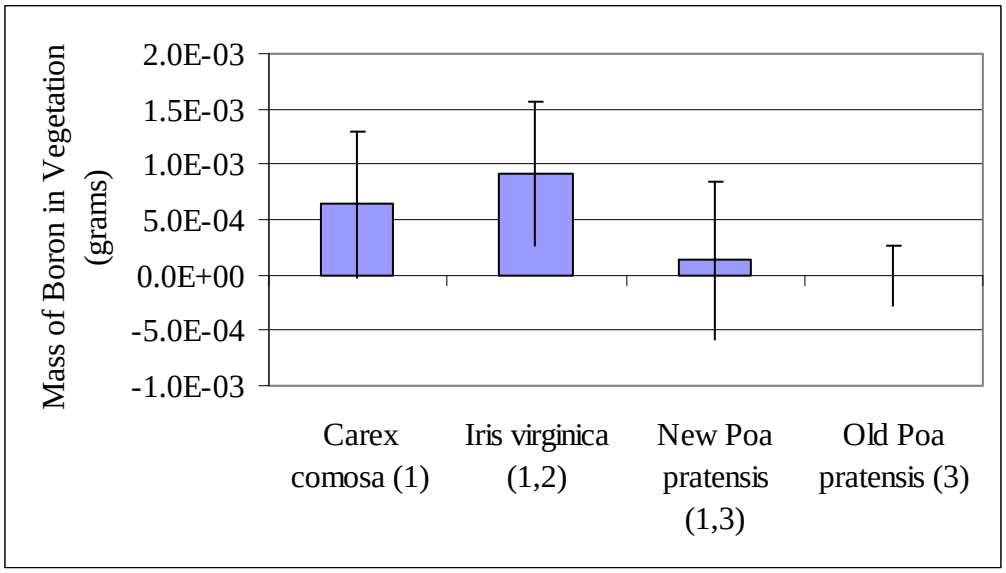
Species was a significant predictor in determining the percent of boron in vegetation using a linear model, shown in Table 4.31. The covariance parameter estimate explained 61.1 percent (R^2) of the variation in the model.

TABLE 4.31 TEST OF FIXED EFFECTS FOR MASS OF BORON IN VEGETATION

Tests of Fixed Effects	F value	Pr>F
Species	9.42	0.0012

Iris virginica showed the highest boron mass (9.14E-04 [3.0E-04, 1.6E-04] grams) followed by *Carex comosa* (6.38E-04 [0.00, 1.3E-03] grams) and New *Poa pratensis* (0.00, 8.0E-04] grams). Old *Poa pratensi*s had the lowest boron mass due to the dead and decaying plant matter (7.2E-6 [0.00, 3.4E-04] grams). Statistical analysis of the fixed effects for boron mass in vegetation is shown in Table 4.32. The mean boron mass in vegetation is shown graphically in Figure 4.19.

FIGURE 4.19 MEAN MASS OF BORON IN VEGETATION



(#) Different number indicate significance at a 0.05 level
Error bars indicate 95 percent confidence limit

TABLE 4.32 SOLUTION FOR FIXED EFFECTS FOR MASS BORON IN VEGETATION

Species Parameters	Estimate mg	Standard Error	Pr > | t |
Carex comosa	6.38E-04	1.79E-04	0.0069
Iris virginica	9.14E-04	1.79E-04	0.0003
New Poa pratensis	1.30E-04	2.07E-04	0.7832
Old Poa pratensis	7.20E-05	1.27E-04	0.5787

*Old *Poa pratensis* is the reference category

Iris virginica is significantly different from New *Poa pratensis* and Old *Poa pratensis* while *Carex comosa* is significantly differently from Old *Poa pratensis*. There was not a significant difference between all other columns, shown in Table 4.32.

TABLE 4.32 DIFFERENCES OF LEAST SQUARES MEANS FOR MASS OF BORON IN VEGETATION

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	-1.54	0.1456	Tukey-Kramer	0.4409
Carex comosa	New Poa pratensis	2.46	0.0277	Tukey-Kramer	0.1114
Carex comosa	Old Poa pratensis	3.16	0.0069	Tukey-Kramer	0.0312
Iris virginica	New Poa pratensis	3.79	0.0020	Tukey-Kramer	0.0095
Iris virginica	Old Poa pratensis	4.70	0.0003	Tukey-Kramer	0.0017
New Poa pratensis	Old Poa pratensis	0.28	0.7832	Tukey-Kramer	0.9920

Copper Results

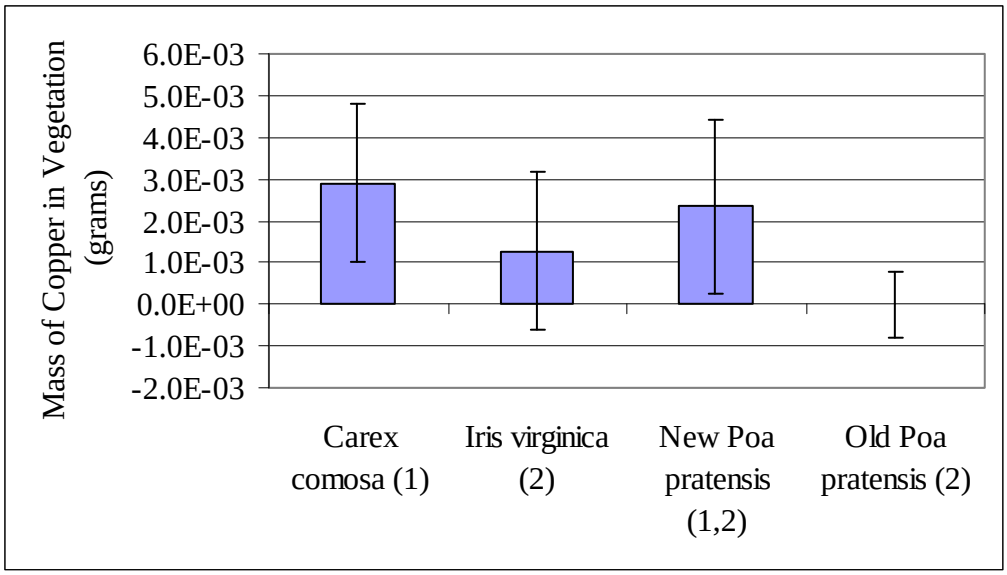
Species was a significant predictor in determining the percent of copper in vegetation using a linear model, shown in Table 4.34. The covariance parameter estimate explained 48.0 percent (R^2) of the variation in the model.

TABLE 4.34 TEST OF FIXED EFFECTS FOR MASS OF COPPER IN VEGETATION

Tests of Fixed Effects	F value	Pr>F
Species	5.60	0.0098

Carex comosa showed the highest copper mass (2.89E-03 [1.0E-03, 4.8E-03] grams) followed by New *Poa pratensis* (2.34E-03 [3.0E-04, 4.4E-03] grams) and *Iris virginica* (1.28E-03 [0.00, 3.2E-03] grams). Old *Poa pratensis* had the lowest copper mass due to the dead and decaying plant matter (1.0E-3 [2.3E-04, 1.8E-03] grams). Statistical analysis of the fixed effects for copper mass in vegetation is shown in Table 4.35. The mean copper mass in vegetation is shown graphically in Figure 4.20.

FIGURE 4.20 MEAN MASS OF COPPER IN VEGETATION



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.35 SOLUTION FOR FIXED EFFECTS FOR MASS COPPER IN VEGETATION

Species Parameters	Estimate mg	Standard Error	Pr > | t |
Carex comosa	6.38E-04	1.79E-04	0.0069
Iris virginica	9.14E-04	1.79E-04	0.0003
New Poa pratensis	1.30E-04	2.07E-04	0.7832
Old Poa pratensis	7.20E-05	1.27E-04	0.5787

*Old *Poa pratensis* is the reference category

Carex comosa is significantly differently from Iris virginica and Old *Poa pratensis*. There was not a significant difference between all other columns, shown in Table 4.36.

TABLE 4.36 DIFFERENCES OF LEAST SQUARES MEANS FOR MASS OF COPPER IN VEGETATION

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	3.12	0.0075	Tukey-Kramer	0.0337
Carex comosa	New Poa pratensis	0.92	0.3729	Tukey-Kramer	0.7945
Carex comosa	Old Poa pratensis	3.62	0.0028	Tukey-Kramer	0.0131
Iris virginica	New Poa pratensis	-1.78	0.0966	Tukey-Kramer	0.3223
Iris virginica	Old Poa pratensis	0.50	0.6236	Tukey-Kramer	0.9573
New Poa pratensis	Old Poa pratensis	2.22	0.0438	Tukey-Kramer	0.1668

Iron Results

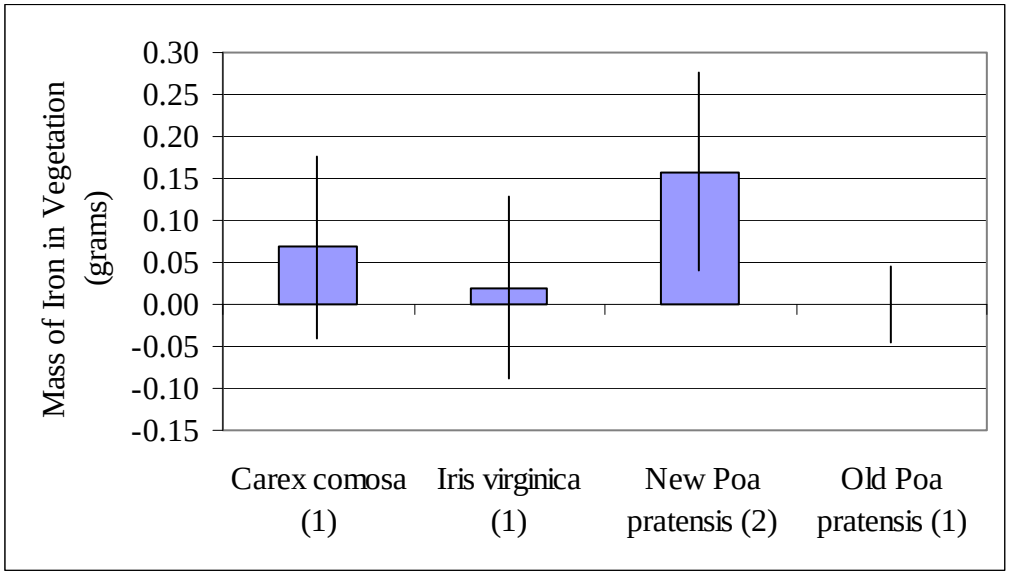
Species was a significant predictor in determining the mass of iron in vegetation using a linear model, shown in Table 4.39. The covariance parameter estimate explained 54.8 percent (R^2) of the variation in the model.

TABLE 4.37 TEST OF FIXED EFFECTS FOR MASS OF IRON IN VEGETATION

Tests of Fixed Effects	F value	Pr>F
Species	7.29	0.0035

New *Poa pratensis* showed the highest iron mass (0.16 [0.04, 0.38] grams) followed by *Carex comosa* (0.07 [0.00, 0.18] grams) and *Iris virginica* (0.02 [0.00, 0.13] grams). Old *Poa pratensis* had the lowest iron mass due to the dead and decaying plant matter (0.01 [0.00, 0.06] grams). Statistical analysis of the fixed effects for iron mass in vegetation is shown in Table 4.38. The mean iron mass in vegetation is shown graphically in Figure 4.21.

FIGURE 4.21 MEAN MASS OF IRON IN VEGETATION



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.38 SOLUTION FOR FIXED EFFECTS FOR MASS IRON IN VEGETATION

	Estimate		
Species Parameters	mg	Standard Error	Pr > | t |
Carex comosa	0.07	0.03	0.0881
Iris virginica	0.02	0.03	0.8402
New Poa pratensis	0.16	0.03	0.0008
Old Poa pratensis	0.01	0.02	0.5078

*Old *Poa pratensis* is the reference category

New *Poa pratensis* is significantly differently from all other columns. There was not a significant difference between *Carex comosa*, *Iris virginica* or Old *Poa pratensis*, shown in Table 4.39.

TABLE 4.39 DIFFERENCES OF LEAST SQUARES MEANS FOR MASS OF IRON IN VEGETATION

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	1.63	0.1259	Tukey-Kramer	0.3955
Carex comosa	New Poa pratensis	-2.66	0.0188	Tukey-Kramer	0.0785
Carex comosa	Old Poa pratensis	1.83	0.0881	Tukey-Kramer	0.2994
Iris virginica	New Poa pratensis	-4.07	0.0012	Tukey-Kramer	0.0056
Iris virginica	Old Poa pratensis	0.21	0.8402	Tukey-Kramer	0.9968
New Poa pratensis	Old Poa pratensis	4.24	0.0008	Tukey-Kramer	0.0040

Manganese Results

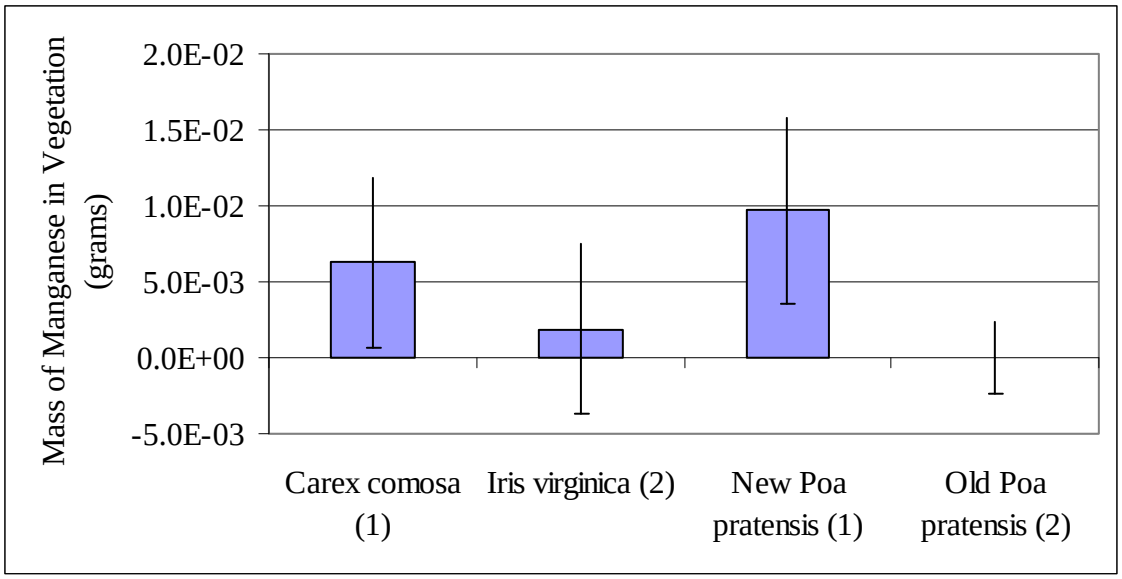
Species was a significant predictor in determining the mass of manganese in vegetation using a linear model, shown in Table 4.40. The covariance parameter estimate explained 65.6 percent (R^2) of the variation in the model.

TABLE 4.40 TEST OF FIXED EFFECTS FOR MASS OF MANGANESE IN VEGETATION

Tests of Fixed Effects	F value	Pr>F
Species	11.71	0.0004

New *Poa pratensis* showed the highest manganese mass (9.70E-03 [3.58E-03, 1.58E-02] grams) followed by *Carex comosa* (6.29E-03 [6.86E-04, 1.19E-02] grams) and *Iris virginica* (1.86E-03 [0.00, 7.46E-03] grams). Old Poa pratensis had the lowest manganese mass due to the dead and decaying plant matter (5.64E-04 [0.00, 2.9E-03] grams). Statistical analysis of the fixed effects for manganese mass in vegetation is shown in Table 4.43. The mean manganese mass in vegetation is shown graphically in Figure 4.41.

FIGURE 4.22 MEAN MASS OF MANGANESE IN VEGETATION



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.41 SOLUTION FOR FIXED EFFECTS FOR MASS MANGANESE IN VEGETATION

Species Parameters	Estimate mg	Standard Error	Pr > | t |
Carex comosa	6.29E-03	1.1E-03	0.6104
Iris virginica	1.86E-03	1.5E-03	0.0022
New Poa pratensis	9.70E-03	1.5E-03	0.4127
Old Poa pratensis	5.64E-04	1.8E-03	0.0001

*Old *Poa pratensis* is the reference category

All columns were found to be significantly different from each other with the exception of *Carex comosa* and New *Poa pratensis* and *Iris virginica* and Old *Poa pratensis*, shown in Table 4.42.

TABLE 4.42 DIFFERENCES OF LEAST SQUARES MEANS FOR MASS OF MANGANESE IN VEGETATION

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	2.90	0.0117	Tukey-Kramer	0.0507
Carex comosa	New Poa pratensis	-1.93	0.0746	Tukey-Kramer	0.2614
Carex comosa	Old Poa pratensis	3.74	0.0022	Tukey-Kramer	0.0104
Iris virginica	New Poa pratensis	-4.44	0.0006	Tukey-Kramer	0.0028
Iris virginica	Old Poa pratensis	0.84	0.4127	Tukey-Kramer	0.8326
New Poa pratensis	Old Poa pratensis	5.17	0.0001	Tukey-Kramer	0.0007

Zinc Results

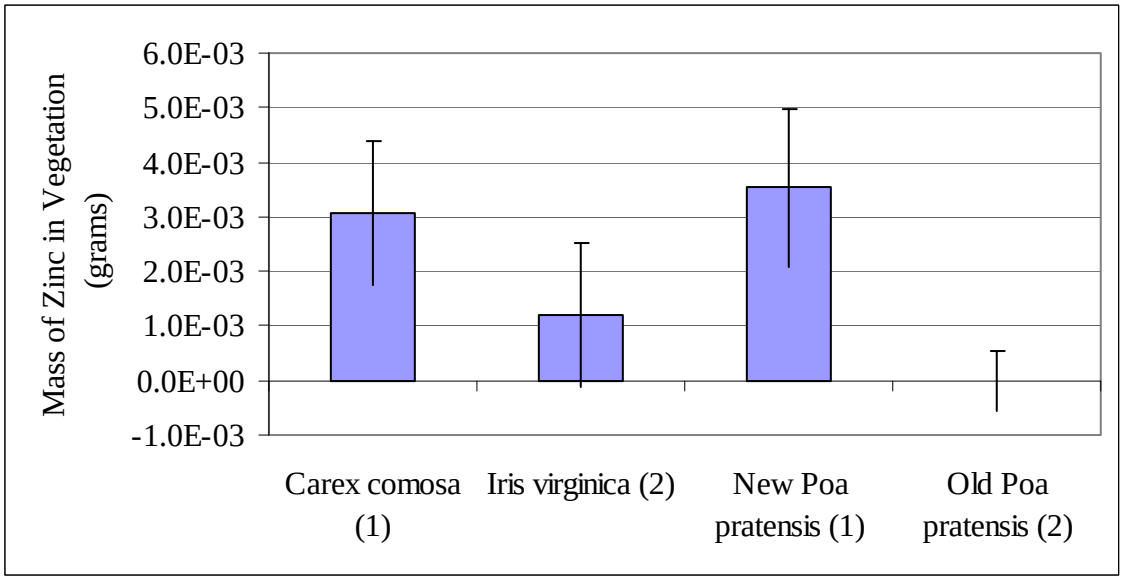
Species was a significant predictor in determining the mass of zinc in vegetation using a linear model, shown in Table 4.43. The covariance parameter estimate explained 81.0 percent (R^2) of the variation in the model.

TABLE 4.43 TEST OF FIXED EFFECTS FOR MASS OF ZINC IN VEGETATION

Tests of Fixed Effects	F value	Pr>F
Species	25.59	<.0001

New *Poa pratensis* showed the highest zinc mass (3.53E-03 [2.1E-03, 5.0E-03] grams) followed by *Carex comosa* (3.05E-03 [1.74E-03, 4.37E-03] grams) and *Iris virginica* (1.21E-03 [0.00, 2.52E-03] grams). Old *Poa pratensis* had the lowest zinc mass due to the dead and decaying plant matter (6.50E-04 [1.1E-04, 1.2E-03 grams). Statistical analysis of the fixed effects for zinc mass in vegetation is shown in Table 4.44. The mean zinc mass in vegetation is shown graphically in Figure 4.23.

FIGURE 4.23 MEAN MASS OF ZINC IN VEGETATION



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.44 SOLUTION FOR FIXED EFFECTS FOR MASS ZINC IN VEGETATION

	Estimate		
Species Parameters	mg	Standard Error	Pr > | t |
Carex comosa	3.05E-03	3.59E-03	<.0001
Iris virginica	1.21E-03	3.59E-03	0.1428
New Poa pratensis	3.53E-03	4.15E-03	<.0001
Old Poa pratensis	6.50E-04	2.54E-03	0.0228

*Old *Poa pratensis* is the reference category

There was not a significant difference between *Carex comosa* and New *Poa pratensis* or *Iris virginica* and Old *Poa pratensis*, but both groups were significantly differently from each other, shown in Table 4.45.

TABLE 4.45 DIFFERENCES OF LEAST SQUARES MEANS FOR MASS OF ZINC IN VEGETATION

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	5.14	0.0002	Tukey-Kramer	0.0008
Carex comosa	New Poa pratensis	-1.15	0.2705	Tukey-Kramer	0.6678
Carex comosa	Old Poa pratensis	6.69	<.0001	Tukey-Kramer	<.0001
Iris virginica	New Poa pratensis	-5.60	<.0001	Tukey-Kramer	0.0003
Iris virginica	Old Poa pratensis	1.55	0.1428	Tukey-Kramer	0.4346
New Poa pratensis	Old Poa pratensis	6.94	<.0001	Tukey-Kramer	<.0001

Soil Results

Potting Soil Results

Nitrate Potting Soil Results

Species was a significant predictor in determining the concentration of nitrate in the potting soil using a linear model, shown in Table 4.46. The covariance parameter estimate explained 73.4 percent (R^2) of the variation in the model.

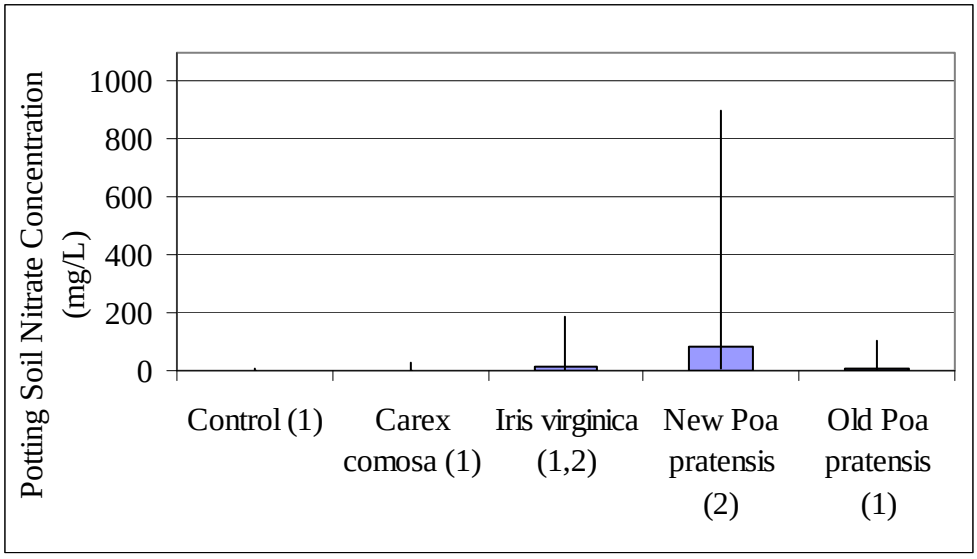
TABLE 4.46 TEST OF FIXED EFFECTS FOR CONCENTRATION OF NITRATE IN POTTING SOIL

Tests of Fixed Effects	F value	Pr>F
Species	10.34	0.0014

New *Poa pratensis* showed the highest concentration of nitrate (82.8 [7.6, 902] ppm) followed by *Iris virginica* (17.0 [1.56, 186] ppm) and Old *Poa pratensis* (9.6 [0.88, 105] ppm). *Carex comosa* did not show a significant difference from the Control (2.6 [0.24,28.3] and 2.8 [1.1, 7.6] ppm). Statistical analysis of the fixed effects for nitrate concentration in potting soil is

shown in Table 4.47. The geometric mean nitrate concentration in potting soil is shown graphically in Figure 4.24.

FIGURE 4.24 GEOMETRIC MEAN CONCENTRATION OF NITRATE IN POTTING SOIL



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.47 SOLUTION FOR FIXED EFFECTS FOR NITRATE CONCENTRATION IN POTTING SOIL

	Estimate		
Species Parameters	mg/L	Standard Error	Pr > | t |
Control	2.84	1.56	0.0407
Carex comosa	2.60	1.87	0.8927
Iris virginica	17.0	1.87	0.0171
New Poa pratensis	82.8	1.87	0.0003
Old Poa pratensis	9.62	1.87	0.0805

*Control is the reference category

Carex comosa was significantly different from New *Poa pratensis* and *Iris virginica* was significantly different from Old *Poa pratensis*. Old and New *Poa pratensis* were also significantly different from each other, shown in Table 4.48.

TABLE 4.48 DIFFERENCES OF LEAST SQUARES MEANS FOR NITRATE CONCENTRATION IN POTTING SOIL

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	-2.99	0.0135	Tukey	0.0792
Carex comosa	New Poa pratensis	-5.51	0.0003	Tukey	0.0019
Carex comosa	Old Poa pratensis	-2.08	0.0639	Tukey	0.2979
Carex comosa	Control	-0.14	0.8927	Tukey	0.9999
Iris virginica	New Poa pratensis	-2.52	0.0305	Tukey	0.1621
Iris virginica	Old Poa pratensis	0.91	0.3838	Tukey	0.8864
Iris virginica	Control	2.85	0.0171	Tukey	0.0979
New Poa pratensis	Old Poa pratensis	3.43	0.0065	Tukey	0.0404
New Poa pratensis	Control	5.37	0.0003	Tukey	0.0022
Old Poa pratensis	Control	1.94	0.0805	Tukey	0.3559

Ammonia Potting Soil Results

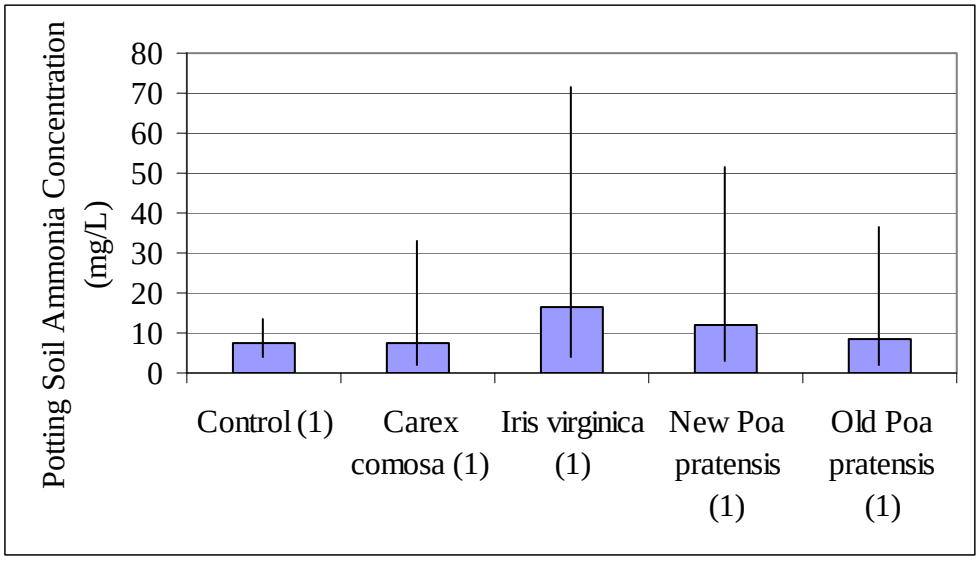
Species was not a significant predictor in determining the concentration of ammonia in the potting soil using a linear model, shown in Table 4.49. The covariance parameter estimate explained 30.7 percent (R^2) of the variation in the model.

TABLE 4.49 TEST OF FIXED EFFECTS FOR CONCENTRATION OF AMMONIA IN POTTING SOIL

Tests of Fixed Effects	F value	Pr>F
Species	1.66	0.2340

Iris virginica showed the highest concentration of ammonia (16.6 [3.88, 71.3] ppm) followed by New *Poa pratensis* (12.1 [2.81, 51.7] ppm) and Old *Poa pratensis* (8.56 [2.00, 36.7] ppm). *Carex comosa* did not show a significant difference from the Control (7.70 [1.80, 33.0] and 7.27 [3.98, 13.3] ppm). Statistical analysis of the fixed effects for ammonia concentration in potting soil is shown in Table 4.50. The geometric mean ammonia concentration in potting soil is shown graphically in Figure 4.25.

FIGURE 4.25 GEOMETRIC MEAN CONCENTRATION OF AMMONIA IN POTTING SOIL



(#) Different number indicate significance at a 0.05 level
Error bars indicate 95 percent confidence limit

TABLE 4.50 SOLUTION FOR FIXED EFFECTS FOR AMMONIA CONCENTRATION IN POTTING SOIL

Species Parameters	Estimate mg/L	Standard Error	Pr > | t |
Control	7.27	1.31	<.0001
Carex comosa	7.70	1.47	0.8846
Iris virginica	16.6	1.47	0.0560
New Poa pratensis	12.1	1.47	0.2161
Old Poa pratensis	8.56	1.47	0.6785

*Control is the reference category

There was not a significant difference between any of the columns, shown in Table 4.51.

TABLE 4.51 DIFFERENCES OF LEAST SQUARES MEANS FOR AMMONIA CONCENTRATION IN POTTING SOIL

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	-2.01	0.0719	Tukey	0.3264
Carex comosa	New Poa pratensis	-1.17	0.2685	Tukey	0.7666
Carex comosa	Old Poa pratensis	-0.28	0.7867	Tukey	0.9985
Carex comosa	Control	0.15	0.8846	Tukey	0.9999
Iris virginica	New Poa pratensis	0.84	0.4202	Tukey	0.9117
Iris virginica	Old Poa pratensis	1.73	0.1135	Tukey	0.4571
Iris virginica	Control	2.16	0.0560	Tukey	0.2682
New Poa pratensis	Old Poa pratensis	0.89	0.3925	Tukey	0.8929
New Poa pratensis	Control	1.32	0.2161	Tukey	0.6858
Old Poa pratensis	Control	0.43	0.6785	Tukey	0.9920

Total Nitrogen Potting Soil Results

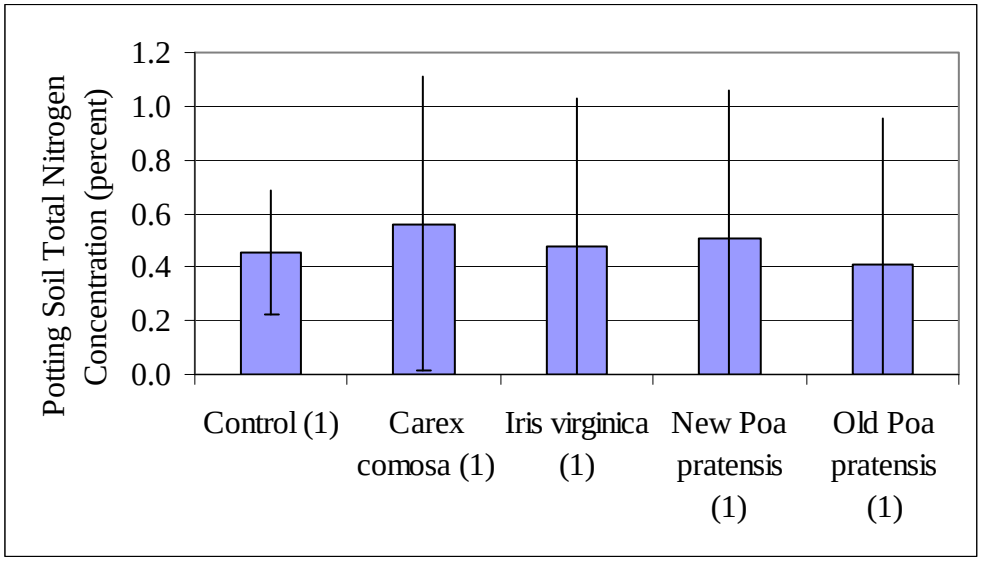
Species was not a significant predictor in determining the concentration of total nitrogen in the potting soil using a linear model, shown in Table 4.52. The covariance parameter estimate explained 7.9 percent (R^2) of the variation in the model.

TABLE 4.52 TEST OF FIXED EFFECTS FOR CONCENTRATION OF TOTAL NITROGEN IN POTTING SOIL

Tests of Fixed Effects	F value	Pr>F
Species	0.32	0.8568

All columns exhibited between 0.40 and 0.57 percent of total nitrogen in the potting soil. Old *Poa pratensis* had the lowest total nitrogen concentration at 0.41 [0.0, 0.96] percent while Carex comosa had the highest concentration at 0.56 [0.01, 1.11] percent. Statistical analysis of the fixed effects for total nitrogen concentration in potting soil is shown in Table 4.53. The mean total nitrogen concentration in potting soil is shown graphically in Figure 4.26.

FIGURE 4.26 MEAN CONCENTRATION OF TOTAL NITROGEN IN POTTING SOIL



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.53 SOLUTION FOR FIXED EFFECTS FOR TOTAL NITROGEN CONCENTRATION IN POTTING SOIL

	Estimate		
Species Parameters	Percent	Standard Error	Pr > | t |
Control	0.45	0.10	0.0012
Carex comosa	0.56	0.14	0.4737
Iris virginica	0.48	0.14	0.8622
New Poa pratensis	0.51	0.14	0.7333
Old Poa pratensis	0.41	0.14	0.7450

*Control is the reference category

There was not a significant difference between any of the columns, shown in Table 4.54.

TABLE 4.54 DIFFERENCES OF LEAST SQUARES MEANS FOR TOTAL NITROGEN CONCENTRATION IN POTTING SOIL

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	0.57	0.5836	Tukey	0.9771
Carex comosa	New Poa pratensis	0.39	0.7017	Tukey	0.9941
Carex comosa	Old Poa pratensis	1.08	0.3060	Tukey	0.8131
Carex comosa	Control	0.74	0.4737	Tukey	0.9407
Iris virginica	New Poa pratensis	-0.17	0.8666	Tukey	0.9998
Iris virginica	Old Poa pratensis	0.51	0.6195	Tukey	0.9841
Iris virginica	Control	0.18	0.8622	Tukey	0.9997
New Poa pratensis	Old Poa pratensis	0.68	0.5091	Tukey	0.9554
New Poa pratensis	Control	0.35	0.7333	Tukey	0.9962
Old Poa pratensis	Control	-0.33	0.7450	Tukey	0.9968

Bray Phosphorus Potting Soil Results

Species was a significant predictor in determining the concentration of phosphorus in the potting soil using a linear model, shown in Table 4.55. The covariance parameter estimate explained 57.9 percent (R^2) of the variation in the model.

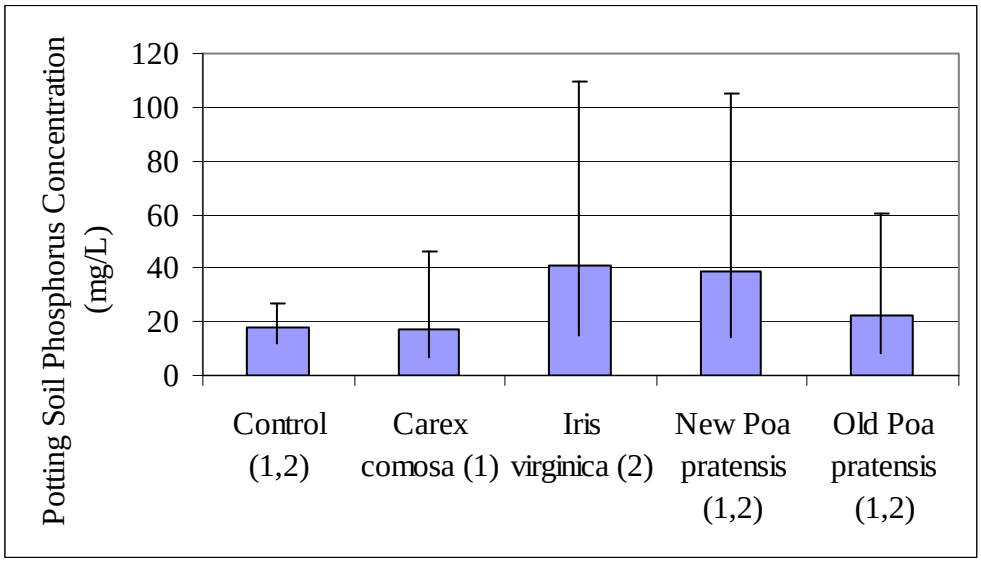
TABLE 4.55 TEST OF FIXED EFFECTS FOR CONCENTRATION OF BRAY PHOSPHORUS IN POTTING SOIL

Tests of Fixed Effects	F value	Pr>F
Species	5.16	0.0162

Iris virginica showed the highest concentration of phosphorus (40.7 [15.1, 110] ppm) followed by New *Poa pratensis* (39.1 [14.5, 105] ppm) and Old *Poa pratensis* (22.4 [8.3, 60.4] ppm). *Carex comosa* did not show a significant difference from the Control (17.1 [6.3, 46.1] and 18.0 [11.9, 27.1] ppm). Statistical analysis of the fixed effects for phosphorus concentration in

potting soil is shown in Table 4.56. The geometric mean phosphorus concentration in potting soil is shown graphically in Figure 4.27.

FIGURE 4.27 GEOMETRIC MEAN CONCENTRATION OF BRAY PHOSPHORUS IN POTTING SOIL



(#) Different number indicate significance at a 0.05 level
Error bars indicate 95 percent confidence limit

TABLE 4.56 SOLUTION FOR FIXED EFFECTS FOR BRAY PHOSPHORUS CONCENTRATION IN POTTING SOIL

	Estimate		
Species Parameters	mg/L	Standard Error	Pr > | t |
Control	18.0	1.2	<.0001
Carex comosa	17.1	1.3	0.8505
Iris virginica	40.7	1.3	0.0105
New Poa pratensis	39.1	1.3	0.0137
Old Poa pratensis	22.4	1.3	0.4160

*Control is the reference category

Carex comosa was significantly different than New *Poa pratensis* and *Iris virginica*. *Iris virginica* was significantly different from the Control and New *Poa pratensis* at a 0.1 level, shown in Table 4.57.

TABLE 4.57 DIFFERENCES OF LEAST SQUARES MEANS FOR BRAY PHOSPHORUS CONCENTRATION IN POTTING SOIL

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	-3.33	0.0076	Tukey	0.0469
Carex comosa	New Poa pratensis	-3.18	0.0099	Tukey	0.0597
Carex comosa	Old Poa pratensis	-1.04	0.3220	Tukey	0.8307
Carex comosa	Control	-0.19	0.8505	Tukey	0.9996
Iris virginica	New Poa pratensis	0.16	0.8795	Tukey	0.9998
Iris virginica	Old Poa pratensis	2.29	0.0450	Tukey	0.2246
Iris virginica	Control	3.14	0.0105	Tukey	0.0633
New Poa pratensis	Old Poa pratensis	2.13	0.0586	Tukey	0.2780
New Poa pratensis	Control	2.98	0.0137	Tukey	0.0805
Old Poa pratensis	Control	0.85	0.4160	Tukey	0.9090

Bioretention Soil Results

Nitrate Bioretention Soil Results

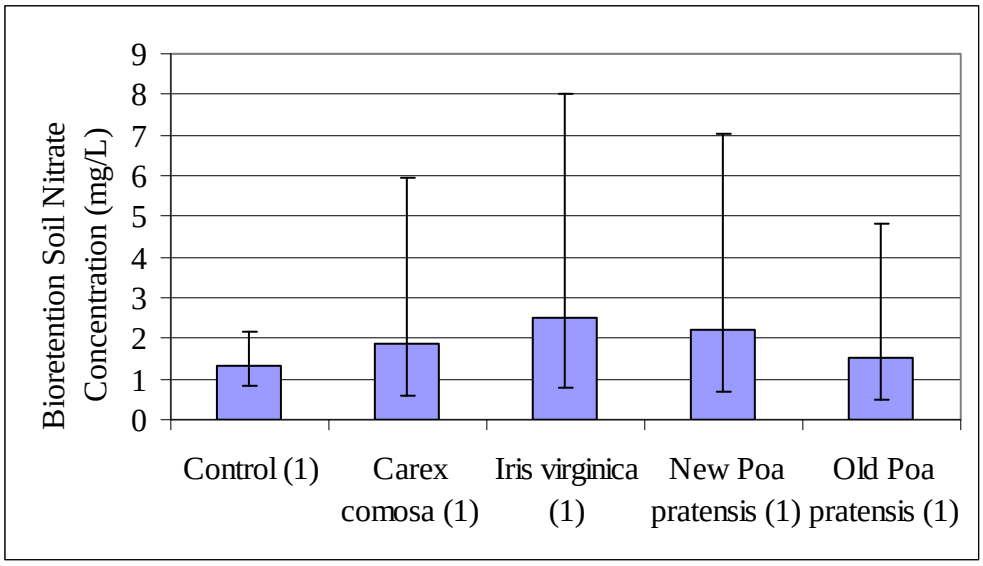
Species was not a significant predictor in determining the concentration of nitrate in the bioretention soil using a linear model, shown in Table 4.58. The covariance parameter estimate explained 27.8 percent (R^2) of the variation in the model.

TABLE 4.58 TEST OF FIXED EFFECTS FOR CONCENTRATION OF NITRATE IN BIORETENTION SOIL

Tests of Fixed Effects	F value	Pr>F
Species	1.45	0.2883

Iris virginica showed the highest concentration of nitrate (2.5 [0.79, 8.0] ppm) followed by New *Poa pratensis* (2.2 [0.69, 7.1] ppm). *Carex comosa* (1.9 [0.59, 6.0] ppm) and Old *Poa pratensis* (1.5 [0.47, 4.8] ppm) did not show a significant difference from the Control (1.3 [0.83, 2.1] ppm). Statistical analysis of the fixed effects for nitrate concentration in bioretention soil is shown in Table 4.59. The geometric mean nitrate concentration in bioretention soil is shown graphically in Figure 4.28.

FIGURE 4.28 GEOMETRIC MEAN CONCENTRATION OF NITRATE IN BIORETENTION SOIL



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.59 SOLUTION FOR FIXED EFFECTS FOR NITRATE CONCENTRATION IN BIORETENTION SOIL

	Estimate		
Species Parameters	mg/L	Standard Error	Pr > | t |
Control	1.35	1.24	0.1973
Carex comosa	1.87	1.36	0.3035
Iris virginica	2.52	1.36	0.0665
New Poa pratensis	2.20	1.36	0.1379
Old Poa pratensis	1.51	1.36	0.7190

*Control is the reference category

There was not a significant difference between any of the columns, shown in Table 4.60.

TABLE 4.60 DIFFERENCES OF LEAST SQUARES MEANS FOR NITRATE CONCENTRATION IN BIORETENTION SOIL

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	-0.97	0.3530	Tukey	0.8609
Carex comosa	New Poa pratensis	-0.53	0.6090	Tukey	0.9812
Carex comosa	Old Poa pratensis	0.71	0.4911	Tukey	0.9483
Carex comosa	Control	1.08	0.3035	Tukey	0.8104
Iris virginica	New Poa pratensis	0.45	0.6650	Tukey	0.9905
Iris virginica	Old Poa pratensis	1.69	0.1222	Tukey	0.4810
Iris virginica	Control	2.06	0.0665	Tukey	0.3073
New Poa pratensis	Old Poa pratensis	1.24	0.2423	Tukey	0.7288
New Poa pratensis	Control	1.61	0.1379	Tukey	0.5219
Old Poa pratensis	Control	0.37	0.7190	Tukey	0.9953

Ammonia Bioretention Soil Results

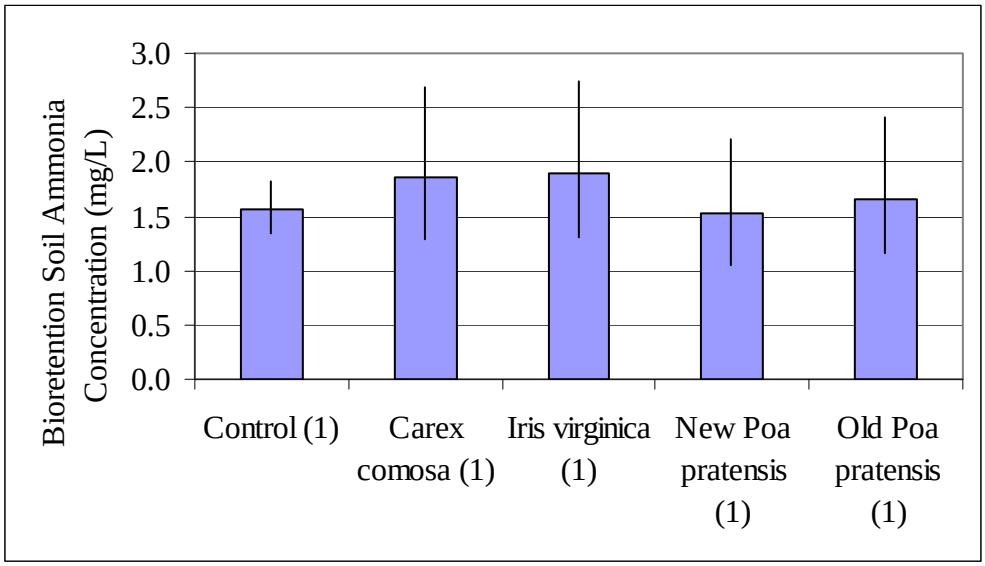
Species was not a significant predictor in determining the concentration of ammonia in the bioretention soil using a linear model, shown in Table 4.61. The covariance parameter estimate explained 34.8 percent (R^2) of the variation in the model.

TABLE 4.61 TEST OF FIXED EFFECTS FOR CONCENTRATION OF AMMONIA IN BIORETENTION SOIL

Tests of Fixed Effects	F value	Pr>F
Species	2.00	0.1704

Iris virginica showed the highest concentration of ammonia (1.90 [1.31, 2.74] ppm) followed by *Carex comosa* (1.85 [1.28, 2.68] ppm) and Old *Poa pratensis* (1.67 [1.51, 2.41] ppm). New *Poa pratensis* did not show a significant difference from the Control (1.52 [1.05, 2.20] and 1.57 [1.35, 1.83] ppm). Statistical analysis of the fixed effects for ammonia concentration in bioretention soil is shown in Table 4.62. The geometric mean ammonia concentration in bioretention soil is shown graphically in Figure 4.29.

FIGURE 4.29 GEOMETRIC MEAN CONCENTRATION OF AMMONIA IN BIORETENTION SOIL



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.62 SOLUTION FOR FIXED EFFECTS FOR AMMONIA CONCENTRATION IN BIORETENTION SOIL

Species Parameters	Estimate mg/L	Standard Error	Pr > | t |
Control	1.57	1.07	<.0001
Carex comosa	1.85	1.10	0.1212
Iris virginica	1.90	1.10	0.0815
New Poa pratensis	1.52	1.10	0.7620
Old Poa pratensis	1.67	1.10	0.5579

*Control is the reference category

There was not a significant difference between any of the columns, shown in Table 4.63.

TABLE 4.63 DIFFERENCES OF LEAST SQUARES MEANS FOR AMMONIA CONCENTRATION IN BIORETENTION SOIL

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	-0.24	0.8128	Tukey	0.9991
Carex comosa	New Poa pratensis	2.00	0.0728	Tukey	0.3296
Carex comosa	Old Poa pratensis	1.09	0.3025	Tukey	0.8092
Carex comosa	Control	1.69	0.1212	Tukey	0.4785
Iris virginica	New Poa pratensis	2.25	0.0484	Tukey	0.2383
Iris virginica	Old Poa pratensis	1.33	0.2129	Tukey	0.6804
Iris virginica	Control	1.94	0.0815	Tukey	0.3593
New Poa pratensis	Old Poa pratensis	-0.92	0.3805	Tukey	0.8838
New Poa pratensis	Control	-0.31	0.7620	Tukey	0.9976
Old Poa pratensis	Control	0.61	0.5579	Tukey	0.9709

Total Nitrogen Bioretention Soil Results

Species was not a significant predictor (alpha 0.05) in determining the concentration of total nitrogen in the bioretention soil using a linear model, shown in Table 4.64. However, it was a predictor at the 0.1 level. The covariance parameter estimate explained 44.1 percent (R^2) of the variation in the model.

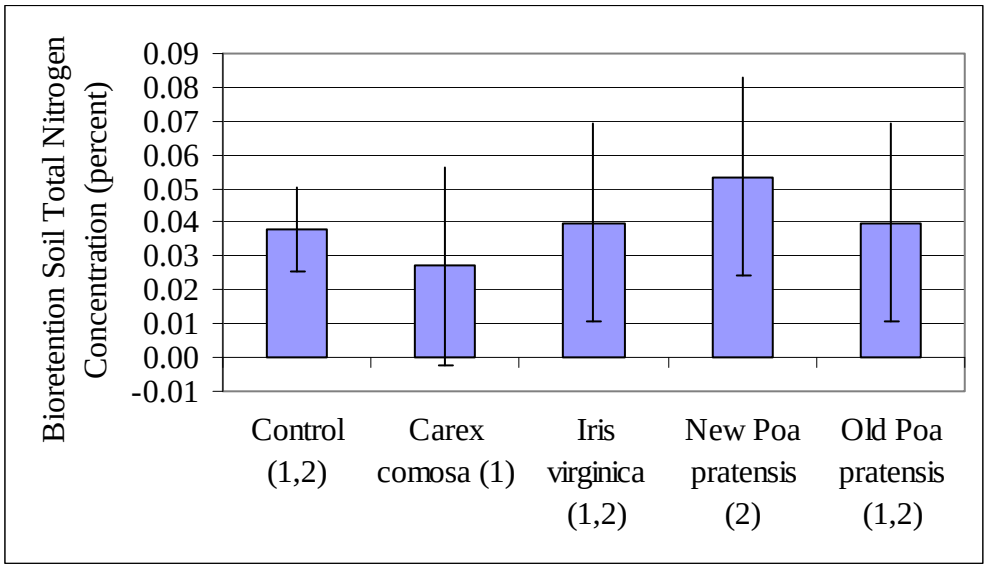
TABLE 4.64 TEST OF FIXED EFFECTS FOR CONCENTRATION OF TOTAL NITROGEN IN BIORETENTION SOIL

Tests of Fixed Effects	F value	Pr>F
Species	2.95	0.0751

All columns exhibited between 3 and 5 percent of total nitrogen in the bioretention soil. *Carex comosa* had the lowest total nitrogen concentration at 3.8 [0.02, 5.6] percent while New *Poa pratensis* had the highest concentration at 5.4 [2.4, 8.3] percent. Statistical analysis of the

fixed effects for total nitrogen concentration in bioretention soil is shown in Table 4.65. The mean total nitrogen concentration in bioretention soil is shown graphically in Figure 4.30.

FIGURE 4.30 MEAN CONCENTRATION OF TOTAL NITROGEN IN BIORETENTION SOIL



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.65 SOLUTION FOR FIXED EFFECTS FOR TOTAL NITROGEN CONCENTRATION IN BIORETENTION SOIL

	Estimate		
Species Parameters	Percent	Standard Error	Pr > | t |
Control	0.038	0.55	<.0001
Carex comosa	0.027	0.77	0.1934
Iris virginica	0.040	0.77	0.7994
New Poa pratensis	0.054	0.77	0.0707
Old Poa pratensis	0.040	0.	0.7979

*Control is the reference category

There was a significant difference found between *Carex comosa* and New *Poa pratensis*. All other columns were not significantly different, shown in Table 4.66.

TABLE 4.66 DIFFERENCES OF LEAST SQUARES MEANS FOR TOTAL NITROGEN CONCENTRATION IN BIORETENTION SOIL

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	-1.66	0.1288	Tukey	0.4987
Carex comosa	New Poa pratensis	-3.42	0.0066	Tukey	0.0411
Carex comosa	Old Poa pratensis	-1.66	0.1284	Tukey	0.4976
Carex comosa	Control	-1.39	0.1934	Tukey	0.6442
Iris virginica	New Poa pratensis	-1.76	0.1086	Tukey	0.4432
Iris virginica	Old Poa pratensis	-0.00	0.9985	Tukey	1.0000
Iris virginica	Control	0.26	0.7994	Tukey	0.9988
New Poa pratensis	Old Poa pratensis	1.76	0.1090	Tukey	0.4442
New Poa pratensis	Control	2.02	0.0707	Tukey	0.3222
Old Poa pratensis	Control	0.26	0.7979	Tukey	0.9988

Bray Phosphorus Bioretention Soil Results

Species was a significant predictor in determining the concentration of phosphorus in the bioretention soil using a linear model, shown in Table 4.67. The covariance parameter estimate explained 50.1 percent (R^2) of the variation in the model.

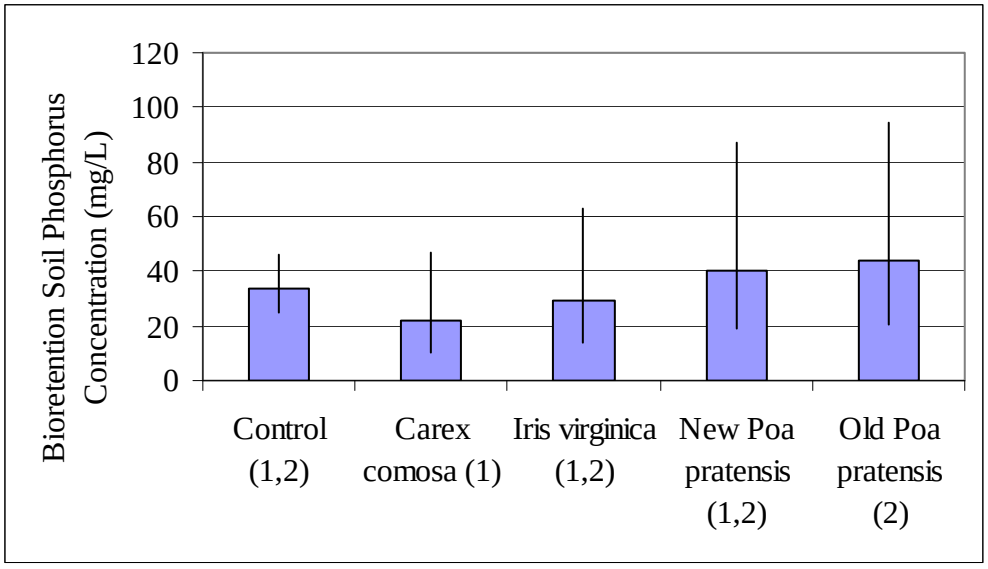
TABLE 4.67 TEST OF FIXED EFFECTS FOR CONCENTRATION OF BRAY PHOSPHORUS IN BIORETENTION SOIL

Tests of Fixed Effects	F value	Pr>F
Species	2.74	0.0031

Old *Poa pratensis* and New *Poa pratensis* showed the highest concentration of phosphorus (44.4 [20.5, 94.1] ppm and 40.6 [18.9, 86.9]). *Carex comosa* (22.0 [10.3, 47.2] ppm)

and *Iris virginica* (29.5 [13.7, 63.1] were both lower than the Control (33.8 [24.6, 46.3] ppm). Statistical analysis of the fixed effects for phosphorus concentration in bioretention soil is shown in Table 4.68. The geometric mean phosphorus concentration in bioretention soil is shown graphically in Figure 4.31.

FIGURE 4.31 GEOMETRIC MEAN CONCENTRATION OF BRAY PHOSPHORUS IN BIORETENTION SOIL



(#) Different number indicate significance at a 0.05 level

Error bars indicate 95 percent confidence limit

TABLE 4.68 SOLUTION FOR FIXED EFFECTS FOR BRAY PHOSPHORUS CONCENTRATION IN BIORETENTION SOIL

Species Parameters	Estimate mg/L	Standard Error	Pr > | t |
Control	33.8	1.15	<.0001
Carex comosa	22.0	1.22	0.0585
Iris virginica	29.5	1.22	0.5083
New Poa pratensis	40.6	1.22	0.3815
Old Poa pratensis	44.0	1.22	0.2182

*Control is the reference category

Carex comosa was significantly different from Old *Poa pratensis*. All other columns were not significantly different, shown in Table 4.69.

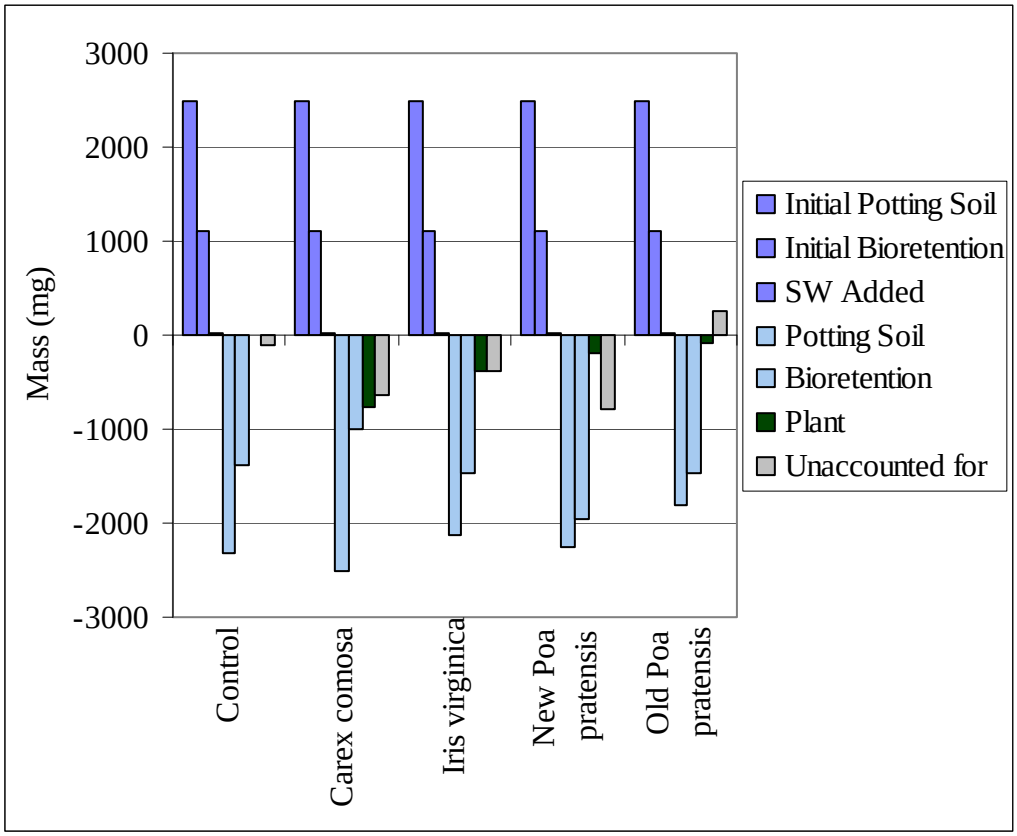
TABLE 4.69 DIFFERENCES OF LEAST SQUARES MEANS FOR BRAY PHOSPHORUS CONCENTRATION IN BIORETENTION SOIL

Species	Species	t Value	Pr > |t|	Adjustment	Adj P
Carex comosa	Iris virginica	-1.45	0.1778	Tukey	0.6131
Carex comosa	New Poa pratensis	-3.05	0.0122	Tukey	0.0725
Carex comosa	Old Poa pratensis	-3.45	0.0062	Tukey	0.0391
Carex comosa	Control	-2.14	0.0585	Tukey	0.2777
Iris virginica	New Poa pratensis	-1.60	0.1403	Tukey	0.5280
Iris virginica	Old Poa pratensis	-2.00	0.0734	Tukey	0.3317
Iris virginica	Control	-0.69	0.5083	Tukey	0.9551
New Poa pratensis	Old Poa pratensis	-0.40	0.6988	Tukey	0.9938
New Poa pratensis	Control	0.92	0.3815	Tukey	0.8846
Old Poa pratensis	Control	1.31	0.2182	Tukey	0.6896

Total Nitrogen Balance Results

A total nitrogen mass balance was conducted to evaluate the implications of vegetation species on nitrogen as a whole. The mass of nitrogen in the soil profile (both potting soil and bioretention soil) was added to the mass of nitrogen dosed in each column through stormwater application (nitrate, ammonia, and organic nitrogen species). The mass of nitrogen found in the soil column at the end of the experiment was added to the nitrogen in the plant vegetation and then subtracted from the initial mass of nitrogen. The difference from the initial and final nitrogen mass is considered "unaccounted for" shown in Figure 4.32.

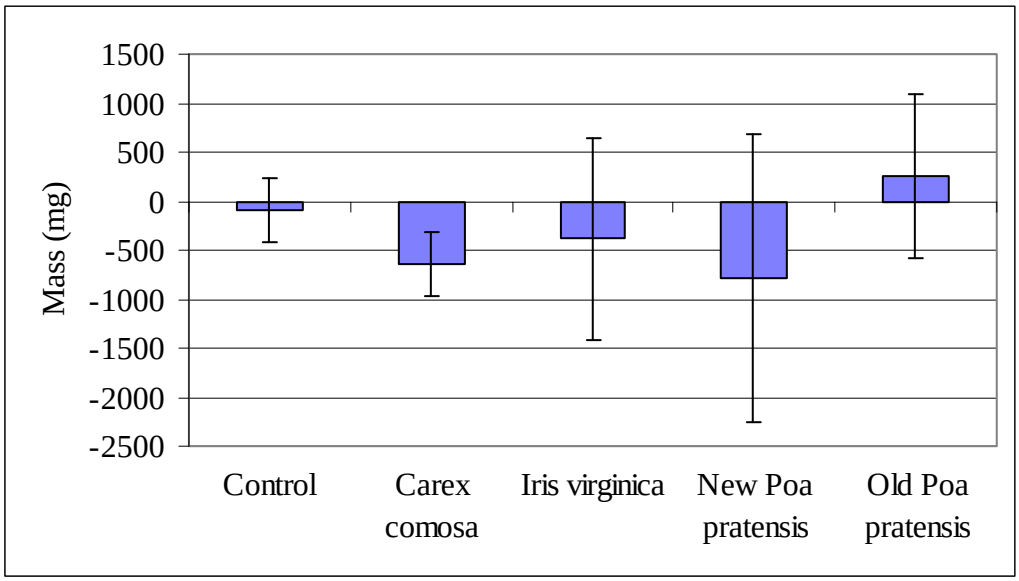
FIGURE 4.32 NITROGEN MASS BALANCE



New *Poa pratensis* showed the greatest mass of unaccounted nitrogen (785 [-680, 2250] mg), followed by *Carex comosa* and *Iris virginica* (640 [317, 963] and 379 [-650, 1410] mg).

New *Poa pratensis* and *Iris virginica* had the greatest variability followed by Old *Poa pratensis*, shown in Figure 4.33. Old *Poa pratensis* was the only column to generate nitrogen.

FIGURE 4.33 UNACCOUNTED FOR NITROGEN BY VEGETATION SPECIES



CHAPTER FIVE: DISCUSSION

QA/QC Discussion

All analysis were completed within required holding times. Target analytes were found in trip blanks on occasion. However, the concentration found was typically just above detection limit. It is assumed that these detections were due to the very low level of analysis and the use of a concentrator column. Results of the matrix spikes and duplicates were typically outside of traditional QC limits of 75 to 125 percent and 0 to 25 percent. Again, meeting these stringent QC limits was not possible due to the extremely low level of detection and analysis. QC data indicate that nitrate nitrogen and orthophosphate laboratory testing procedures are more accurate than digestion samples to determine total nitrogen and total phosphorus. This indicates that there could be some interference due to the digestate. Ammonia QC data signify the importance of insuring the degradation of the standard is not occurring. Degradation of the ammonia standard did not influence the results due to the limited number of detections.

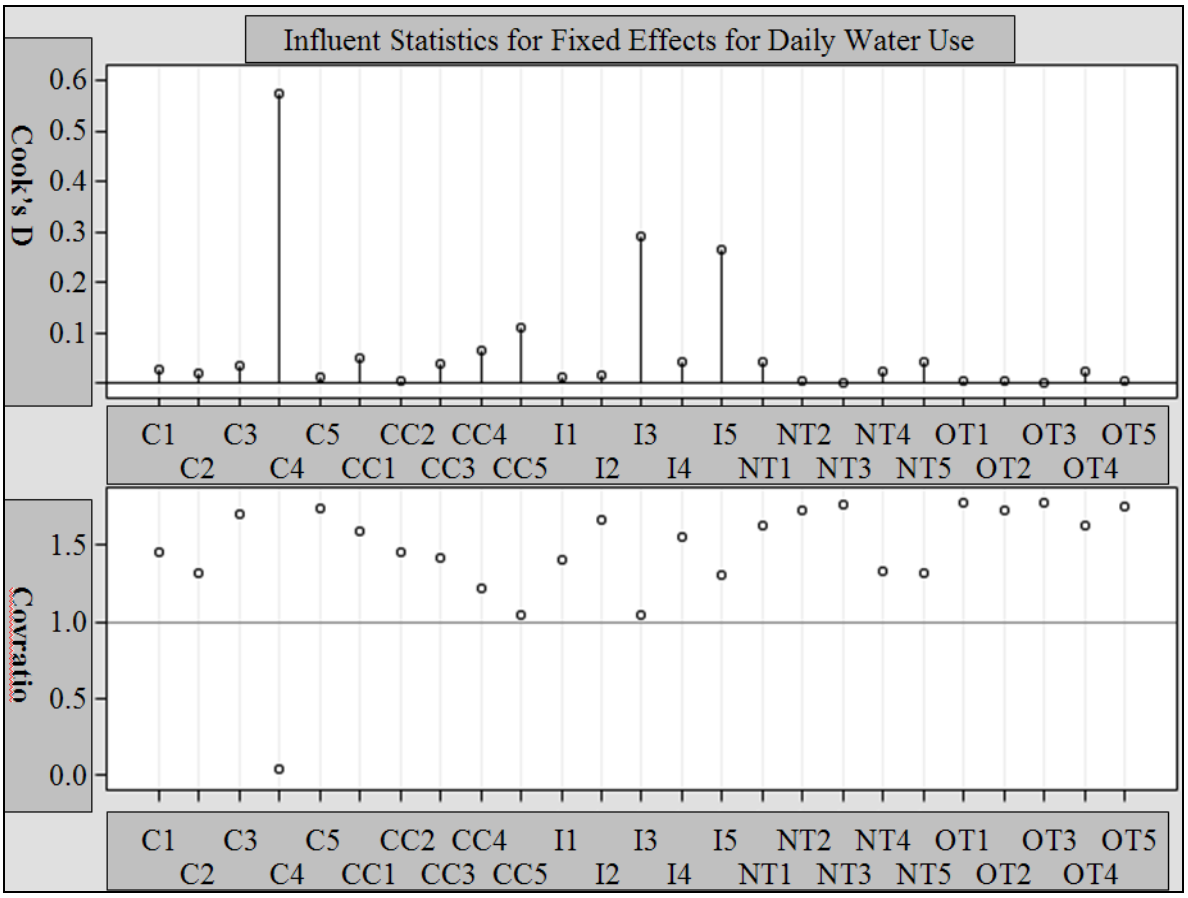
Variability shown in data may have been directly influenced by the laboratory testing procedure, as indicated by the quality assurance samples being outside of the quality Control limits. However, the analysis was able to show significant results with the existing data variability that is inherent when testing at such low concentrations. For additional QA/QC data, see Appendix A.

Water Use

Daily water use data was evaluated for influence on the model. Control C4 column showed the highest influence or deviation on the model results based on Cook's D and the Covariate Ratio shown in Figure 5.1. Evaluation of the raw data shows that column C4 had

extreme daily water use values on 4/1/ 2011, 6/7/2011 and 6/13/2011. Removing these three values changed the geometric mean daily water use from 92.9 cm^3/day to 61.6 cm^3/day. All other Control columns were evaluated and were found to not have experienced extreme daily water use values at the start or end of the experiment as C4 had.

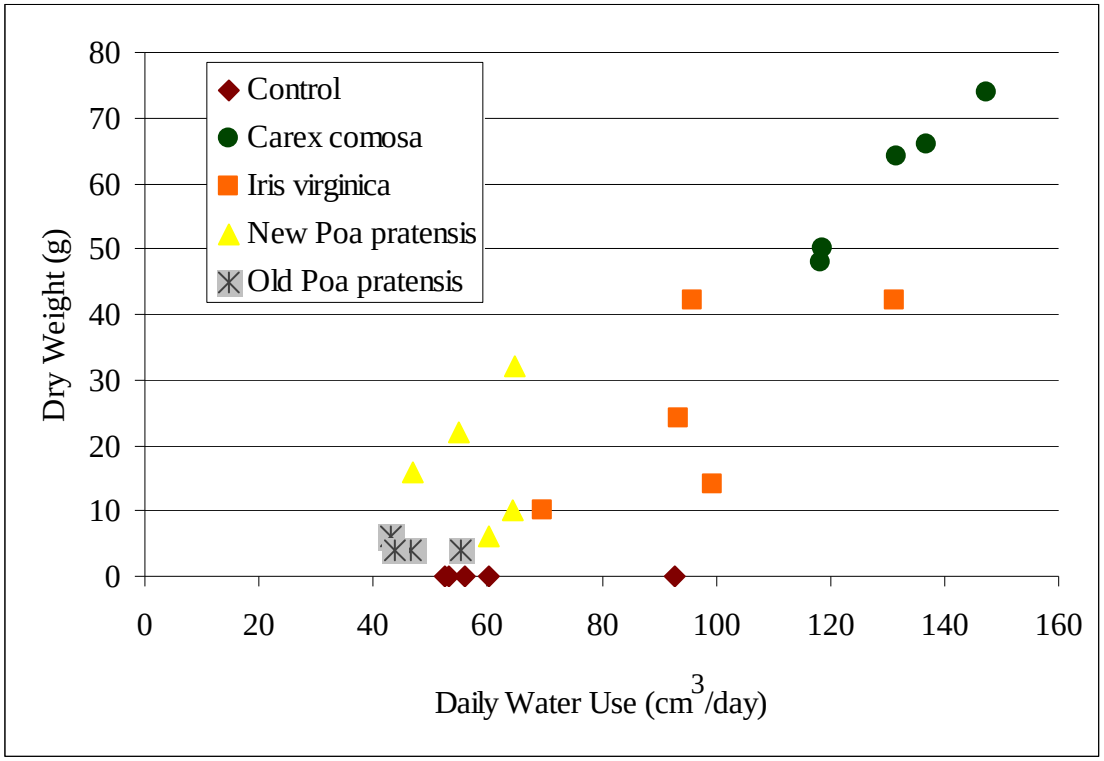
FIGURE 5.1 INFLUENCE STATISTICS FOR FIXED EFFECTS OF DAILY WATER USE



Removing column C4 data from the data set was determined to be insignificant because the covariant parameter estimate of the data with the C4 column explained 73.9 percent of the variation.

The mean daily water use was plotted against the mean total dry weight in Figure 5.2. The mean daily water use increased linearly with the total dry weight of the plant (R^2 = 0.8317 percent without Control, Dry Weight (g) = 0.5924 * DailyWaterUse (cm^3/d) - 22.358).

FIGURE 5.2 DAILY WATER USE VS. TOTAL DRY WEIGHT



The linear relationship shows a minor decrease when evaluated for *Carex comosa* and *Iris virginica* vegetation (Dry Weight (g) = 0.8172* DailyWaterUse (cm^3/d) - 49.96; R^2 = 0.8108). Typically water use is defined by crop coefficients that are determined through on site testing using lysimeters under controlled conditions. Crop coefficients can be significantly affected by the specific crop type, stage of growth, soil moisture, and general crop health [61]. The linear correlation between dry weight and daily water use in the laboratory supports changes in crop coefficients based on stage of growth. However, the significance of the relationship may

be over represented because it does not include a variety of plant types or varying climatic conditions. Additionally, the plants were never placed in a situation of water stress.

Seepage Rate

Hydraulic permeability results indicate that there was not a significant difference in seepage rates in the columns tested. One column (I4) exhibited a seepage rate 280 percent higher than the geometric mean seepage rate of the columns. The vegetation and root mass in column I4 was not significantly different than the other four *Iris virginica* columns. In fact it was one of the smaller plants with the total mass ranked 4 out of 5. The increase in seepage rate may be due to variability in column construction. However, it is more likely that there were changes in the preferential flow pattern due to the health of the plant. Column I4 appeared to be growing vigorously prior to infestation of spider mites. There is a possibility that the plant could have stopped growing and decreased root function after infestation. The seepage rate could be directly influenced by preferential flow patterns around roots that were no longer functioning at the time of testing.

The infiltration rate of bioretention basins and buffer strips has been shown to be greater than row crop land use practices [22, 62]. However, there is limited data available on infiltration rates of bioretention basins in relation to urban land use practices, specifically large lawn areas and golf courses. Variability in hydraulic permeability rates based on plant species was inconclusive in this experiment due to the small number of samples. Future research should consider increasing the number of columns tested or completing pilot scale studies in the field. Infiltration rates determined on a pilot scale level could increase the applicability of the results.

Nutrient Analysis

Ammonia Nitrogen Analysis

Low ammonia concentrations in the synthetic stormwater (0.41 ppm) contributed to a non detect in 99 percent of the samples. Ammonia in the stormwater could have been converted to nitrate through nitrification, been absorbed onto the soil matrix or utilized by the plant. Most likely there were many soil/water/plant interactions occurring during the time of the experiment. Overall ammonia concentrations in the soil decreased during the experiment. Future work on ammonia leached in wastewater may consider increasing the synthetic stormwater concentration of ammonia. Regardless of the change in concentration of the synthetic stormwater a concentrator column should be used with the IC cation column to increase the likelihood of obtaining significant results.

Nitrate Nitrogen Analysis

Carex comosa and *Iris virginica* showed a reduction in nitrate nitrogen leached over the Control where New and Old *Poa pratensis* columns showed a significant increase in nitrate nitrogen leached through the columns. *Carex comosa* reduced mass of nitrate leached 96.7 percent and 90.5 percent in the concentration of nitrate leached over the Control, shown in Table 5.1. *Iris virginica* reduced the mass of nitrate nitrogen by 58.9 percent and reduced the concentration of nitrate nitrogen over the Control by 34.3 percent. Both Old and New *Poa pratensis* generated nitrate nitrogen over the Control, with New Poa pratensis generating over two times as much nitrate nitrogen than Old *Poa pratensis* and three times over the Control. The increase in nitrate nitrogen can be attributed to the slow degradation of New *Poa pratensis* that could have been occurring over the time of the experiment. The average dry weight total for columns NT1, NT3 and NT5 was 10.67 [4.97, 16.36] grams compared to 27 [17.2, 36.8] grams

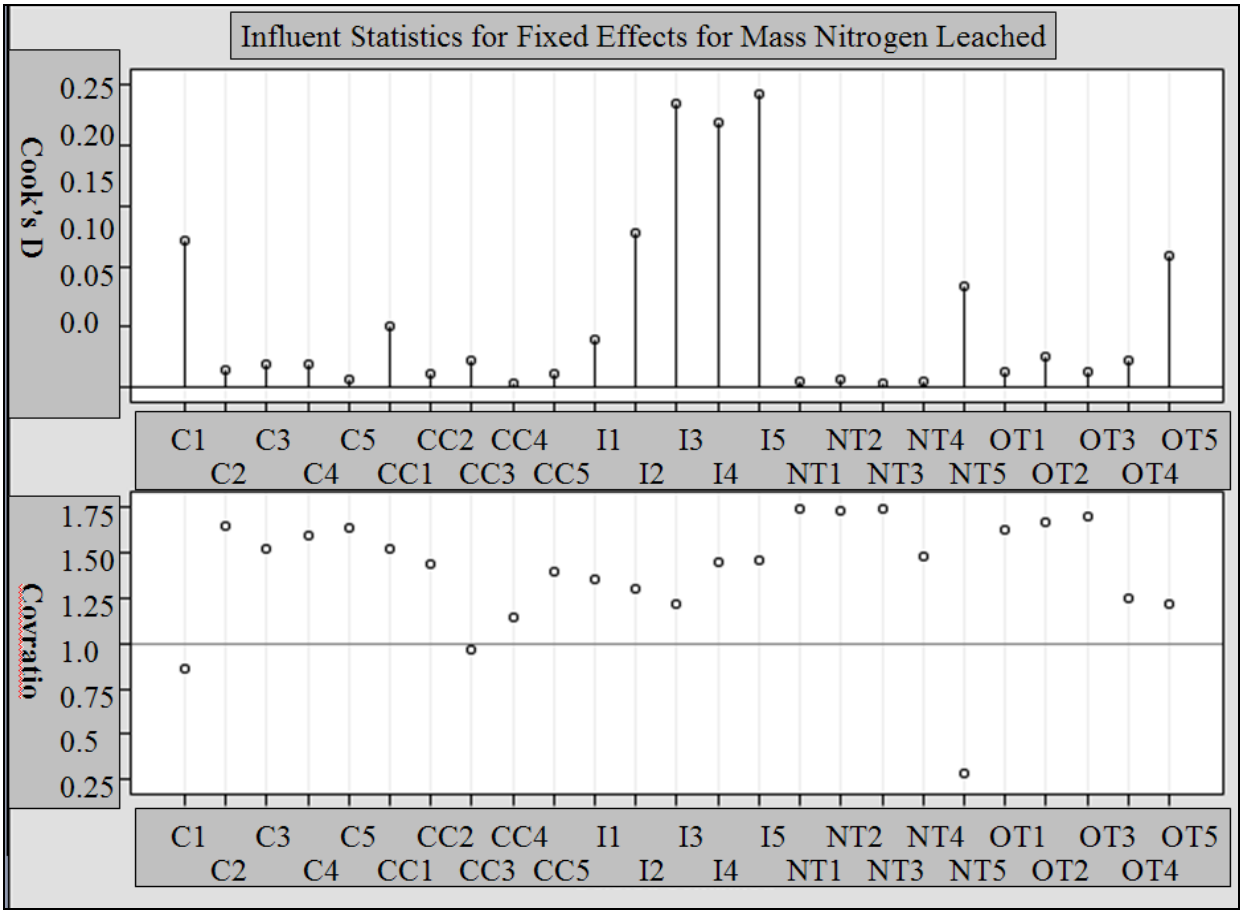
for NT 2 and NT4. This reduction in plant matter indicates that the plant was dead or dying by the end of the experiment.

TABLE 5.1 NITRATE NITROGEN ANALYSIS VS. CONTROL

	Carex comosa	Iris virginica	New Poa pratensis	Old Poa pratensis
Mass	-96.7%	-58.9%	314%	130%
Concentration	-90.5%	-34.3%	309%	116%

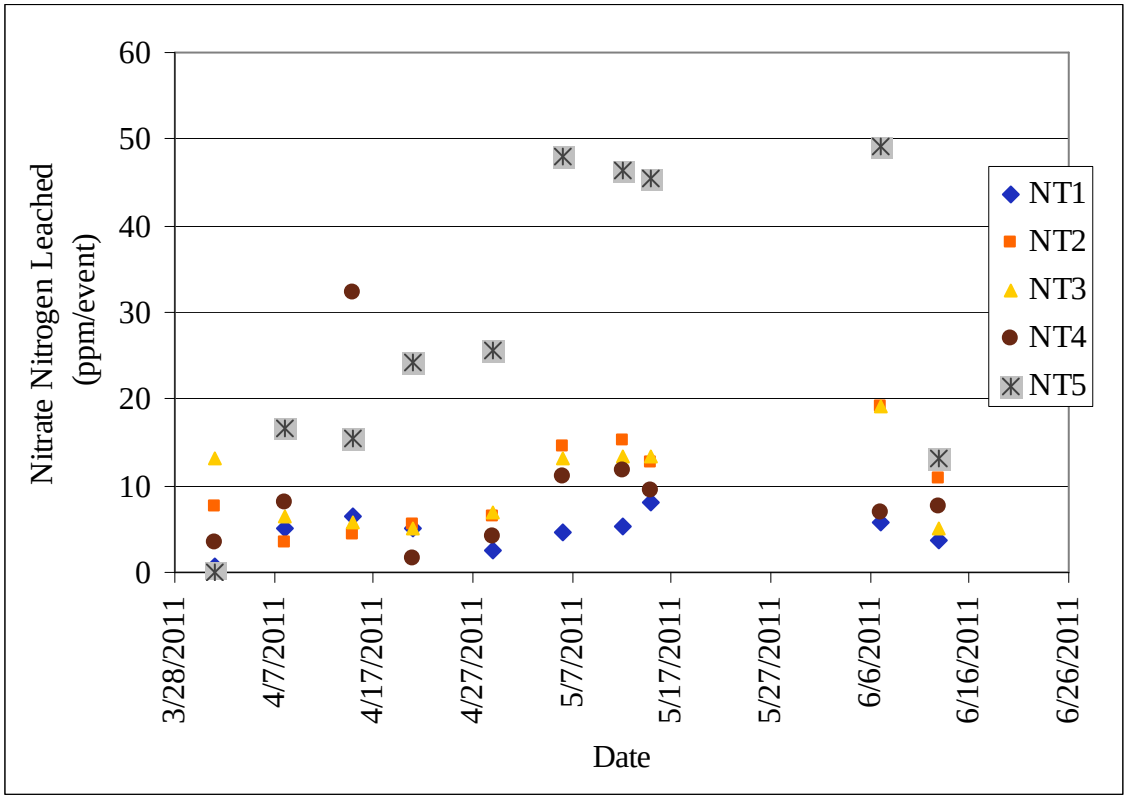
Mass of nitrate nitrogen leached was evaluated for influence on the model. New *Poa pratensis* NT5 column showed the highest influence or deviation on the model results based on Cook's D and the Covariate Ratio shown in Figure 5.3.

FIGURE 5.3 INFLUENCE STATISTICS FOR FIXED EFFECTS OF NITROGEN MASS LEACHED



Evaluation of the raw data shows that New *Poa pratensis* NT5 column showed an increase in the concentration of nitrogen leached as shown in Figure 5.4. The remaining New *Poa pratensis* columns did not experience the same spike in nitrate nitrogen leached.

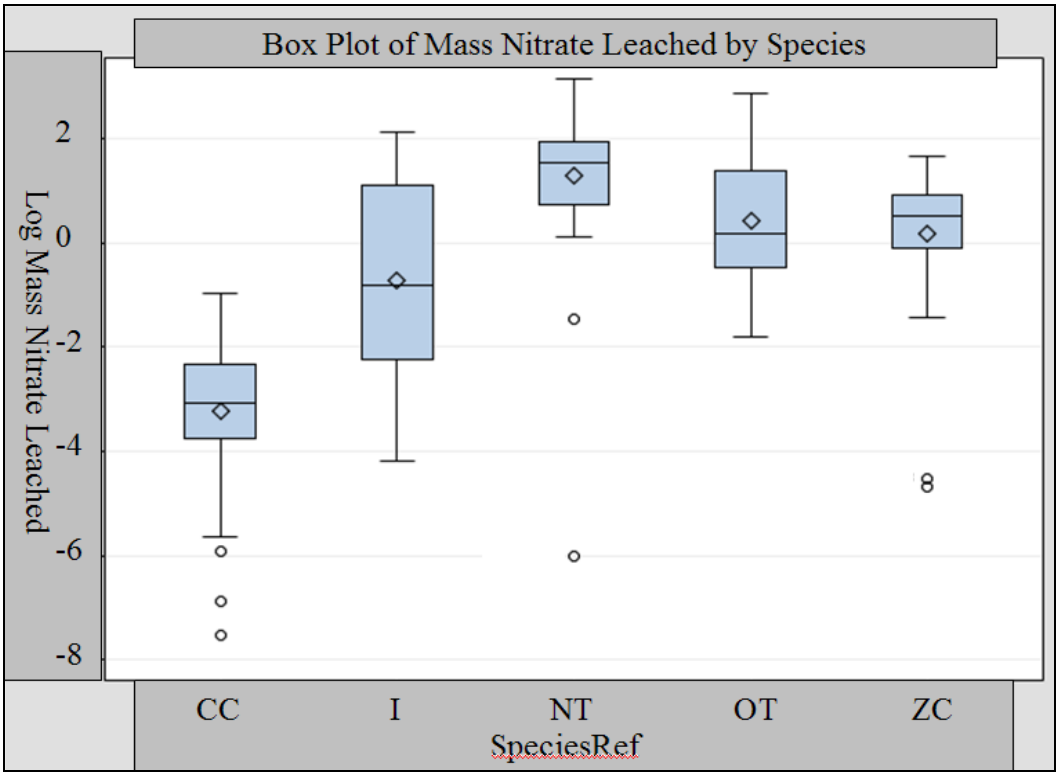
FIGURE 5.4 NEW *POA PRATENSIS* NITRATE NITROGEN LEACHED OVER TIME



The increase in the amount of nitrate nitrogen could possibly be attributed to the health and viability of the plant. Columns NT1, NT3 and NT5 quit growing and started to die off by the end of the experiment. Removing columns NT1, NT3 and NT5 from the data set for the last four runs decreased the R^2 value from 57.5 to 56.8 percent. The least means squared analysis did not change. Due to the minimal changes to the model, all data was subsequently used.

Data variability in the nitrate nitrogen mass leached was greater based on vegetation species compared with the stormwater dosed as indicated by Figure 5.5 and 5.6. Figure 5.5 shows a box plot of the nitrate nitrogen mass leached data by vegetation species and Figure 5.6 shows the same information based on the amount of stormwater dosed.

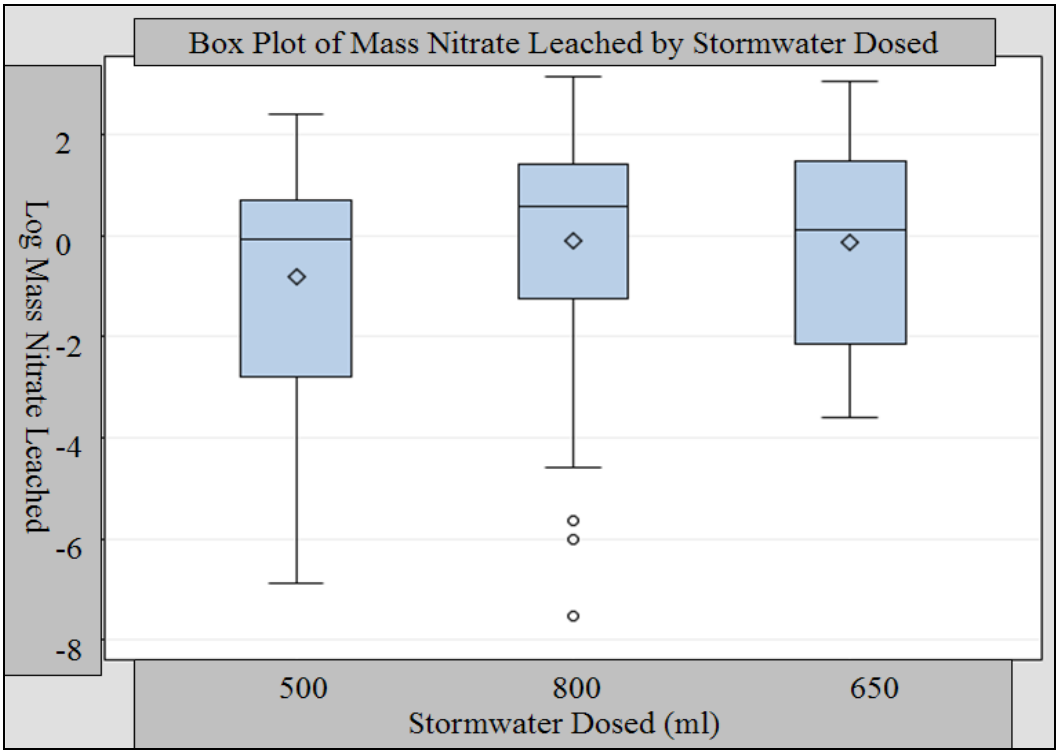
FIGURE 5.5 BOX PLOT OF NITRATE NITROGEN MASS LEACHED VS. VEGETATION SPECIES



CC = Carex comosa, I = Iris virginica, NT = New Poa pratensis,
OT = Old *Poa pratensis*, ZC = Control

Outliers occurred in the *Carex comosa*, New *Poa pratensis* and the Control. Outliers were also found in the 800 ml stormwater dosed. These outliers increased the width of the 95 percent confidence interval. However, the 25th and 75th quartile width shows clustering around the median with the exception of *Iris virginica* whose quartile width is double.

FIGURE 5.6 BOX PLOT OF NITRATE NITROGEN MASS LEACHED VS. STORMWATER DOSED



Control is 650 mL Stormwater Dosed

Nitrate nitrogen results indicate *Carex comosa* and *Iris virginica* selection in bioretention basins can significantly reduce the mass and concentration of nitrate nitrogen leached in bioretention basins. Additional experiments should be conducted to determine if these results can be reproduced for additional native vegetation species over a wider range of stormwater volumes (up to the 25 year 24 hour storm volume).

Total Nitrogen Analysis

Carex comosa and *Iris virginica* reduced the total nitrogen concentration over the Control where New and Old *Poa pratensis* columns showed a slight reduction in total nitrogen concentration for New *Poa pratensis* to an increase in total nitrogen concentration for Old *Poa pratensis* when compared to the Control. *Carex comosa* had a 78.8 percent reduction in the mass

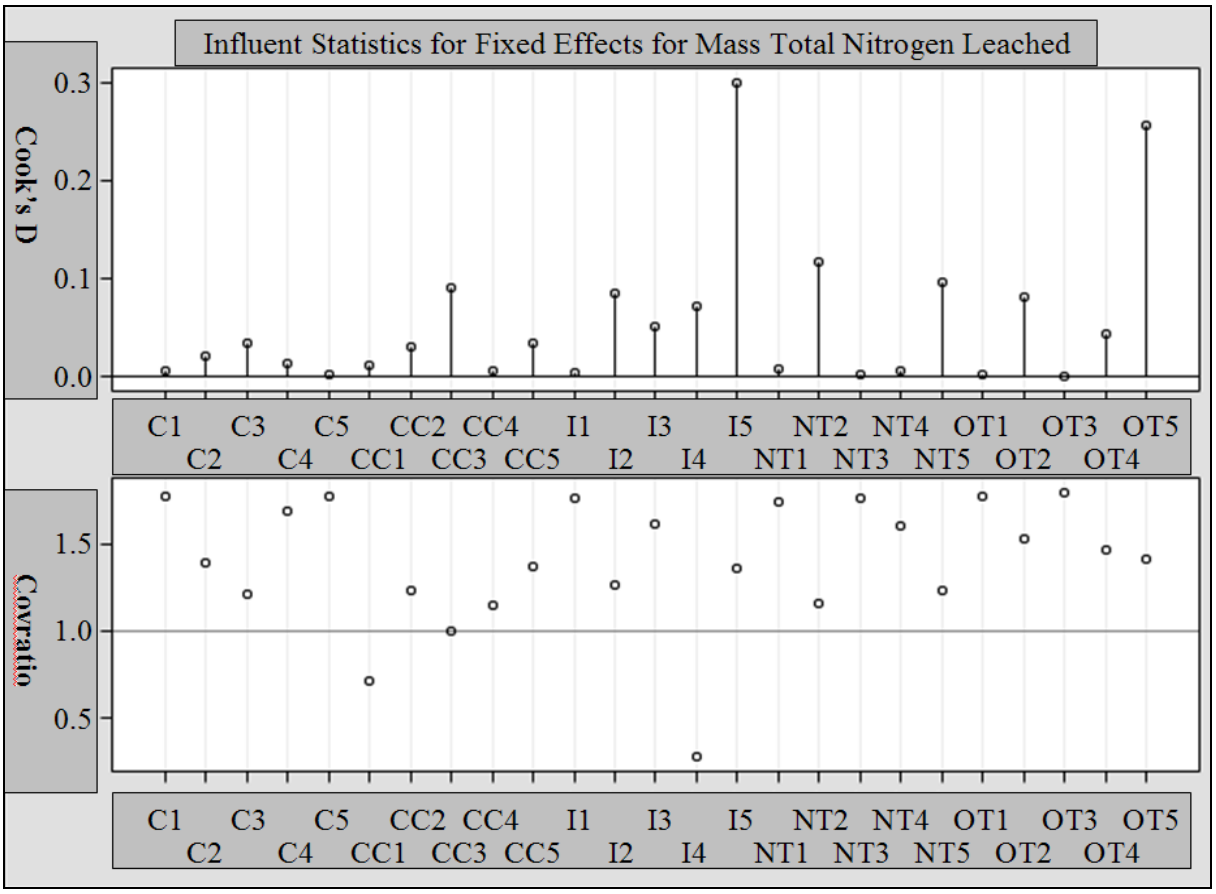
of total nitrogen leached and 35.6 percent reduction in the concentration of total nitrogen leached over the Control, shown in Table 5.2. *Iris virginica* reduced the concentration of total nitrogen by 34.3 percent and a reduction in the mass of total nitrogen over the Control by 24.1 percent. Both Old and New *Poa pratensis* generated total nitrogen over the Control, with New Poa pratensis generating over 87 percent as much total nitrogen. The increase in total nitrogen follows the increase in nitrate nitrogen and can be attributed to the slow degradation of New *Poa pratensis* and possibly *Iris virginica* that could have been occurring over the time of the experiment.

TABLE 5.2 TOTAL NITROGEN ANALYSIS VS. CONTROL

	Carex comosa	Iris virginica	New Poa pratensis	Old Poa pratensis
Mass	-78.8%	-24.1%	192%	137%
Concentration	-35.6%	123.6%	187%	121%

Mass of total nitrogen leached was evaluated for influence on the model. *Iris virginica* column I4 showed the highest influence or deviation on the model results based on Cook's D and the Covariate Ratio shown in Figure 5.7.

FIGURE 5.7 INFLUENCE STATISTICS FOR FIXED EFFECTS OF TOTAL NITROGEN



Evaluation of the raw data shows that *Iris virginica* column I4 had an increase in the mass of total nitrogen leached on 6/7/2011. This column also had a 280 percent increase in the hydraulic seepage rate which may explain an increase in total nitrogen if the plant was experiencing decreased root function after infestation. Total nitrogen could be directly influenced by the amount of water seeping through the column due to preferential flow patterns around roots. In addition there could be an increase in total nitrogen concentration due to degradation of plant material. However, nitrate nitrogen data for columns I4 did not overly influence model results.

Total nitrogen results indicate *Carex comosa* and *Iris virginica* selection in bioretention basins can significantly reduce the mass and concentration of total nitrogen leached in

bioretention basins. Additional experiments should be conducted to determine if these results can be reproduced for additional native vegetation species over a wider range of stormwater volumes (up to the 25 year 24 hour storm volume).

Orthophosphate Analysis

Carex comosa and *Iris virginica* vegetation shows an increase in reduction in orthophosphate leached over *Poa pratensis* vegetation. There was a significant increase in orthophosphate leached by Old *Poa pratensis* over the Control. *Carex comosa* showed a 96.2 percent reduction in the mass of orthophosphate leached and 90.7 percent reduction in the concentration of orthophosphate leached over the Control, shown in Table 5.3. *Iris virginica* reduced the mass of orthophosphate by 76.7 percent and decreased the concentration of orthophosphate over the Control by 62.8 percent. Old *Poa pratensis* also reduced orthophosphate concentrations around 16 percent for both mass and concentration. Old *Poa pratensis* generated orthophosphate over the Control. The increase in orthophosphate can be attributed to the slow degradation of Old *Poa pratensis* that could have been occurring over the time of the experiment, or changes in the columns redoxmorphic conditions.

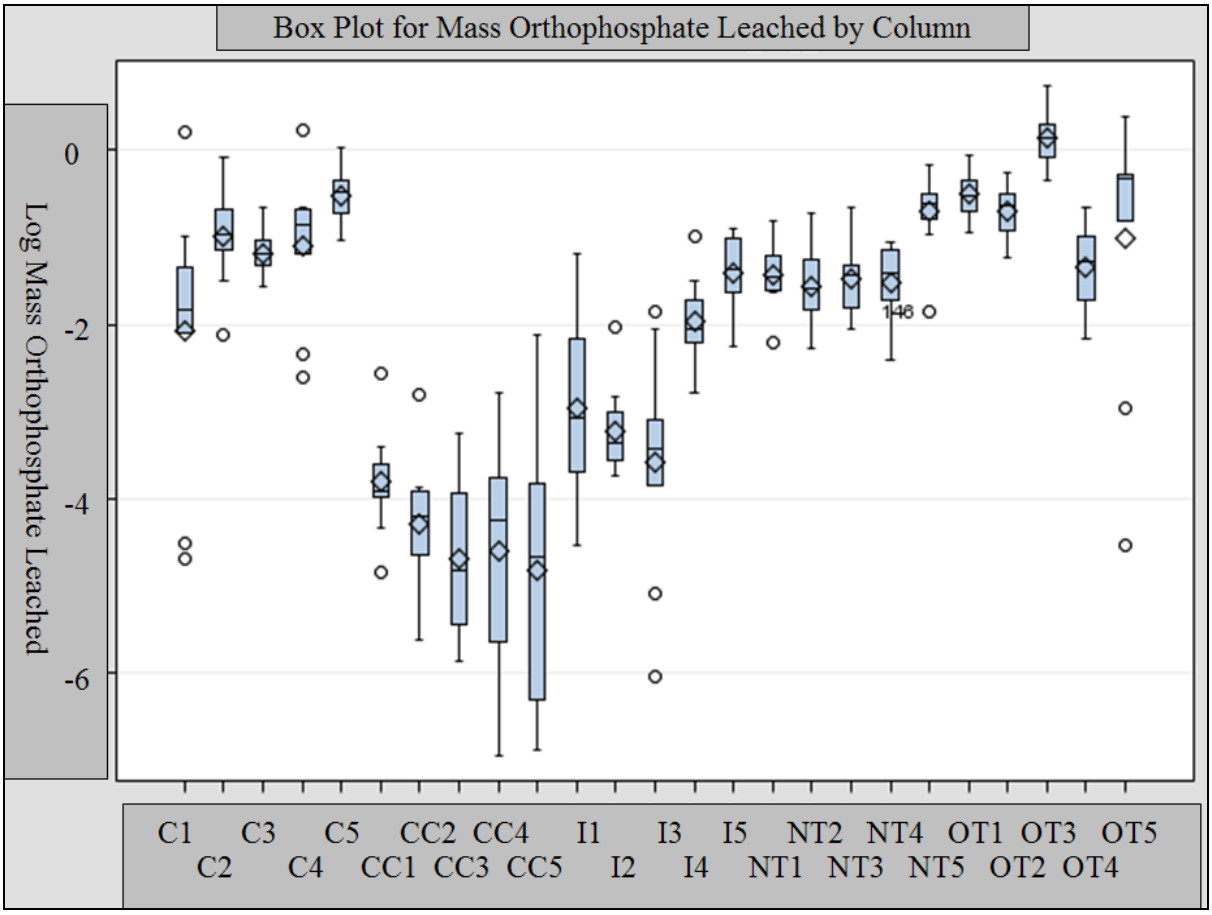
TABLE 5.3 ORTHOPHOSPHATE ANALYSIS VS. CONTROL

	Carex comosa	Iris virginica	New Poa pratensis	Old Poa pratensis
Mass	-96.2%	-76.7%	-15.5%	162%
Concentration	-90.1%	-62.8%	-16.7%	146%

Mass of orthophosphate leached was evaluated for influence on the model. There was significantly more variability in the data for orthophosphate than for other nutrients evaluated.

Of interest was the variability of *Carex comosa* columns compared to all other columns shown in Figure 5.8.

FIGURE 5.8 BOX PLOT ORTHOPHOSPHATE LEACHED FOR EACH COLUMN



Carex comosa columns showed a high variability in data vs. all other columns for mass of orthophosphate leached. There were no discernable patterns in the raw data analysis to explain the variability in data. However, variability may be attributed to the very low numbers that were being reported for *Carex comosa* columns. The geometric mean mass of orthophosphate leached was 0.01 mg per event.

Total Phosphorus Analysis

Carex comosa and *Iris virginica* showed a reduction in total phosphorus mass leached over the Control where non native vegetation showed a slight decrease in total phosphorus mass

leached for New *Poa pratensis* and a significant increase in total phosphorus mass leached by Old *Poa pratensis*. *Carex comosa* showed an 86.3 percent reduction in the mass of total phosphorus leached and 4.5 percent increase in the concentration of total phosphorus leached over the Control, shown in Table 5.4. *Iris virginica* reduced the mass of total phosphorus by 64.1 percent but increased the concentration of total phosphorus over the Control by 46.7 percent. Both Old and New *Poa pratensis* had higher total phosphorus concentrations over the Control. The increase in total phosphorus can be attributed to the degradation of *Poa pratensis* reducing the demand for total phosphorus by the vegetation.

TABLE 5.4 TOTAL PHOSPHORUS ANALYSIS VS. CONTROL

	Carex comosa	Iris virginica	New Poa pratensis	Old Poa pratensis
Mass	-86.3%	-64.1%	-16%	155%
Concentration	104.5%	146.7%	206%	342%

Data evaluation on influence of the model showed no significant outliers or variation in the raw data.

Normalized Nutrient Analysis

Mass of nutrient utilized by each column was divided by the mass of dry weight vegetation to standardize nutrient values for further evaluation. Both values were log transformed prior to the analysis. Species was a significant indicator in determining nutrient utilized for all nitrogen species, shown in Table 5.5. Species was not a significant indicator in determining nutrient utilized for phosphorus. Stormwater dosed was a significant predictor for all nutrient utilization with the exception of nitrate. This could be attributed to the fact that

nitrate nitrogen is mobile in the soil profile while phosphorus is typically adsorbed onto the soil media mixture.

TABLE 5.5 TEST OF FIXED EFFECTS FOR STANDARDIZED NUTRIENT UTILIZATION

Test of Fixed Effects				
	Species		Stormwater Dosed	
Nutrient	F Value	Pr>F	F Value	Pr>F
Ammonia	43.01	<.0001	474.68	<.0001
Nitrate	5.32	0.0139	1.66	0.1965
Total Nitrogen	9.19	<.0001	15.6	<.0001
Orthophosphate	0.45	0.7156	14.88	<.0001
Total Phosphorus	0.15	0.9296	25.33	<.0001

Differences of least squares means for standardized nutrient utilization showed significant differences between *Carex comosa* and *Iris virginica* with Old *Poa pratensis* for all nitrogen species. No significant differences were found between columns for orthophosphate and total phosphorus data.

TABLE 5.5 DIFFERENCES OF LEAST SQUARES MEANS FOR STANDARDIZED NUTRIENT UTILIZATION

Differences of Least Squares Means		NH3 Adj P	NO3 Adj P	TN Adj P	PO4 Adj P	TP Adj P
Carex comosa	Iris virginica	0.1839	0.9819	0.1645	0.9854	0.9942
	New Poa pratensis	0.0082	0.9835	0.2649	0.7744	0.9099
	Old Poa pratensis	<.0001	0.0110	0.0008	0.7804	0.9940
Iris virginica	New Poa pratensis	0.4409	0.9999	0.0181	0.9277	0.9759
	Old Poa pratensis	<.0001	0.0381	<.0001	0.9207	1.0000
New Poa pratensis	Old Poa pratensis	<.0001	0.0958	0.2886	0.9998	0.9839

The standardized data supports the conclusions of nutrient analysis that was not standardized for the nitrogen species. However, the P values are not as significant as shown for data that was not standardized. In addition, there were more significant differences noted between columns with the non standardized data.

The standardized data does not support the conclusions of the nutrient analysis that was not standardized for phosphorus species. This could be due to the fact that soil bioretention mix is a considerable contributing factor to phosphorus sorption and utilization.

Nutrient Summary

Vegetation selection and stormwater dosed significantly impact nutrient removal in this study with one exception. The amount of total phosphorus leached through the columns could not be determined by evaluating the volume of stormwater dosed. However, all other nutrient data could be predicted by the vegetation species and the volume of stormwater dosed including orthophosphate and total phosphorus. Nutrient removal efficiencies have been tied to rooting characteristics [21] with fibrous rooting systems being more efficient than thick rooting systems.

Carex comosa is considered a fibrous rooting plant while *Iris virginica* is a thick root plant with a single tap root supported by other smaller roots.

Read determined that different vegetation species showed significant differences in pollutant removal rates while simulating treatment of stormwater in bioretention basins using 20 native wetland plants [13]. Similar results were found by Lucas [32] determining that nutrient removal rates were greater in vegetated columns vs. unvegetated columns.

Plant Tissue Analysis

Macro-Nutrient Plant Tissue Analysis

Carex comosa and *Iris virginica* showed a higher mass of nitrogen (N), phosphorus (P) and potassium (K) over non native vegetation (shown in Figure 5.9). However, this is mainly due to the mass of vegetation grown by the native vegetation vs. the non native vegetation. Old *Poa pratensis* had the highest percent nitrogen (2.14 ± 0.1 percent) and the same percentage of phosphorus as *Iris virginica* (0.42 ± 0.04 percent). *Carex comosa* and *Iris virginica* showed a marked increase in the percentage of potassium over New and Old *Poa pratensis* columns (shown in Figure 5.10).

FIGURE 5.9 N, P, AND K MASS BY SPECIES

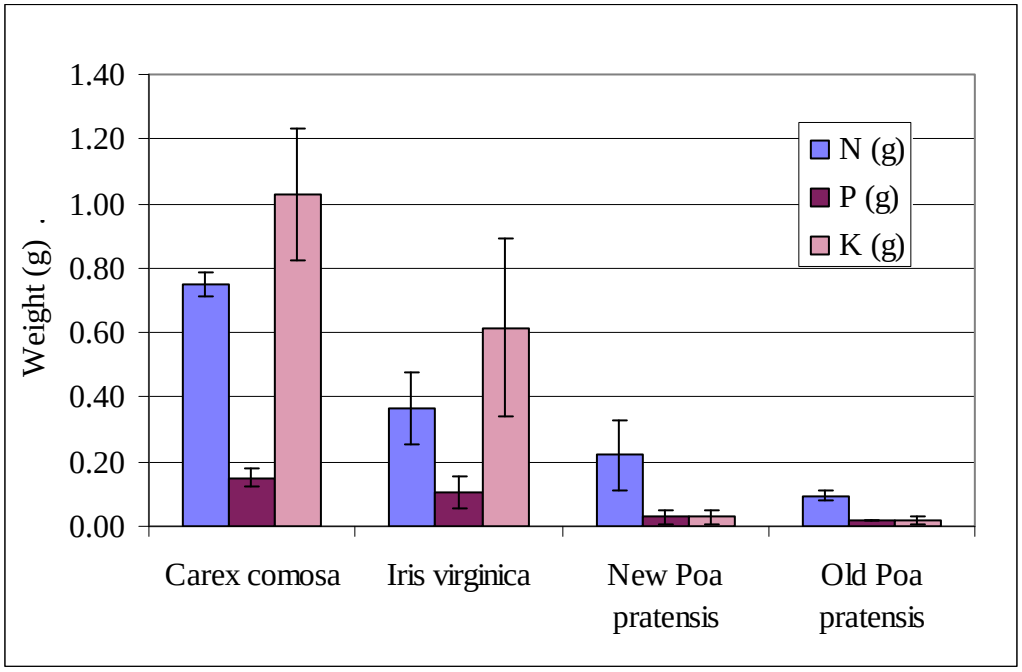
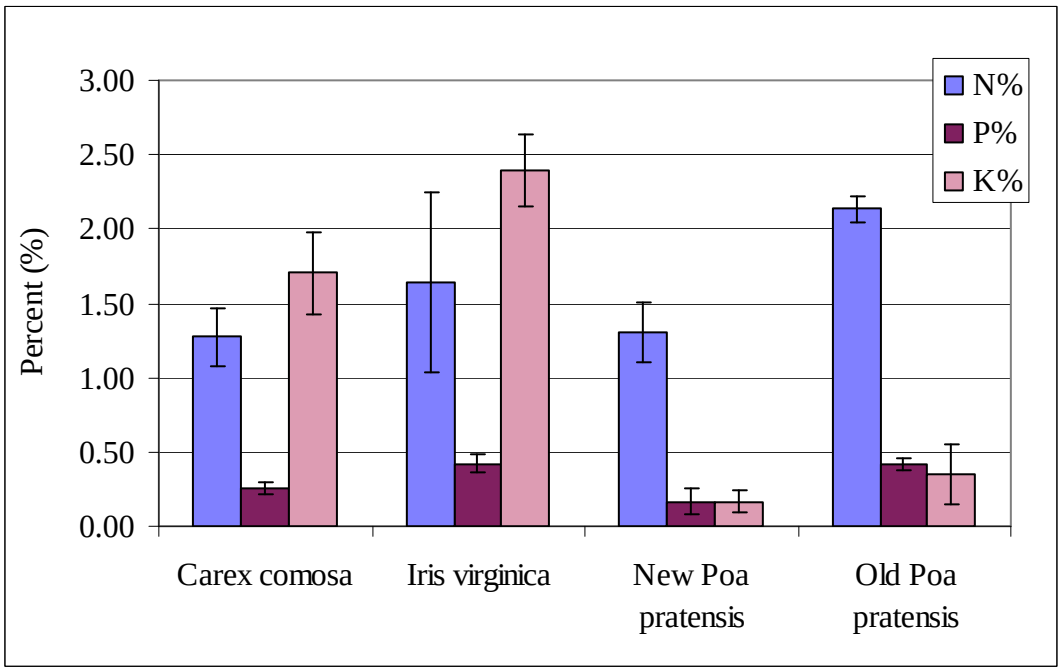
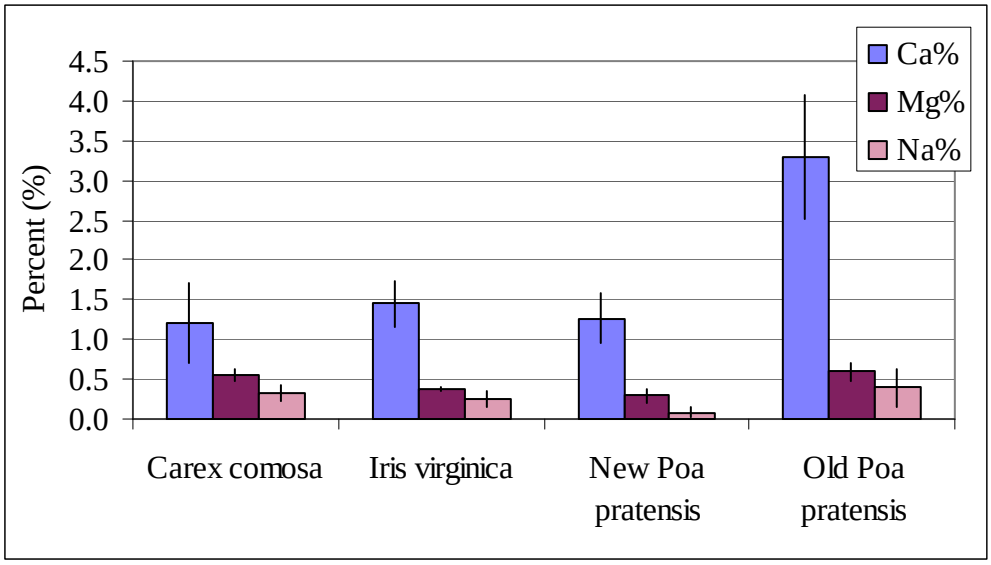


FIGURE 5.10 N, P, AND K PERCENTAGE BY SPECIES



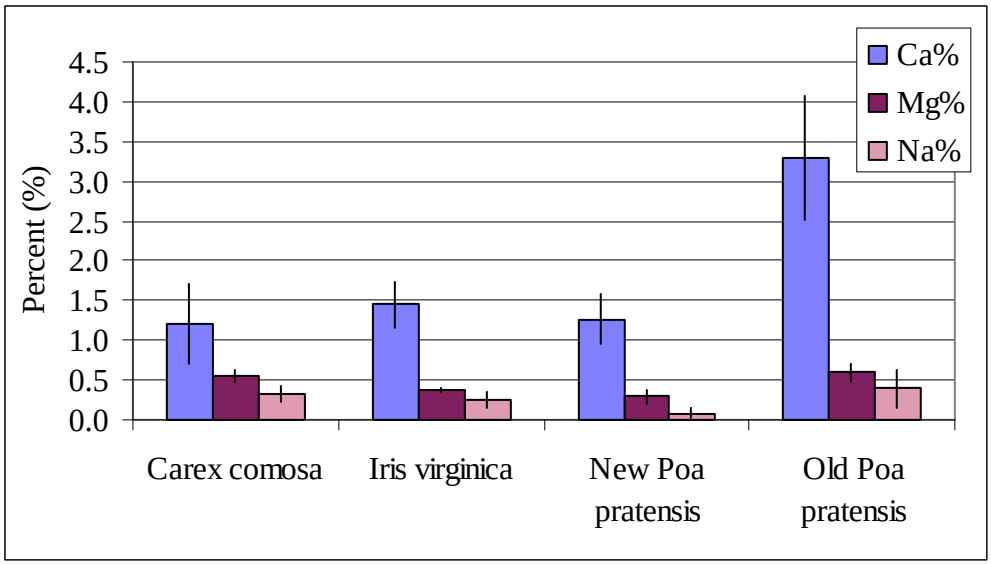
Mass of calcium, manganese and sodium in the vegetation matter follows a similar pattern to the N, P and K data with the *Carex comosa* and *Iris virginica* having a higher mass than New and Old *Poa pratensis* vegetation (shown in Figure 5.11).

FIGURE 5.11 CA, MG, AND NA MASS BY SPECIES



Carex comosa and *Iris virginica* contained a higher mass of calcium, magnesium and sodium due to the mass of vegetation. Old *Poa pratensis* showed the highest percentage of calcium, magnesium and sodium over other species (shown in Figure 5.12). This increase could be attributed to the significant fertilization rates of turf grass.

FIGURE 5.12 CA, MG, AND NA PERCENTAGE BY SPECIES



Plant tissue analysis supports the use of *Carex comosa* and *Iris virginica* over *Poa pratensis* vegetation in bioretention basins to increase the mass of nitrogen and phosphorus

removed with the plant material. This removal is not due to a higher concentration of nutrients in native plants but is contributed by a significant increase in the root and shoots mass of native vegetation over *Poa pratensis*. The addition of large native vegetation is easily evaluated in the field to modify design and implementation of bioretention basins.

Metal Plant Tissue Analysis

New *Poa pratensis* had the highest mass of iron and aluminum followed by *Carex comosa*. The increase in iron and aluminum mass in *Carex comosa* is significantly due to the increase in vegetation mass (see Figure 5.13). New and Old *Poa pratensis* showed appreciably higher concentrations of iron and aluminum over *Carex comosa* and *Iris virginica* columns, shown in Figure 5.14. This may be attributed to the significant amount of commercial fertilizer typically applied to *Poa pratensis*. Iron is applied to lawns to increase the "green" color. Phosphorus applications can also apply iron and aluminum when phosphate rock is used [63]. Availability of aluminum in soils increases with decreasing pH [64]. Depending on availability of iron and aluminum, there may also be some type of complex that is being taken up by the plants. Further research is needed to evaluate the increase of metals by *Poa pratensis*.

FIGURE 5.13 FE AND AL MASS BY SPECIES

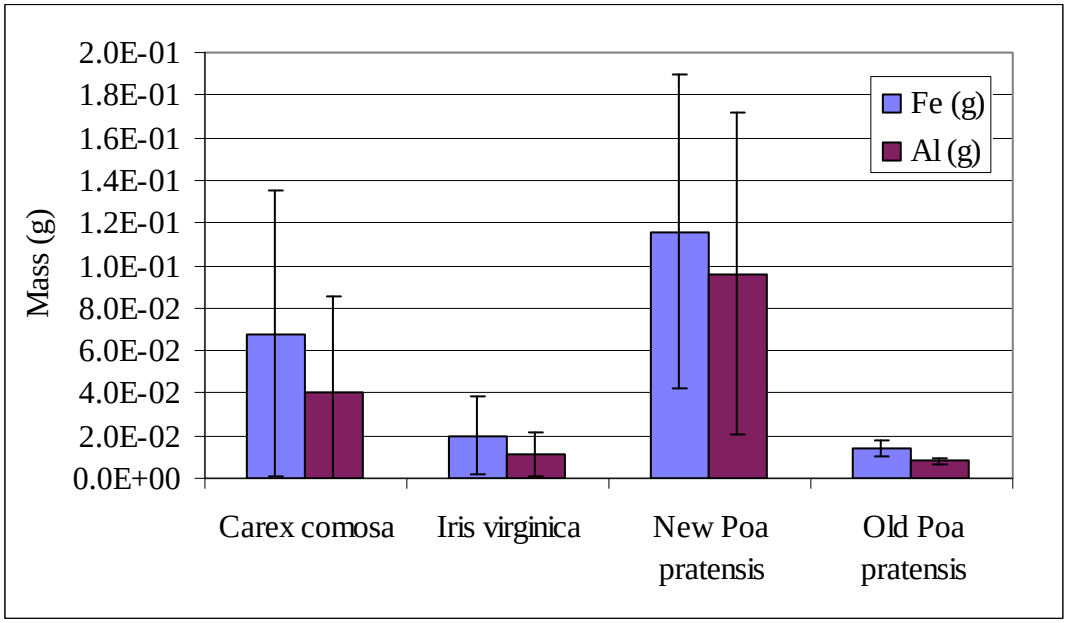
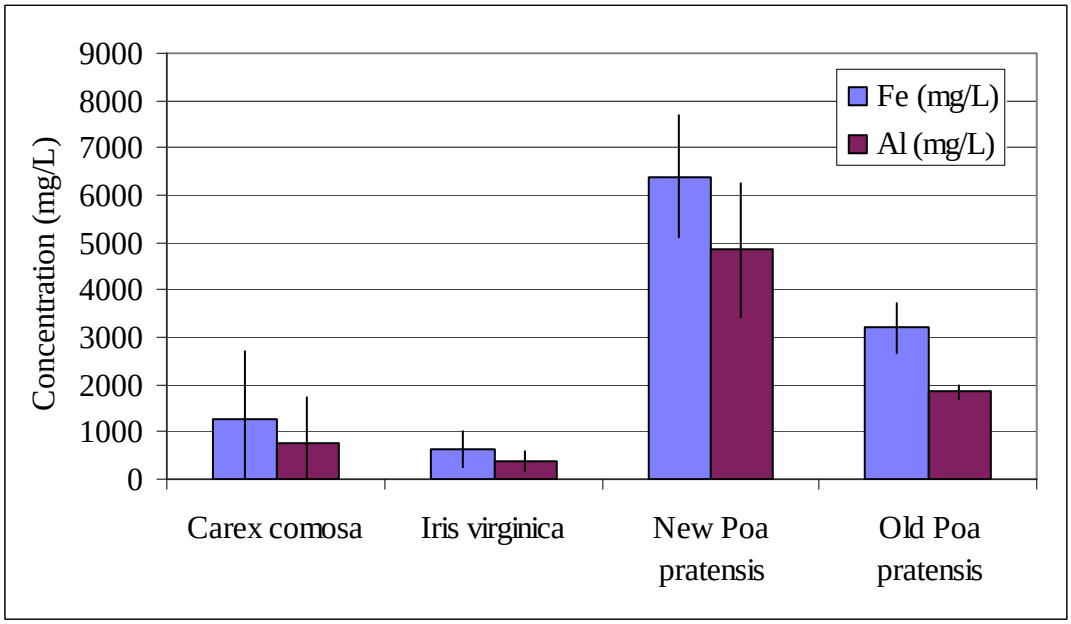
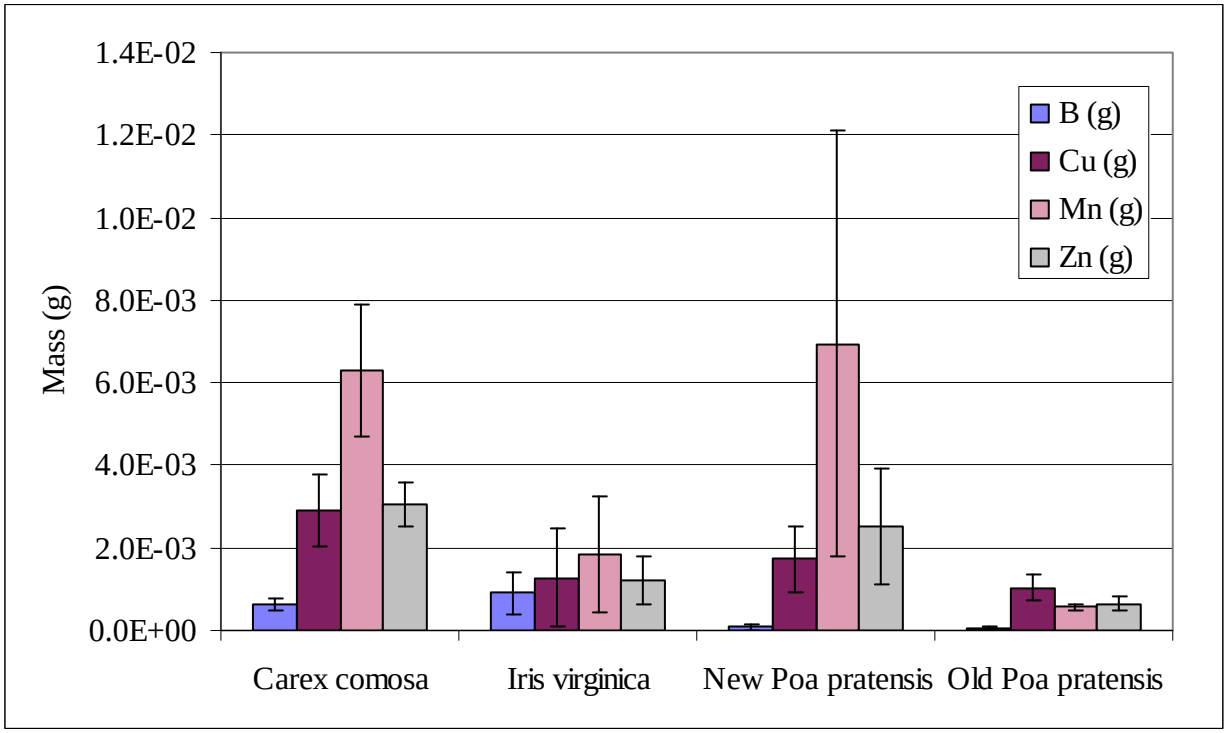


FIGURE 5.14 FE AND AL CONCENTRATION BY SPECIES



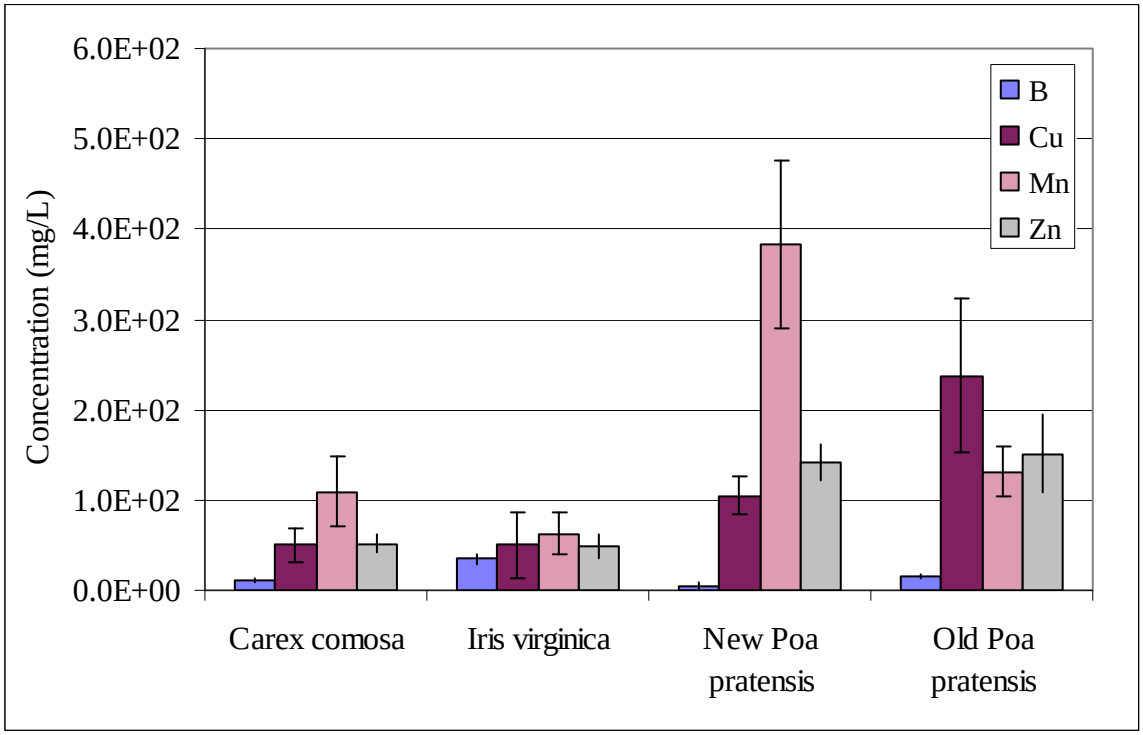
Manganese was found to be the leading micronutrient compared with boron, copper and zinc in all vegetation species except Old *Poa pratensis*. Copper was the leading micronutrient in Old *Poa pratensis*, shown in Figure 5.15.

FIGURE 5.15 B, CU, MN AND ZN MASS BY SPECIES



New *Poa pratensis* showed similar metal mass as *Carex comosa*. However, this is again attributed to the increase in mass of *Carex comosa*. New *Poa pratensis* and Old *Poa pratensis* had the highest concentrations of copper, manganese and zinc over *Carex comosa* and *Iris virginica* columns. However, *Carex comosa* and *Iris virginica* did show a higher concentration of boron than *Poa pratensis*, shown in Figure 5.16.

FIGURE 5.16 B, CU, MN AND ZN CONCENTRATION BY SPECIES



As discussed previously, the increase in copper, manganese and zinc concentrations in non native vegetation may be attributed to the high fertilization rate of *Poa pratensis*. This increase could be due to contaminants in the fertilizer or changes in the pH of the soil that may increase the availability. Soils fertilized with animal manures have been shown to have higher concentrations of extractable copper, boron and zinc [65].

The increase in metal concentration in *Poa pratensis* vegetation did not appear to increase heavy metal contamination from stormwater, as transition metals were non detected in all samples. Evaluation of transition metals in future experiments will require increasing the dose of transition metals in the synthetic stormwater substantially or overloading the soil system with transition metals in an attempt to saturate the soil profile prior to testing.

Plant Tissue Summary

Vegetation species is a significant predictor in determining plant tissue analysis. However, patterns in plant tissue analysis and treatment of stormwater in bioretention basins based on vegetation selection were not apparent. Plant tissue analysis appears to be an inherent property of the plant itself and could not be attributed to increase treatment of stormwater in bioretention basins. These results are difficult to compare with existing research on stormwater treatment in bioretention basins due to limited results. However Sun completed an evaluation on heavy metals in 2007 that showed 88 to 97 percent of the heavy metals evaluated were captured in the soil media, 2 to 11.6 percent were leached through the soil column and 0.5 to 3.3 percent were accumulated in the vegetation biomass [66]. These results indicate that the primary treatment mechanism for heavy metals is adsorption in the soil media.

Soil Analysis

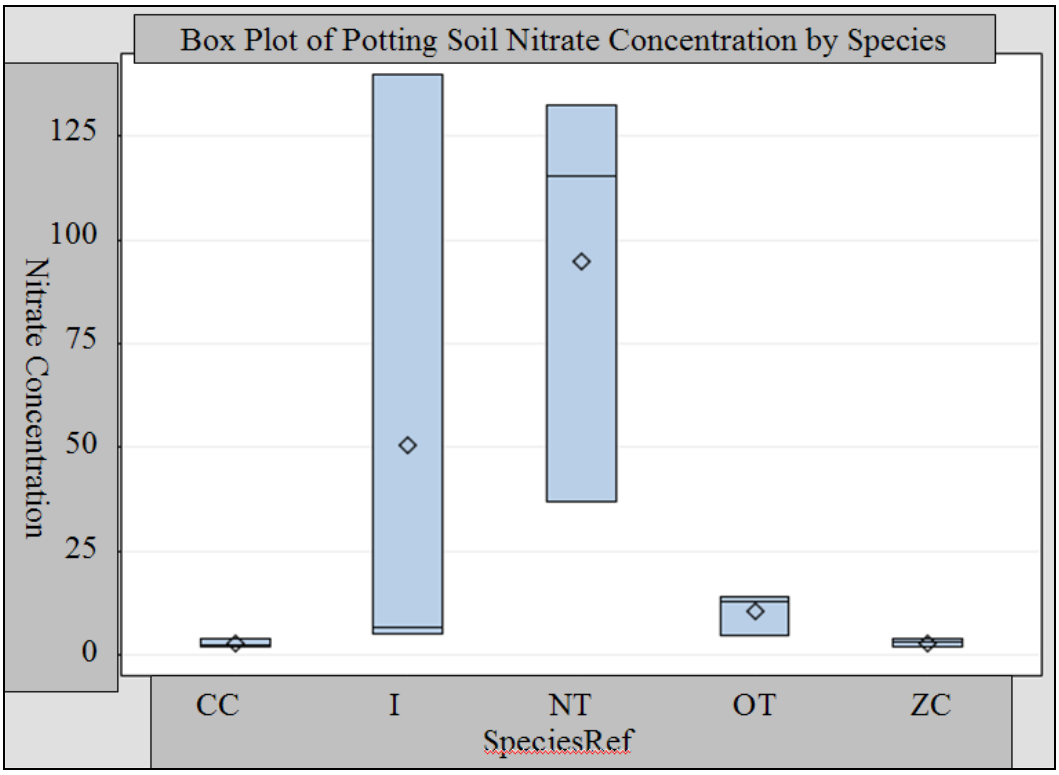
Potting Soil Analysis

Nitrate Potting Soil Analysis

Potting soil was determined to have 393 ppm nitrate nitrogen prior to being planted. All columns reduced nitrate nitrogen concentrations between 76 and 99 percent. Native vegetation was exposed to the potting soil for a longer period of time when compared with non native vegetation and the Control. Therefore, one would assume that the nitrate concentrations would be higher in the Old *Poa pratensis* and New *Poa pratensis* columns than the native vegetation. However, this was not the case. While New *Poa pratensis* had the highest nitrate nitrogen concentrations (87.8 [7.6, 902] ppm) the Control showed similar nitrate concentrations (2.8 [1.1,7.6] ppm) with *Carex comosa* (2.6 [0.24, 28.3] ppm) and Old *Poa pratensis* (9.6 [0.88, 105]

ppm) had less nitrate nitrogen than *Iris virginica* (17.0 [1.56, 1.86] ppm). Variability in nitrate concentrations was significantly higher for New *Poa pratensis* and *Iris virginica*, shown in Figure 5.17. Data analysis was completed on log transformed data to try and compensate for the non normal data. However, the significant variation in these two columns should be noted.

FIGURE 5.17 BOX PLOT OF NITRATE CONCENTRATION IN POTTING SOIL VS. SPECIES



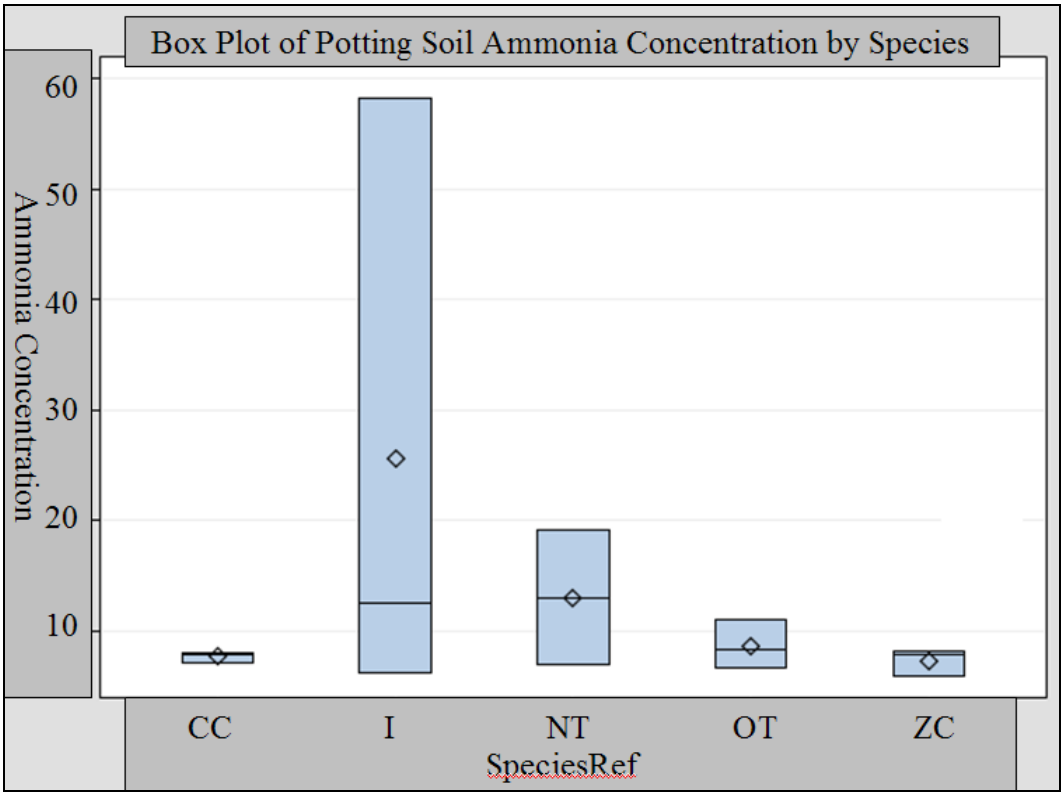
CC = Carex comosa, I = Iris virginica, NT = New Poa pratensis,
OT = Old *Poa pratensis*, ZC = Control

Column I5 had the highest nitrate nitrogen concentration of 140 ppm. Columns I2 and I3 were much lower at 6.7 and 5.3 ppm. Column NT3 (37.1 ppm) was also significantly lower than Columns NT2 and NT5 (115.5 and 132.5 ppm). This variability can be attributed to the differences in rhizosphere microbial populations, plant health and subsequent nutrient uptake in each individual column.

Ammonia Potting Soil Analysis

Potting soil was determined to have 62 ppm ammonia nitrogen prior to being planted. All columns reduced ammonia nitrogen concentrations between 59 and 88 percent. *Iris virginica* had the highest variability and Column I5 had the highest ammonia concentration (58 ppm). *Carex comosa* showed the lowest variability, see Figure 5.18.

FIGURE 5.18 BOX PLOT OF AMMONIA CONCENTRATION IN POTTING SOIL VS. SPECIES



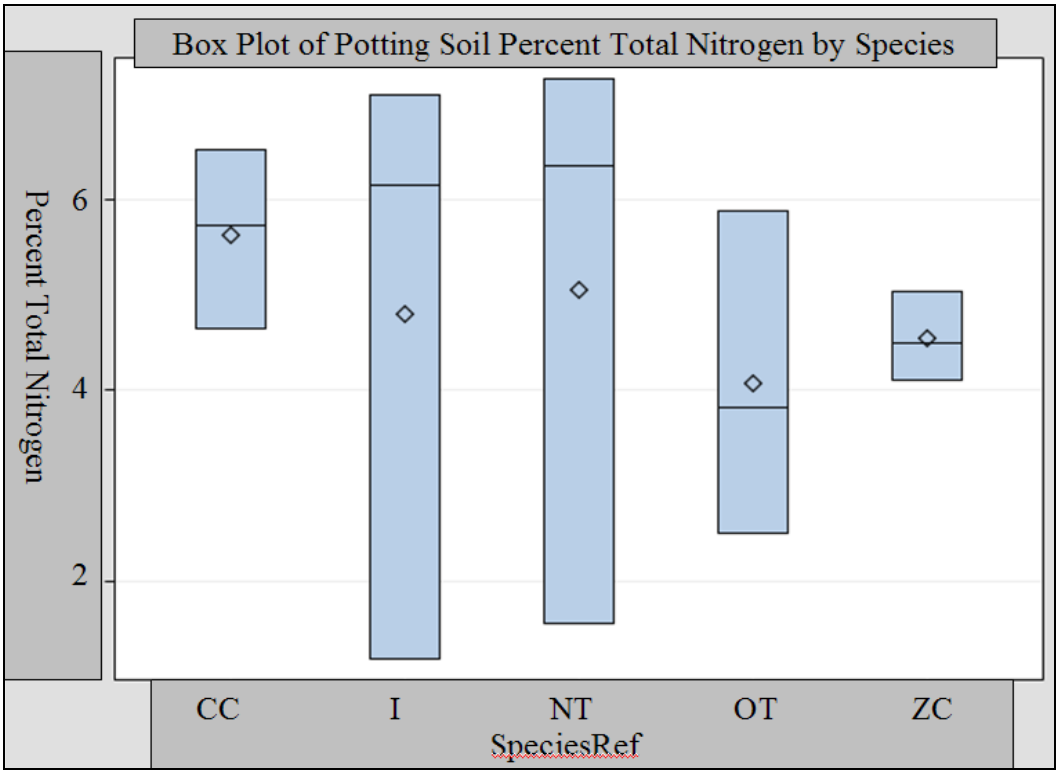
CC = Carex comosa, I = Iris virginica, NT = New Poa pratensis,
OT = Old *Poa pratensis*, ZC = Control

The fact that species was not a significant predictor in determining the concentration of ammonia in the potting soil could be attributed to ammonia volatilization as well as the relative demand on ammonia by vegetation and microbial populations.

Total Nitrogen Potting Soil Analysis

Potting soil was determined to have 56 percent total nitrogen prior to being planted. All columns reduced total nitrogen concentrations between 9.7 and 27 percent with the exception of *Carex comosa*, which showed no change in total nitrogen concentration. *Iris virginica* had the highest variability and Column I5 had the second highest total nitrogen concentration (71 percent). Column I2 had the lowest total nitrogen concentration of 12 percent. The Control showed the lowest variability, see Figure 5.19.

FIGURE 5.19 BOX PLOT OF TOTAL NITROGEN CONCENTRATION IN POTTING SOIL VS. SPECIES



CC = Carex comosa, I = Iris virginica, NT = New Poa pratensis,
OT = Old *Poa pratensis*, ZC = Control

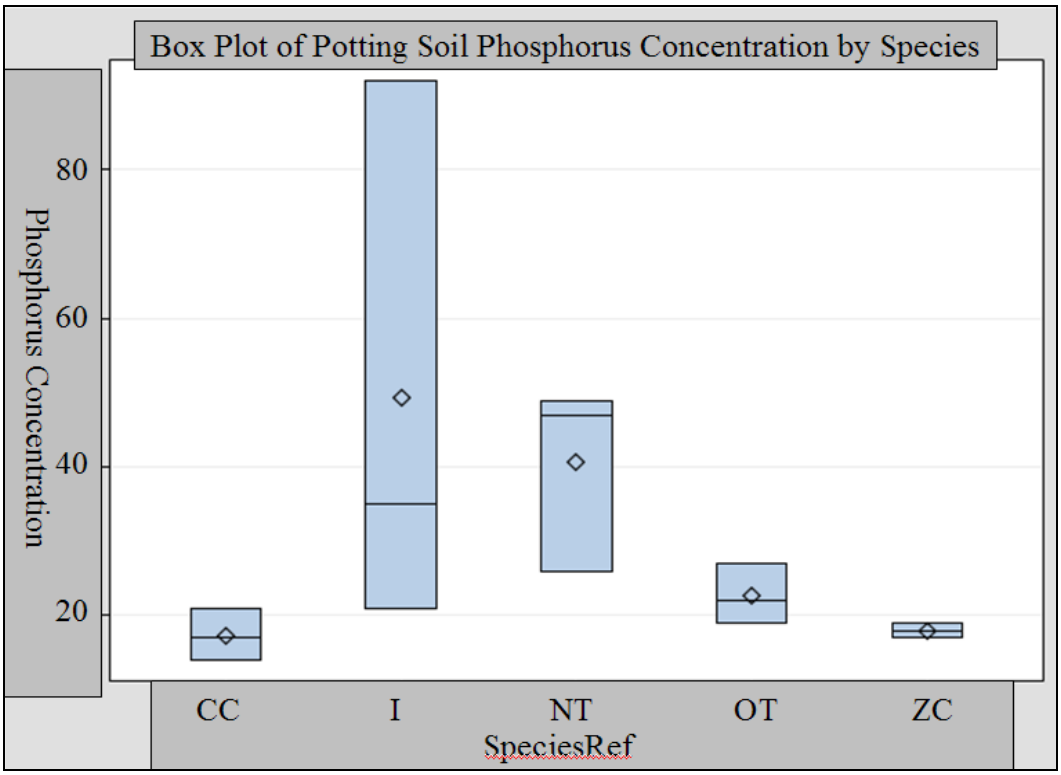
It is no surprise that total nitrogen concentration in potting soil was not significantly impacted by vegetation species. The major portion of total nitrogen in soil is typically bound in organic matter. Mineralization, and therefore availability, is completed through dynamic and complex processes that are difficult to predict. While not statistically significant, it is interesting to note that on average *Carex comosa* total nitrogen concentrations did not change from the original potting soil mixture while all other columns decreased in total nitrogen concentration.

Bray Phosphorus Potting Soil Analysis

Potting soil was determined to have 57 ppm phosphorus prior to being planted. All columns reduced phosphorus concentrations between 13 and 70 percent. *Iris virginica* had the

highest variability (see Figure 5.20) and Column I5 had the highest phosphorus concentration (92 ppm). Column CC3 had the lowest phosphorus concentration of 14 ppm.

FIGURE 5.20 BOX PLOT OF BRAY PHOSPHORUS CONCENTRATION IN POTTING SOIL VS. SPECIES



CC = Carex comosa, I = Iris virginica, NT = New Poa pratensis,
OT = Old *Poa pratensis*, ZC = Control

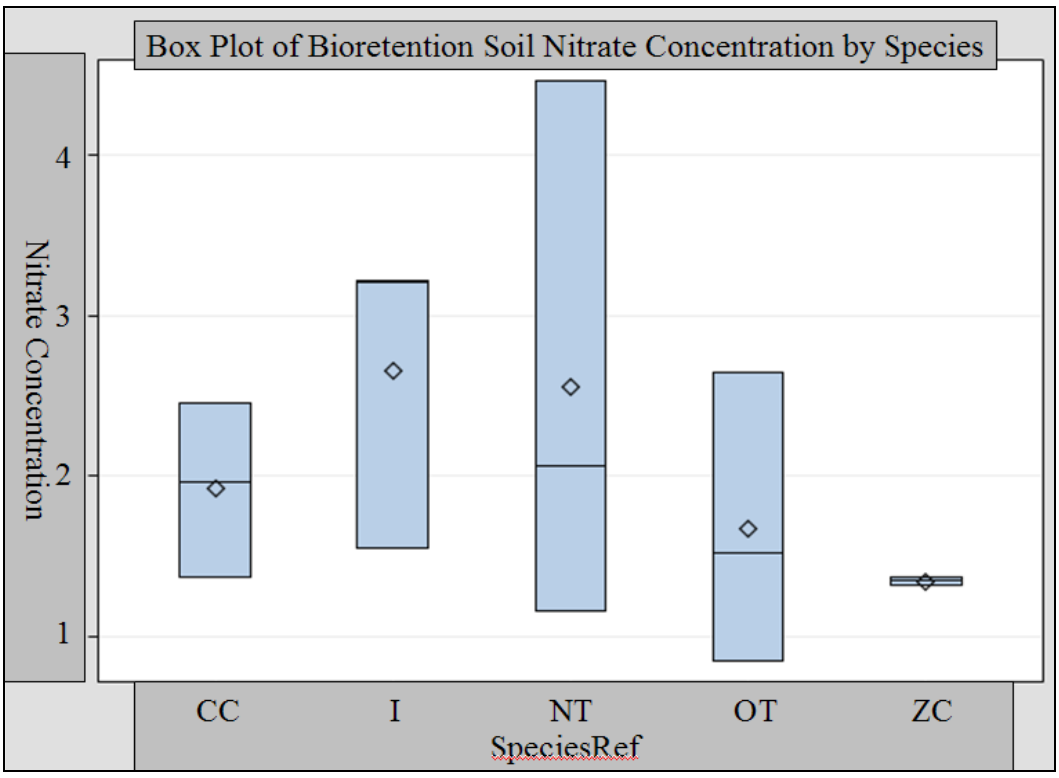
Bray phosphorus concentrations in the soil profile can be effected by soil mixture, soil moisture, microbial populations, root mass and associated area of the rhizosphere. This complex matrix appears to be controlling soil phosphorus concentrations as the Control has the lowest variability in soil phosphorus data.

Bioretention Soil Analysis

Nitrate Bioretention Soil Analysis

Bioretention soil was determined to have 24 ppm nitrate nitrogen prior to being planted. Nitrate nitrogen concentrations were reduced between 89 and 94 percent. All columns showed greater variability than the Control, shown in Figure 5.21. The lack of nitrate and minimal variability in the Control bioretention soil may indicate significant leaching losses of nitrate or that anaerobic conditions may have occurred.

FIGURE 5.21 BOX PLOT OF NITRATE CONCENTRATION IN BIORETENTION SOIL VS. SPECIES

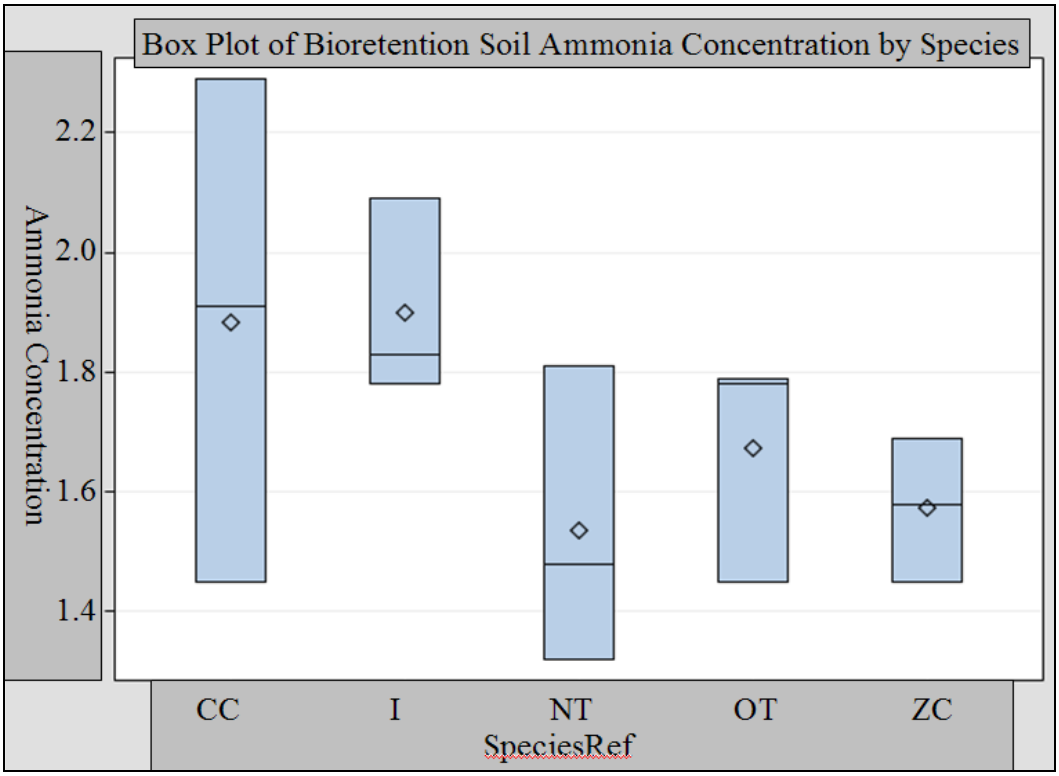


CC = Carex comosa, I = Iris virginica, NT = New Poa pratensis,
OT = Old *Poa pratensis*, ZC = Control

Ammonia Bioretention Soil Analysis

Bioretention soil was determined to have 6.64 ppm ammonia nitrogen prior to being planted. Ammonia nitrogen concentrations were 72 to 74 percent of the preplanted bioretention soil. All columns had roughly the same ammonia concentrations and variability (see Figure 5.22), unlike nitrate nitrogen in the bioretention soil where the Control had minimal variability.

FIGURE 5.22 BOX PLOT OF AMMONIA CONCENTRATION IN BIORETENTION SOIL VS. SPECIES

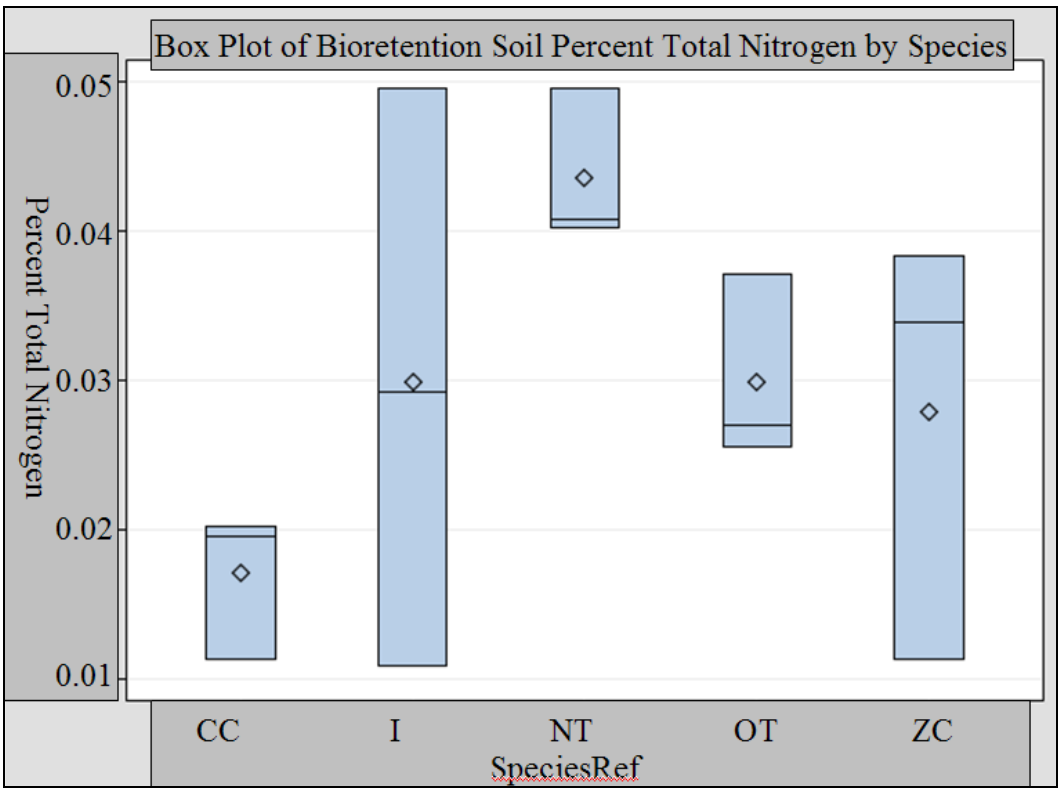


CC = Carex comosa, I = Iris virginica, NT = New Poa pratensis,
OT = Old *Poa pratensis*, ZC = Control

Total Nitrogen Bioretention Soil Analysis

Bioretention soil was determined to have 3 percent total nitrogen prior to being planted. All columns increased total nitrogen percent with the exception of *Carex comosa*, which showed no change in mean total nitrogen. *Iris virginica* had the highest variability, while the Control also exhibited high variability, shown in Figure 5.23.

FIGURE 5.23 BOX PLOT OF TOTAL NITROGEN CONCENTRATION IN BIORETENTION SOIL VS. SPECIES



CC = Carex comosa, I = Iris virginica, NT = New Poa pratensis,
OT = Old *Poa pratensis*, ZC = Control

Total nitrogen concentration in bioretention soil was not significantly impacted by vegetation species. *Carex comosa* total nitrogen concentrations did not change from the original bioretention soil mixture or potting soil mixture while all other columns increased in total nitrogen concentration in the bioretention soil and decreased in the potting soil. Decrease in total nitrogen concentration in the potting soil mix can be attributed to preferential use of total nitrogen in the fist 15.24 centimeters (six inches) or migration of total nitrogen through the soil profile. Most vegetation use water (and associated nutrients) preferentially in a triangular pattern with the majority of uptake occurring close to the soil surface. This phenomenon is supported by the rooting structure of the plant as well with more root mass (including finer roots) located at or

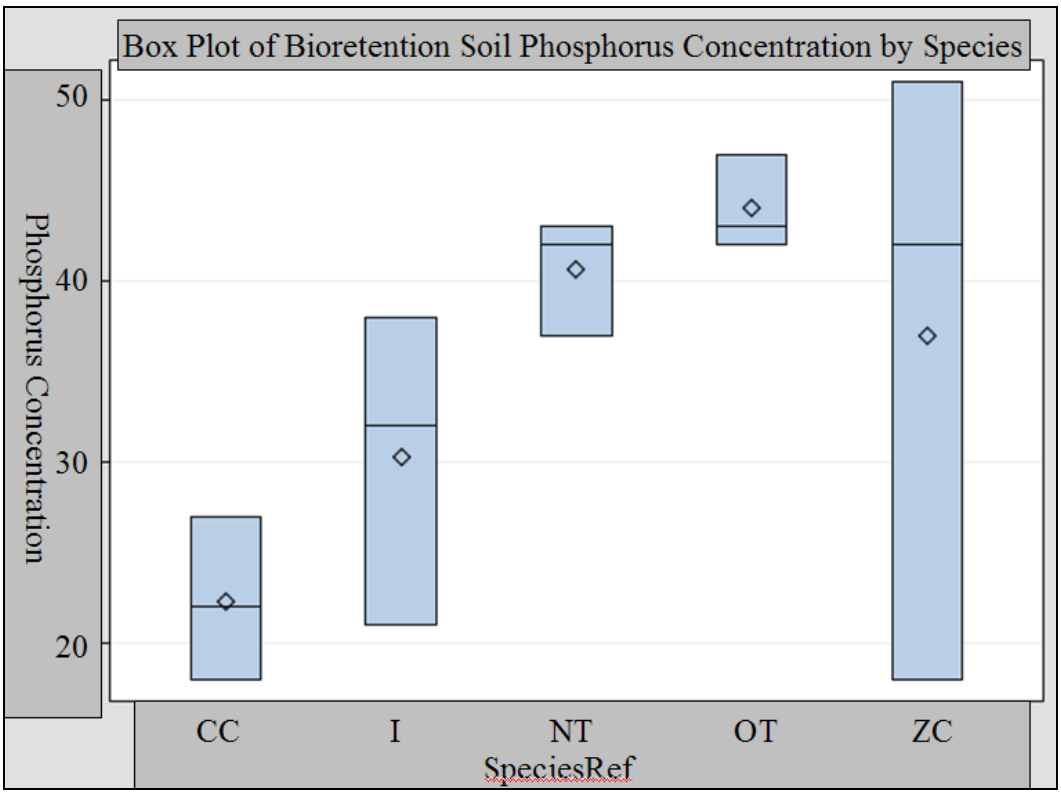
near the surface. Inorganic forms on nitrogen were typically found in greater concentration in the potting soil than the bioretention soil, supporting the preferential depletion of organic nitrogen in the top of the soil columns.

It is unclear why the total nitrogen concentrations did not change in the *Carex comosa* columns. *Carex comosa* significantly reduced both mass and concentration of nitrogen species in the leachate. If nitrogen species were adsorbed in the soil profile one would expect the concentration of total nitrogen to increase. As this was not the case, nitrogen is not being preferentially held in the soil profile in *Carex comosa* columns. *Carex comosa* had the highest concentration of nitrogen in the plant matter, supporting that nitrogen is being utilized for plant growth. However, plant growth would also deplete the total nitrogen concentrations in the potting soil due to preferential uptake of nutrients. There is a possibility a symbiotic relationship with a microbial population may be responsible for no significant changes in soil total nitrogen. This possibility should be evaluated further through DNA testing of the soil microbial population.

Bray Phosphorus Bioretention Soil Analysis

Bioretention soil was determined to have 114 ppm phosphorus prior to being planted. All columns showed a reduction in phosphorus concentrations between 60 and 80 percent. The Control had the highest variability followed by *Carex comosa* and *Iris virginica* (see Figure 5.24).

FIGURE 5.24 BOX PLOT OF BRAY PHOSPHORUS CONCENTRATION IN BIORETENTION SOIL VS. SPECIES



CC = Carex comosa, I = Iris virginica, NT = New Poa pratensis,
OT = Old *Poa pratensis*, ZC = Control

On average, bray phosphorus concentrations in *Carex comosa* and *Iris virginica* were 38 percent lower than New and Old *Poa pratensis* in the bioretention soil. This reduction is most likely due to uptake by *Carex comosa* and *Iris virginica* of phosphorus in the bioretention soil. Both *Carex comosa* and *Iris virginica* had significant rooting structure in the bioretention soil.

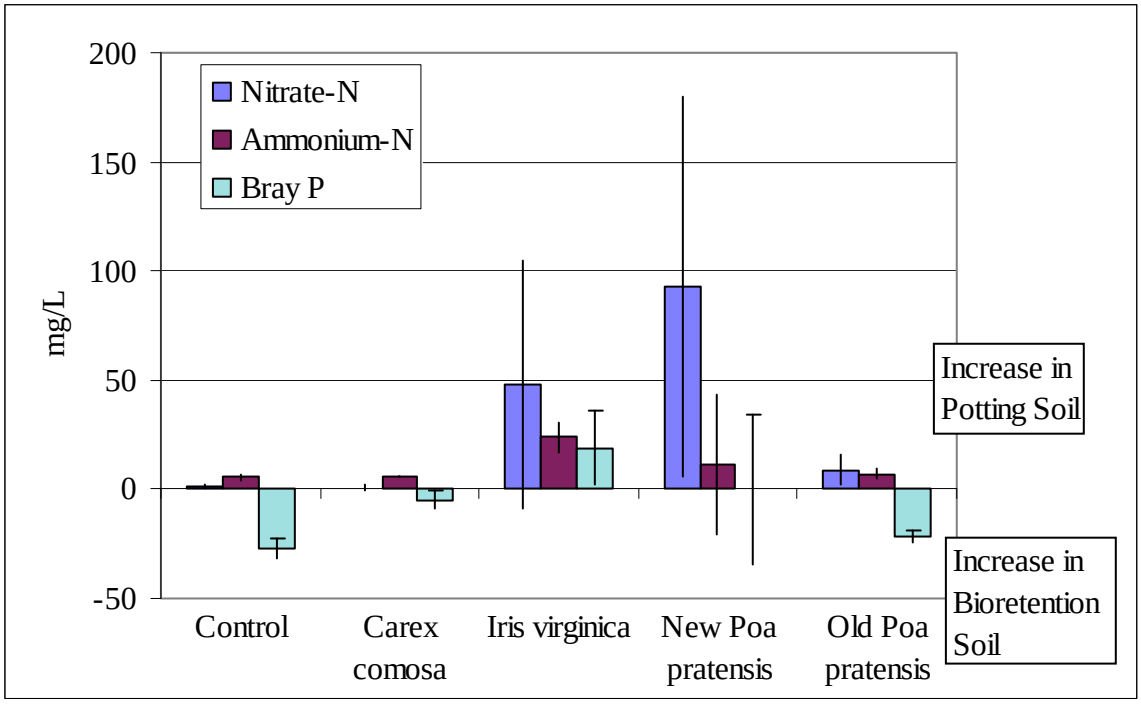
The increase in soil phosphorus variability in Control columns may indicate anaerobic conditions have occurred or were occurring throughout the experiment. Column I5 reported 92 mg/L phosphorus while the average was 49 mg/L. Available or labile phosphorus concentrations in the soil are significantly influenced by redox potential and pH [67]. In the event that a column was operating under anaerobic conditions, labile phosphorus would be released into the soil

water. Under aerobic conditions, available phosphorus would become adsorbed back onto the soil matrix, reducing phosphorus availability.

Soil Analysis Conclusion

Nutrient concentrations in the bioretention soil were subtracted from the nutrient concentrations in the potting soil and compared in Figure 5.25. Positive concentrations indicated an increase in nutrient content in the potting soil while negative concentrations indicate an increase in nutrient content in the bioretention soil.

FIGURE 5.25 NUTRIENT CONCENTRATIONS IN BIORETENTION SOIL SUBTRACTED FROM POTTING SOIL

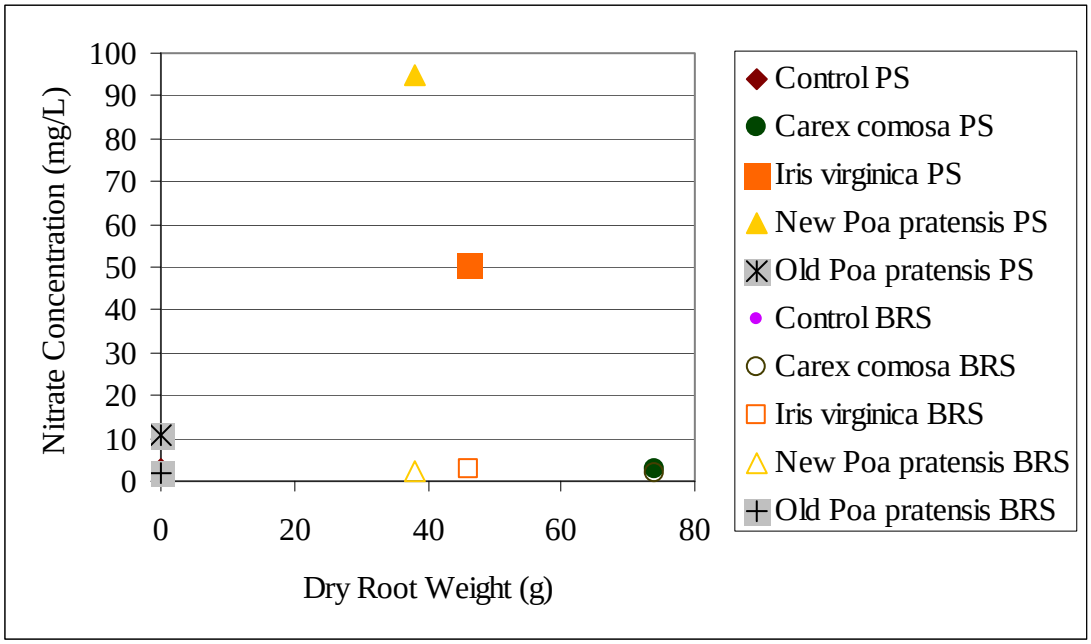


Nitrogen concentrations, both nitrate and ammonia was found in greater concentration in the potting soil. *Carex comosa* showed the most uniform nitrate concentrations in both soil profiles. Phosphorus concentrations were found in greater concentrations in the bioretention soil mixture, with the exception of *Iris virginica* columns. Again, *Carex comosa* showed the most

uniform phosphorus concentrations in both soil profiles. This can be attributed to the increase root mass that was present in both soil profiles for *Carex comosa*. However, *Iris virginica* exhibited the same root profile in both soil profiles and nutrient concentrations were found to be greater in the potting soil. The root mass of *Iris virginica* is smaller than *Carex comosa* (17.2 [6.7, 27.7] grams and 39.2 [32.5, 45.9]). In addition the nutrient requirements of *Iris virginica* could be less than *Carex comosa*, allowing for fewer nutrients utilized in the potting soil mix when compared to *Carex comosa*.

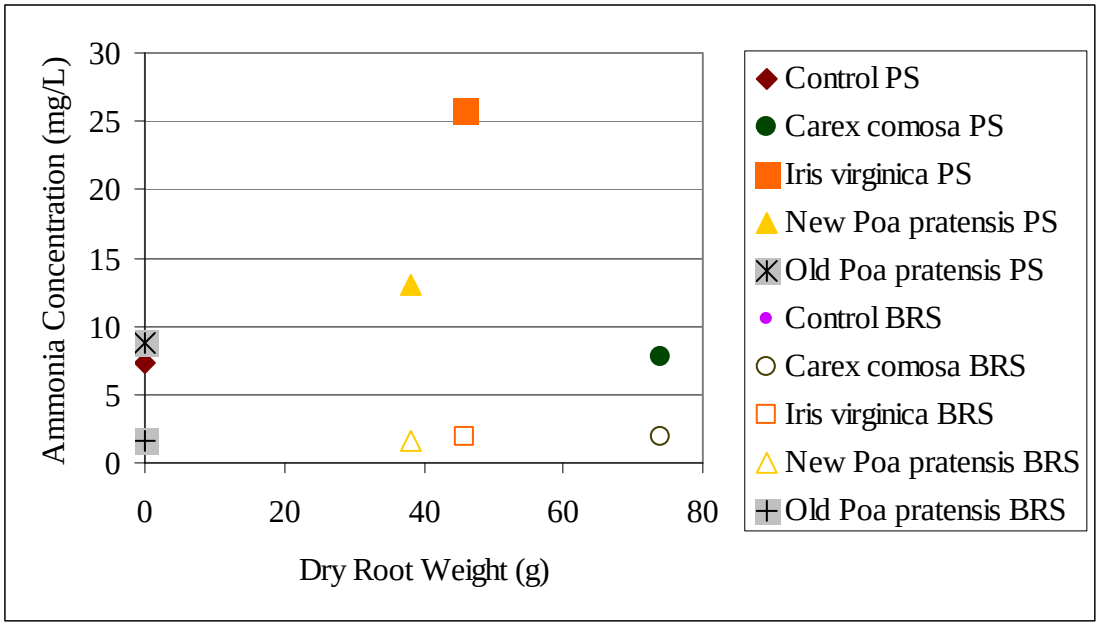
Soil nutrient values were plotted against root dry weight in Figures 5.26 through 5.29.

FIGURE 5.26 SOIL NITRATE CONCENTRATION VS. ROOT DRY WEIGHT



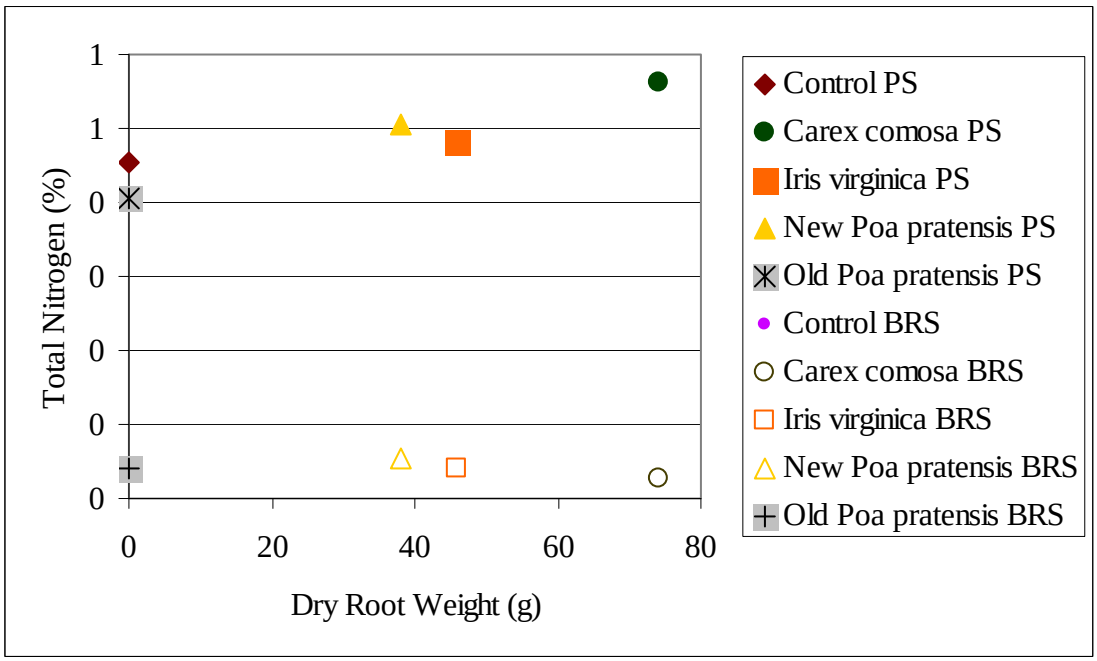
PS = Potting Soil, BRS = Bioretention Soil

FIGURE 5.27 SOIL AMMONIA CONCENTRATION VS. ROOT DRY WEIGHT



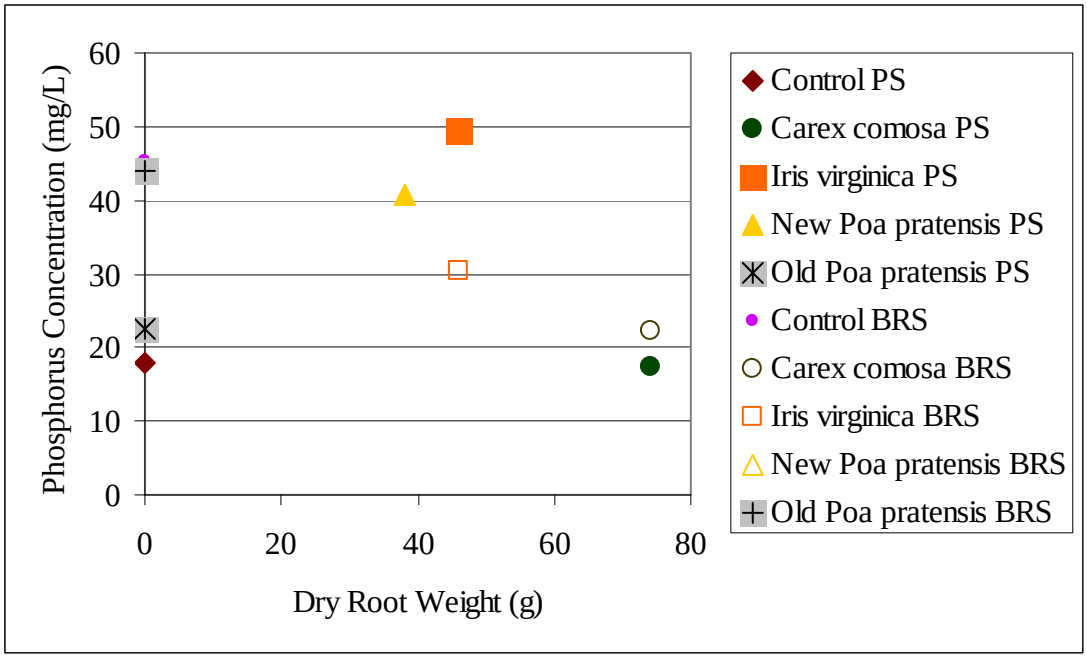
PS = Potting Soil, BRS = Bioretention Soil

FIGURE 5.28 SOIL TOTAL NITROGEN VS. ROOT DRY WEIGHT



PS = Potting Soil, BRS = Bioretention Soil

FIGURE 5.29 SOIL PHOSPHORUS CONCENTRATION VS ROOT DRY WEIGHT



PS = Potting Soil, BRS = Bioretention Soil

There is a general trend with decreased concentration of nutrient with an increase in dry root weight in both potting soil and bioretention soil for nitrate, ammonia and phosphorus. This trend was not observed in the total nitrogen data. However, the total nitrogen data shows uniform concentrations in bioretention soil mixtures vs. the potting soil.

Soil Analysis Summary

Vegetation species significantly predicted nitrate and bray phosphorus concentrations in the potting soil and bray phosphorus concentrations in the bioretention soil. Phosphorus availability has been shown to be directly linked to root development [43] and will impact removal efficiencies. *Poa pratensis* columns did not have root mass in the bioretention soil mix which could influence results based on vegetation species in this area of the columns. Studies

evaluating soil nutrient concentrations in bioretention basins typically focus on the entire soil profile, disregarding differences in the potting soil [3].

Total Nitrogen Balance Analysis

Nitrogen loss from the columns could have occurred through denitrification of nitrate nitrogen and volatilization of ammonia nitrogen. The Control columns and *Poa pratensis* columns exhibited strong mottling of oximorphic reduction regions in the bioretention soil mixture giving strong evidence of anaerobic conditions at one time or another in the soil profile during the experiment, shown in Figures 5.30 and 5.31. Figure 5.30 shows orange coloration typically formed when iron is reduced under anaerobic conditions. Soils with large amounts of reduced iron are considered “gleyed” showing gray colors or “washed out” as shown in Figure 5.31.

FIGURE 5.30 REDOXMOPHIC FEATURES IN BIORETENTION SOIL

FIGURE 5.31 GLEYING OF BIORETENTION SOIL

Anaerobic conditions are necessary to facilitate denitrification by the soil microbial population. Denitrification could be a significant contributor to the “unaccounted for” nitrogen. Denitrification losses can be up to 4 to 5 percent in saturated soils over 65 degrees Fahrenheit [68]. While columns were typically not saturated for long periods of time, it took a minimum of four hours to drain columns after stormwater application. Irrigation water from the potable drinking water system is known to have high concentrations of iron (based on the coloration of the water). Irrigation water was never tested to confirm contaminant concentrations. Based on the activity in the bioretention profile there is a possibility that available oxygen sources were utilized during that time and anaerobic conditions were experienced. Soil evidence of anaerobic conditions was not found in *Carex comosa* or *Iris virginica* columns. However, denitrification could be occurring in smaller environments within the soil profile.

The addition of nitrogen from Old *Poa pratensis* can be attributed to the degradation of the vegetation and root matter that occurred during the experiment. It was assumed that the plant vegetation matter in Old *Poa pratensis* columns contained 362 mg nitrogen (highest nitrogen

concentration observed in the New *Poa pratensis* columns), to determine that the unaccounted nitrogen drops to -22 mg, indicating that the degradation of the plant material is likely responsible for the increase in nitrogen.

Future Work

Hydraulic permeability results were inconclusive due to the limited number of replicates tested. Native vegetation and non cultivated areas have been shown to increase the hydraulic permeability of soils over native vegetation [69, 70]. Additional work should be conducted to determine if plant species is a significant indicator of hydraulic permeability in bioretention basins.

This study was conducted using stormwater volumes to the median stormwater events in mid Michigan. Results show a significant increase in treatment efficiency for *Carex comosa* and *Iris virginica* over *Poa pratensis* vegetation. Increased treatment efficiency due to vegetation selection will most likely decrease with increased volumes of stormwater dosed until a minimum treatment efficiency is achieved. At this point treatment efficiency will most likely be limited by soil filtering and adsorption processes. Additional work should be conducted to determine the relationship between the volume of stormwater treatment and vegetation selection in treatment efficiency.

Soil media in bioretention basins are effective at filtering and adsorbing metal concentrations in stormwater [2, 71]. In this experiment, transition metal concentrations in the leachate were below detection limits. A breakthrough analysis of heavy metals was conducted by Hatt in 2011. It was determined that after 10 to 15 years of use heavy metal leachate in bioretention basins will still be below detection limits. However, the concentrations in the soil may be considered harmful and require special disposal. Future work with heavy metal

concentrations should be eliminated from column studies. It is unclear at this time how the soil matrix could be overloaded to increase concentrations of transition metals in the leachate without negatively impacting plant health and viability. In addition, transition metals will foul the anion and cation columns using IC for analysis.

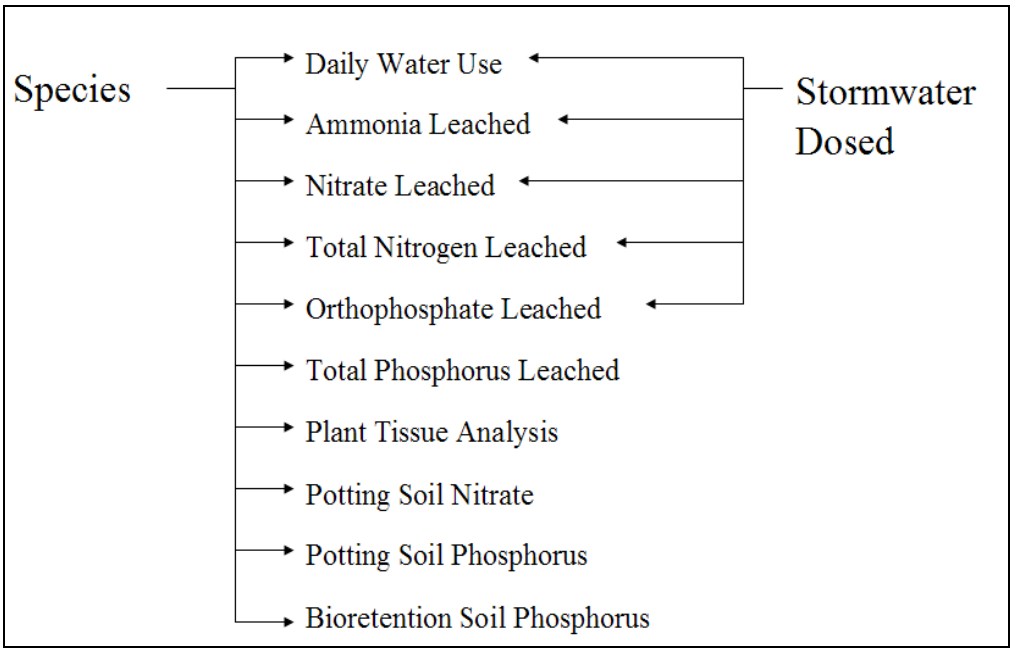
Vegetation analysis supported greater biomass volume will uptake more nutrients for growth. In the future, analysis of plant tissue may be unnecessary and could be neglected.

Nitrogen data from the leachate, potting soil and bioretention soil mixtures support that *Carex comosa* and *Iris virginica* vegetation is more effective at reducing nitrogen concentrations than *Poa pratensis* vegetation. In addition, *Carex comosa* is more efficient at utilizing nitrogen than *Iris virginica*. It is unclear if the increase in treatment efficiency is due specifically to the vegetation selection or if there is microbial interaction that was not evaluated. Vegetation selection directly affects the rhizosphere and microbial populations in the soil profile [38, 72]. The interaction between vegetation selection and microbial population is intriguing and should be evaluated in future research when evaluating vegetation selection in bioretention basins.

CHAPTER 6: CONCLUSION

Bioretention basins have been shown to manage stormwater runoff sustainably by using natural processes for treatment. This study determined that vegetation species tested were a significant predictor in determining stormwater nutrient concentrations in bioretention basins, supporting work completed by Read in 2010 [20], shown in Figure 6.1 . Vegetation species was also a significant predictor in determining plant tissue content and potting soil nutrient concentrations.

FIGURE 6.1 SIGNIFICANT PREDICTORS



Carex comosa and *Iris virginica* showed greater treatment efficiency than *Poa pratensis* vegetation. *Carex comosa* reduced mass of nitrate nitrogen by 96.7 percent and total phosphorus by 86.3 percent over the Control. In most cases, *Poa pratensis* vegetation increased nitrogen mass over the Control. *Poa pratensis* columns had higher concentrations of iron, aluminum, copper, manganese and zinc in their plant tissue. However, *Carex comosa* and *Iris virginica* had

similar mass of these constituents due to the increase in plant matter of *Carex comosa* and *Iris virginica* over *Poa pratensis*. Nutrient mass leached in the columns could also be contributed to the amount of stormwater dosed during the experiment. Higher stormwater volumes increased the mass of nutrient leached in all columns.

Species was not a significant predictor of nutrient concentrations found in the bioretention soil mixture with the exception of phosphorus concentrations. These results could be influenced by rooting depth of the *Carex comosa* and *Iris virginica* vegetation and anaerobic conditions present in the *Poa pratensis* and Control columns. Total nitrogen concentrations decreased in the potting soil mix while increasing in the bioretention soil mix for all species except *Carex comosa*.

Although many aspects of bioretention basin design need further study to maximize treatment efficiency, evaluation of plant species is a key step towards filling those gaps. Treatment of stormwater in bioretention basins is directly influenced by vegetation selection and the volume of stormwater treated. Including *Carex comosa* and *Iris virginica* vegetation in bioretention basin design will increase treatment efficiency and sustainably manage stormwater runoff.

APPENDICES

Appendix A – Raw Data

QA QC Data

TABLE A.1 QAQC DATA

Date	Ana	Blank	Duplicate A	Duplicate B	Standard A	Standard Duplicate	Matrix Spike	Matrix Spike Duplicate
4/8/2011	TN	n.a.	97.7%					
4/15/2011	TN	n.a.	185.9%	185.9%	-61.7%	-70.77%	-1061.78%	-754.48%
4/21/2011	TN	0.74	13.8%	14.2%	185.8%	72.05%	-32.70%	292.40%
4/29/2011	TN	n.a.	6.4%	198.0%			-1173.70%	-1181.71%
5/6/2011	TN	n.a.	7.8%	3.1%	29.4%	-83.04%	-1656.17%	-1605.54%
5/12/2011	TN	0.32	1.3%	18.3%	3.9%		-943.93%	-795.44%
5/15/2011	TN	n.a.	18.5%	18.3%	-94.1%	-80.76%	-478.65%	-163.57%
6/7/2011	TN	n.a.	11.2%	8.4%	129.8%	155.19%	-364.70%	-344.64%
6/13/2011	TN	n.a.	11.2%	8.4%	129.8%	155.19%	-321.90%	-506.86%
average		0.53	39.31%	56.81%	46.12%	24.64%	-754.19%	-632.48%
st dev		0.21	58.77%	78.22%	97.76%	106.57%	506.85%	554.96%
conf		0.29	38.39%	51.10%	63.87%	69.62%	331.14%	362.57%

TABLE A.1 (CONT'D)

Date	Ana	Blank	Duplicate A	Duplicate B	Standard A	Standard Duplicate	Matrix Spike	Matrix Spike Duplicate
4/8/2011	TP	n.a.	21.4%					
4/15/2011	TP	n.a.	86.1%	0.0%	-163.9%	-108.89%	-208.62%	-109.48%
4/21/2011	TP	0.56	86.0%	0.0%	-66.7%	5.61%	0.00%	478.62%
4/29/2011	TP	n.a.	2.5%	147.5%			37.96%	38.38%
5/6/2011	TP	n.a.	0.0%	0.0%	-84.7%	-84.68%	0.00%	-14.03%
5/12/2011	TP	n.a.	4.0%	25.5%	3.3%		54.45%	53.13%
5/15/2011	TP	n.a.	22.4%	25.5%	89.8%	36.80%	-9.37%	46.14%
6/7/2011	TP	n.a.	139.8%	198.3%	-73.8%	-87.38%	101.42%	98.72%
6/13/2011	TP	n.a.	109.8%	17.2%	-192.4%	-187.00%	3.98%	4.62%
average		0.56	52.44%	51.76%	-69.76%	-70.92%	-2.52%	74.51%
st dev		0.00	50.16%	71.82%	88.60%	73.98%	85.34%	163.19%
conf		#NUM!	32.77%	46.92%	57.88%	48.33%	55.76%	106.61%

TABLE A.1 (CONT'D)

Date	Ana	Blank	Duplicate A	Duplicate B	Standard A	Standard Duplicate	Matrix Spike	Matrix Spike Duplicate
4/1/2011	NO3	n.a.	12.2%					
4/8/2011	NO3	0.46	1.2%		26.5%			
4/15/2011	NO3	n.a.	4.7%	0.3%	4.1%	4.92%	95.86%	101.65%
4/21/2011	NO3	0.67	52.1%	38.4%	-6.2%	-1.35%	123.27%	133.90%
4/29/2011	NO3	n.a.	27.4%	4.6%	100.0%	-14.75%	-1106.28%	-980.19%
5/6/2011	NO3	n.a.	4.6%	0.1%	8.2%	15.89%	-2161.22%	-2161.64%
5/12/2011	NO3	n.a.	4.5%	3.2%	-2.1%	4.38%	-750.70%	-616.81%
5/15/2011	NO3	n.a.	13.0%	2.6%	-13.5%	n.a.	-76.27%	-39.59%
6/7/2011	NO3	n.a.	28.3%	31.3%	-82.1%	-81.24%	-80.63%	31.34%
6/13/2011	NO3	0.88	12.1%	21.9%	-194.3%	-193.06%	-7.25%	-8.51%
average		0.67	16.01%	12.79%	-17.71%	-37.89%	-495.40%	-442.48%
st dev		0.17	14.95%	14.41%	76.51%	70.04%	752.63%	748.20%
conf		0.33	9.27%	8.93%	47.42%	43.41%	466.48%	463.73%

TABLE A.1 (CONT'D)

Date	Ana	Blank	Duplicate A	Duplicate B	Standard A	Standard Duplicate	Matrix Spike	Matrix Spike Duplicate
4/1/2011	PO4	n.a.	0.2%					
4/8/2011	PO4	n.a.	19.4%		24.5%			
4/15/2011	PO4	n.a.	2.2%	6.7%	4.6%	3.32%	92.91%	88.98%
4/21/2011	PO4	n.a.	29.9%	34.6%	18.6%	21.94%	91.11%	932.09%
4/29/2011	PO4	n.a.	64.7%	0.9%	31.0%	20.42%	22.77%	44.63%
5/6/2011	PO4	n.a.	17.1%	2.0%	21.4%	17.66%	97.75%	69.08%
5/12/2011	PO4	0.08	10.5%	0.8%	118.0%	120.48%	71.99%	88.71%
5/15/2011	PO4	3.74	22.6%	13.6%	145.6%	118.46%	64.11%	83.85%
6/7/2011	PO4	n.a.	61.3%	55.4%	75.4%	-5.24%	79.38%	75.23%
6/13/2011	PO4	n.a.	0.0%	0.0%	-35.6%	-27.83%	3.94%	4.61%
average		1.91	22.78%	14.26%	44.84%	33.65%	65.49%	173.40%
st dev		1.83	22.21%	18.97%	54.13%	51.86%	32.21%	288.00%
conf		3.58	13.77%	11.75%	33.55%	32.14%	19.96%	178.50%

TABLE A.1 (CONT'D)

Date	Ana	Blank	Duplicate A	Duplicate B	Standard A	Standard Duplicate	Matrix Spike	Matrix Spike Duplicate
4/21/2011	NH4	n.a.	5.0%	5.0%	71.8%	86.06%	78.93%	83.55%
5/6/2011	NH4	n.a.	0.0%	0.0%	5.3%	9.44%	74.68%	78.78%
5/12/2011	NH4	n.a.	0.0%	0.0%	-10.5%	-7.29%	77.26%	75.12%
5/16/2011	NH4	n.a.	0.00%	0.00%	<DL	<DL	106.06%	18.00%
6/7/2011	NH4	n.a.	0.00%	0.00%	-9.88%	-9.83%	54.60%	54.23%
6/13/2011	NH4	n.a.	0.00%	0.00%	-16.72%	-10.98%	58.51%	57.99%
average		#DIV/0!	0.83%	0.83%	8.00%	13.48%	75.01%	61.28%
st dev		#DIV/0!	1.86%	1.86%	32.69%	37.03%	16.70%	22.09%
conf		#DIV/0!	1.49%	1.49%	26.16%	29.63%	13.36%	17.67%

Standard Curves

TABLE A.2 STANDARD CURVES

Sample	Sample Name	Amount	Amount
No.		ppm	ppm
		Nitrate	Phosphate
		CD_1	CD_1
1	1H	n.a.	n.a.
2	1H	3.8204	5.0006
3	1H	5.3918	8.1366
4	2H	9.8411	14.6913
5	2H	9.7405	14.6954
6	2H	10.3544	15.5113
7	3H	14.9145	22.2694
8	3H	14.5797	22.0301
9	3H	15.4702	23.1383
10	4H	19.5568	29.2066
11	4H	20.6746	30.8796
12	4H	19.8051	29.9545
13	5H	39.8015	59.3104
14	5H	40.6659	60.8107
45	5H	39.5327	59.8789
15	1	0.0073	n.a.
16	1	0.0130	n.a.
17	1	0.0069	n.a.
18	2	0.0419	0.0585
19	2	0.0397	0.0563
20	2	0.0375	0.0640
21	3	0.0826	0.1244
22	3	0.0785	0.1198
23	3	0.0793	0.1154
24	4	0.1635	0.2453
25	4	0.1685	0.2544
26	4	0.1496	0.2216
27	5	0.2847	0.4043
28	5	0.2795	0.4241
29	5	0.2725	0.4275
30	6	0.3810	0.6056
31	6	0.3726	0.5931
32	6	0.4659	0.6028
33	7	0.8299	1.2012
34	7	0.8143	1.2357
35	7	0.7486	1.1572
36	8	1.2560	1.8230
37	8	1.2314	1.8302
38	8	1.1218	1.7451
39	9	1.6937	2.4523
40	9	1.6133	2.4745
41	9	1.4807	2.2826
42	10	2.3076	3.3908
43	10	1.9601	2.9778
44	10	1.9223	2.9061
45	5H	39.5327	59.8789
Old Digestion Curve			
1	BLANK	n.a.	n.a.

TABLE A.2 (CONT'D)

2	1	1.0605	n.a.
3	1	0.7312	n.a.
4	1	0.7966	n.a.
5	2	0.0564	n.a.
6	2	0.0783	n.a.
7	2	0.1566	n.a.
8	3		n.a.
9	3	0.0795	n.a.
10	3	0.0492	n.a.
11	4		n.a.
12	4	0.0577	n.a.
13	4	0.0637	0.5021
14	5	0.0179	0.1462
15	5	0.0563	0.5042
16	5	0.0731	0.5548
17	6		0.5070
18	6	0.1083	0.5791
19	6	0.0524	0.3225
20	7		1.0925
21	7	0.6736	1.2908
22	7	0.6149	1.2383
23	8		1.5949
24	8	0.6375	1.7740
25	8	0.7551	1.9913
26	9		2.2061
27	9	1.3388	2.4775
28	9	1.4183	2.4193
29	10	3.8640	2.8623
30	10	1.6853	3.3067
31	10	1.3890	3.0449
32	1H	0.7634	6.3121
33	1H	5.7897	7.6592
34	1H	5.8958	8.2203
35	2H	11.3387	13.9009
36	2H	9.5510	15.6957
37	2H	9.3390	15.2559
38	3H	14.0864	22.9592
39	3H	16.2610	20.7312
40	3H	14.1274	22.8551
41	4H	21.3823	31.4328
42	4H	20.9947	28.1568
43	4H	18.2926	35.3891
44	5H	41.3304	50.0178
45	5H	40.0955	67.9641
46	5H	38.5740	62.0181
Digestion Curve			
1	1	0.0610	0.0353
2	1	0.0410	0.0402
3	1	0.5765	0.3622
4	2	0.0390	0.0479
5	2	0.0826	0.1309
6	2	0.0390	0.0297
7	3	0.3952	0.1154
8	3		0.1026

TABLE A.2 (CONT'D)

9	3	0.3080	0.2242
10	4	0.3066	0.0895
11	4	0.1582	0.2104
12	4	0.1307	0.1985
13	5	0.3504	0.4645
14	5	0.3310	0.3921
15	5	0.2186	0.2404
16	6	0.2323	0.5699
17	6		0.6377
18	6	0.2740	0.5613
19	7		1.1494
20	7	0.4050	1.1925
21	7	0.5229	1.2376
22	8	1.0402	1.7705
23	8	1.2914	1.8668
24	8	1.2009	1.7633
25	9	1.4332	2.3795
26	9	1.7756	2.4192
27	9	1.6110	2.4036
28	10	1.8194	2.9602
29	10	2.1851	3.2392
30	10	1.9971	2.9426
31	1H	4.7481	7.3353
32	1H	5.2322	7.6292
33	1H	4.9827	7.3970
34	2H	9.3705	14.7759
35	2H	10.9521	15.2368
36	2H	9.9708	14.9423
37	3H	14.3184	22.3759
38	3H	15.8731	22.6314
39	3H	13.8241	22.4833
40	4H	19.4389	29.7440
41	4H	20.8194	30.2061
42	4H	19.8362	30.0170
43	5H	38.2715	59.4573
44	5H	41.3324	60.7054
45	5H	40.3961	59.8373
Sample No.	Sample Name	Amount	Type
		Ammonia	Ammonia
		CD_1	CD_1
1	1	0.5126	BMB*
2	1	0.5615	BMB*
3	1	0.4924	BMB*
4	2	0.0877	BMB
5	2	0.1078	BMB
6	2	0.1041	BMB
7	3	0.4137	BMB
8	3	0.3643	BMB*
9	3	0.4229	BMB
10	4	1.1904	BMB
11	4	0.9588	BMB
12	4	0.9079	BMB
13	5	3.9510	BMB
14	5	3.7222	BMB*

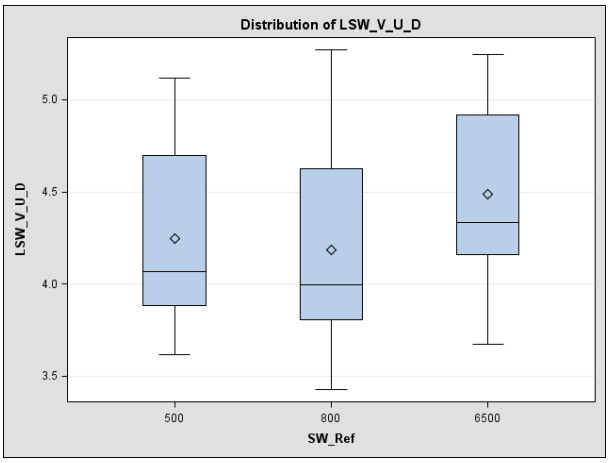
TABLE A.2 (CONT'D)

15	5	4.4104	BMB
16	6	9.9257	BMB
17	6	10.0081	BMB
18	6	10.0946	BMB
19	7	19.7587	BMB
20	7	20.4179	BMB
21	7	19.8828	BMB
22	8	29.9168	BMB
23	8	30.0430	BMB
24	8	30.0402	BMB

Appendix B – Box Plots

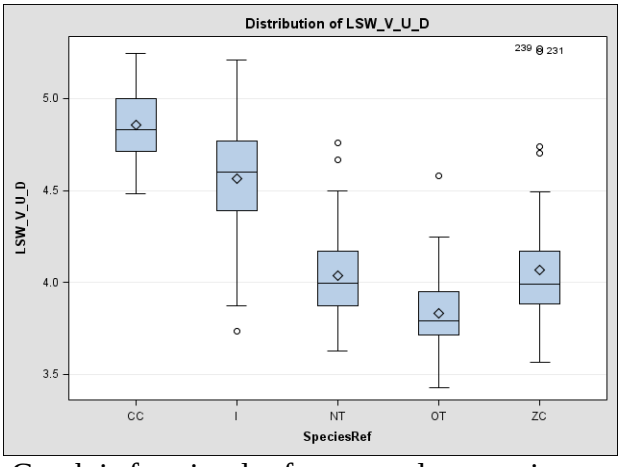
Water Use

FIGURE B.1 BOX PLOT LOG AVERAGE DAILY WATER USE VS. STORMWATER DOSED



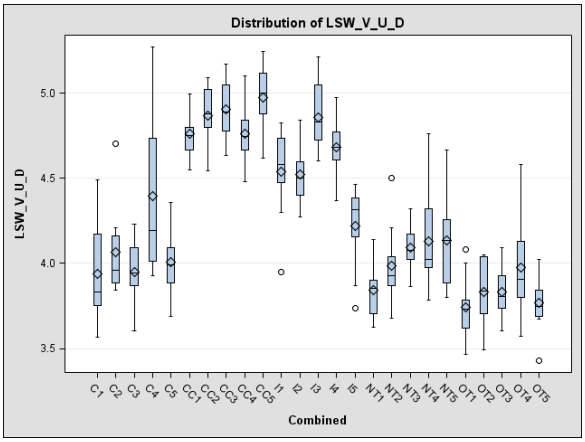
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.2 BOX PLOT LOG AVERAGE DAILY WATER USE VS. VEGETATION SPECIES



Graph is for visual reference only – text is not meant to be readable.

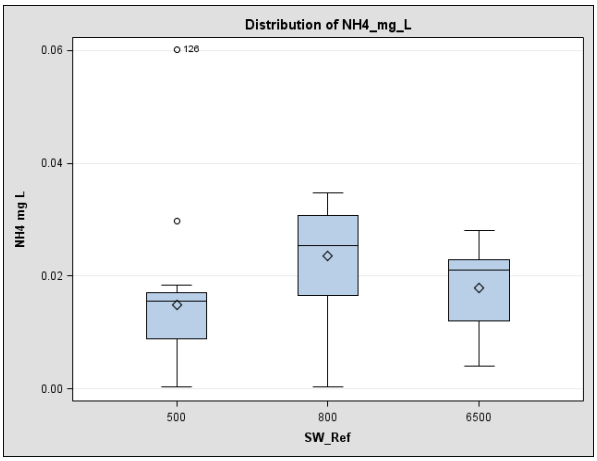
FIGURE B.3 BOX PLOT LOG AVERAGE DAILY WATER USE VS. COLUMN



Graph is for visual reference only – text is not meant to be readable.

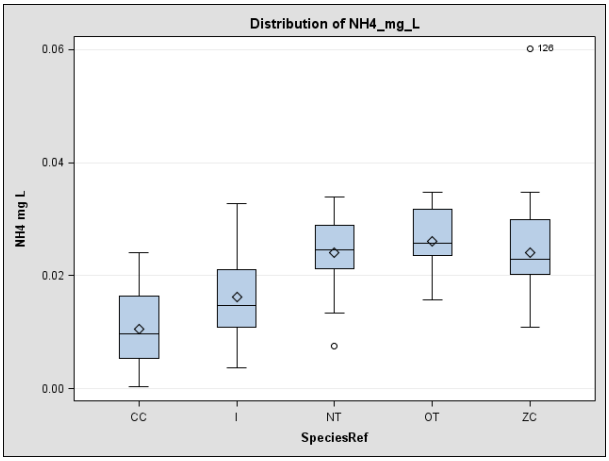
Nutrients

FIGURE B.4 BOX PLOT AMMONIA MASS LEACHED VS. STORMWATER DOSED



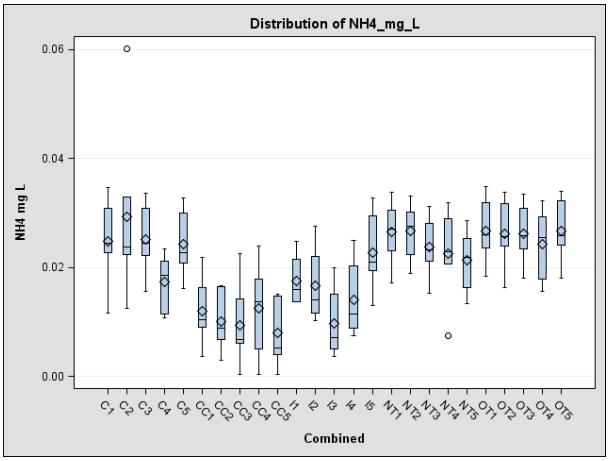
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.5 AMMONIA MASS LEACHED VS. VEGETATION SPECIES



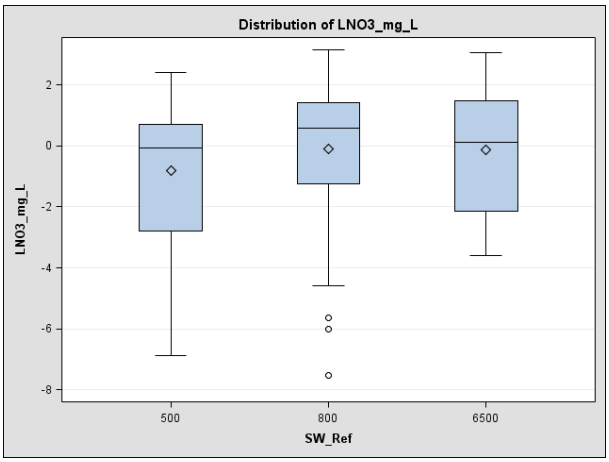
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.6 AMMONIA MASS LEACHED VS. COLUMN



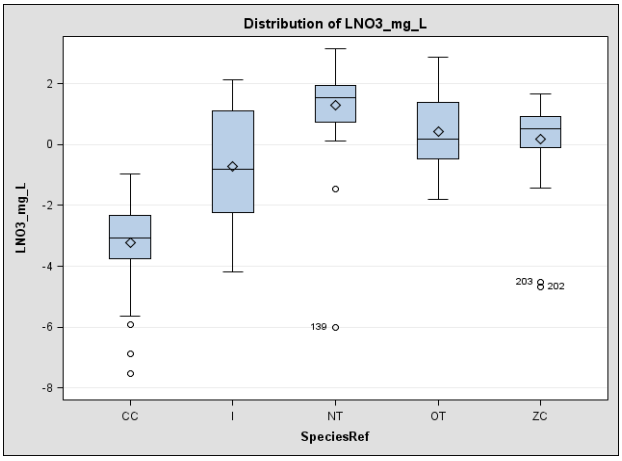
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.7 LOG NITRATE MASS LEACHED (MG) VS. STORMWATER DOSED



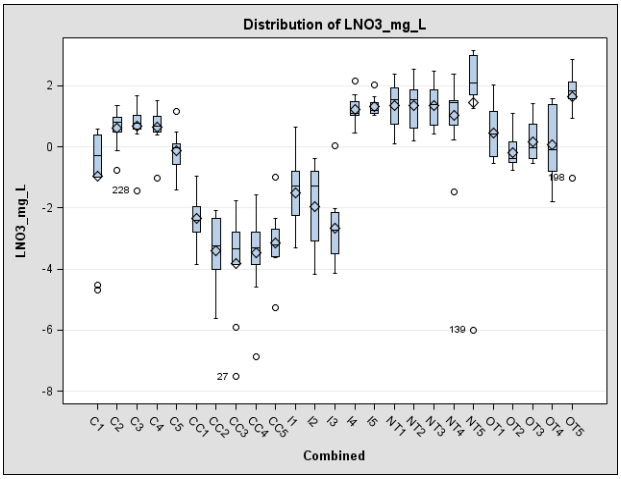
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.8 LOG NITRATE MASS LEACHED (MG) VS. VEGETATION SPECIES



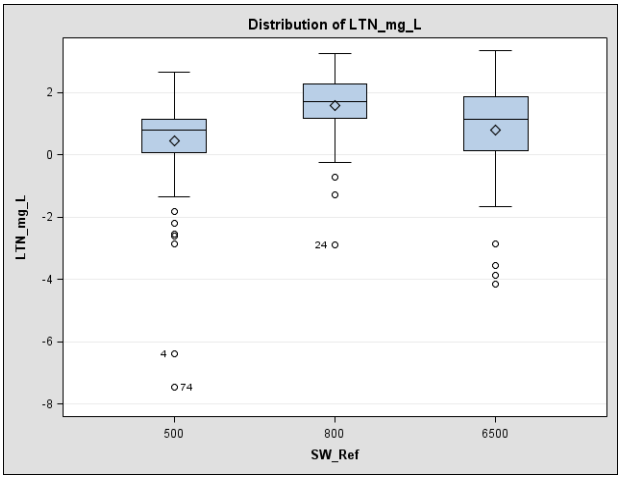
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.9 BOX PLOT LOG NITRATE MASS LEACHED (MG) VS. COLUMN



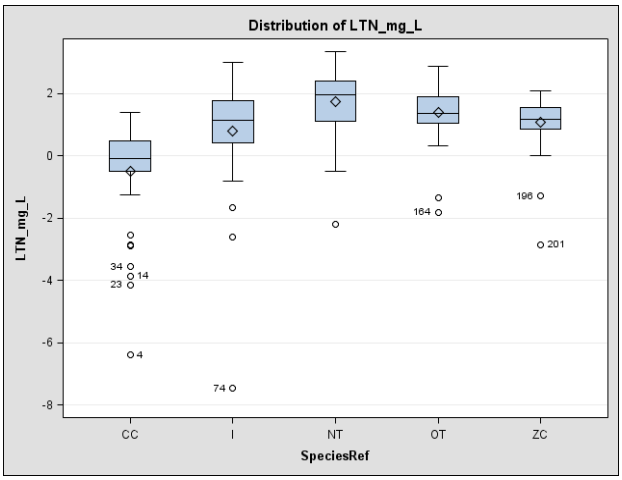
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.10 BOX PLOT LOG TOTAL NITROGEN MASS LEACHED (MG) VS. STORMWATER DOSED



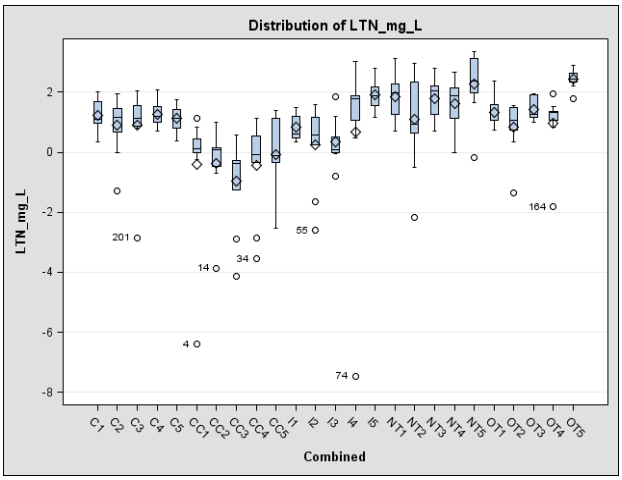
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.11 BOX PLOT LOG TOTAL NITROGEN MASS LEACHED (MG) VS. VEGETATION SPECIES



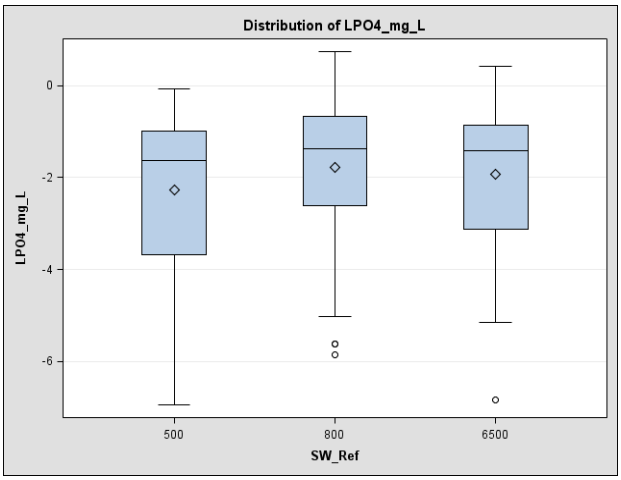
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.11 BOX PLOT LOG TOTAL NITROGEN MASS LEACHED (MG) VS. COLUMN



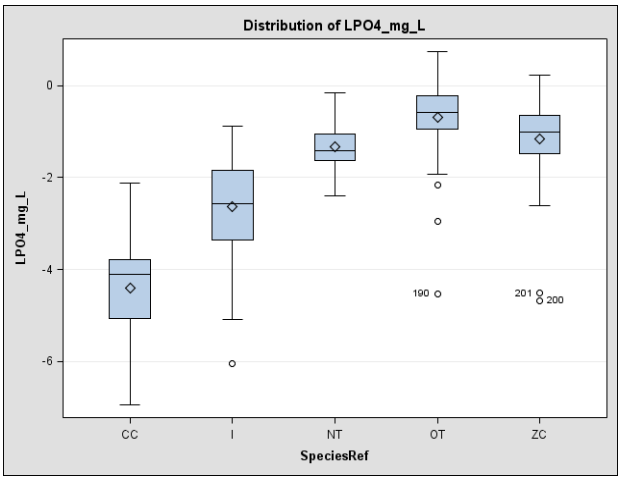
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.12 BOX PLOT LOG ORTHOPHOSPHATE MASS LEACHED (MG) VS. STORMWATER DOSED



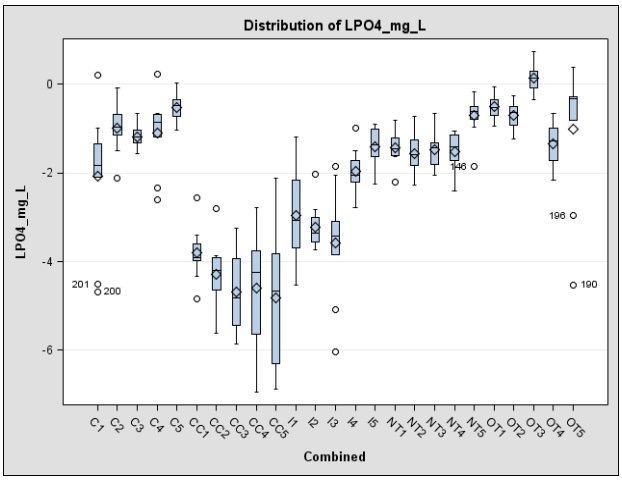
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.13 BOX PLOT LOG ORTHOPHOSPHATE MASS LEACHED (MG) VS. VEGETATION SPECIES



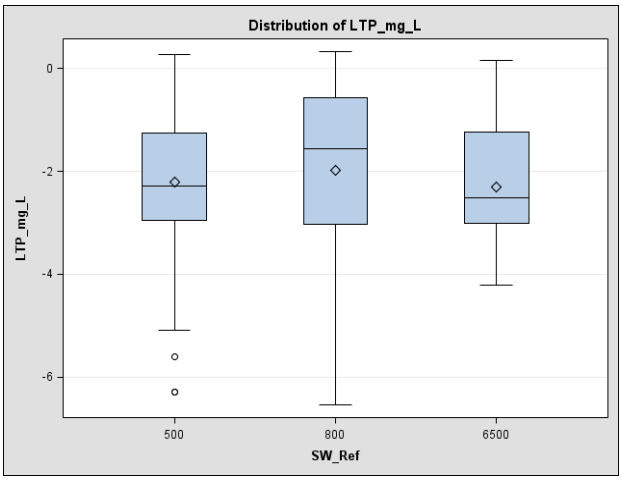
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.14 BOX PLOT LOG ORTHOPHOSPHATE MASS LEACHED (MG) VS. COLUMN



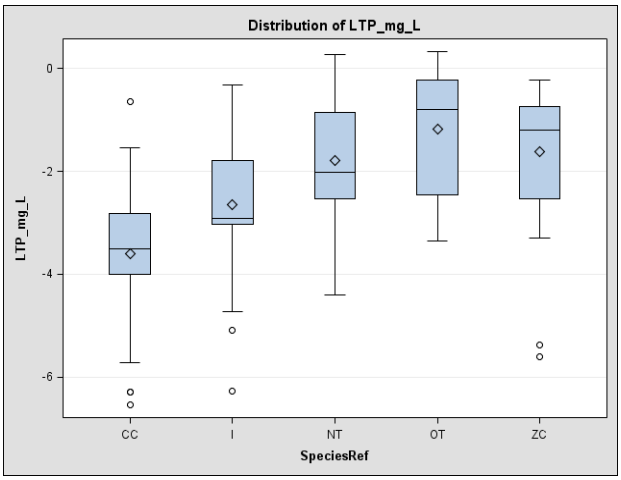
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.15 BOX PLOT LOG TOTAL PHOSPHORUS MASS LEACHED (MG) VS. STORMWATER DOSED



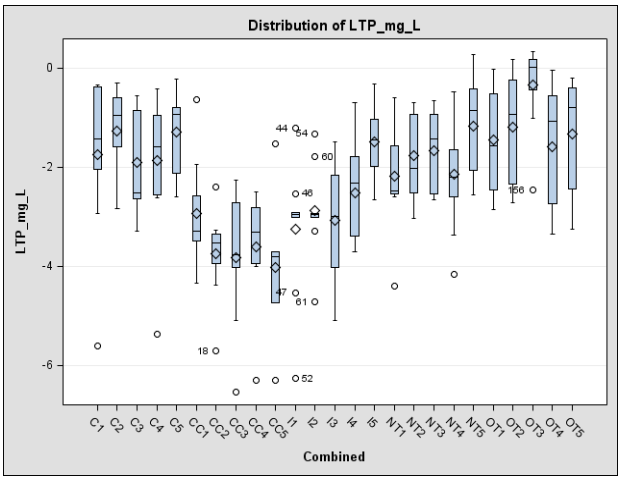
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.16 BOX PLOT LOG TOTAL PHOSPHORUS MASS LEACHED (MG) VS. VEGETATION SPECIES



Graph is for visual reference only – text is not meant to be readable.

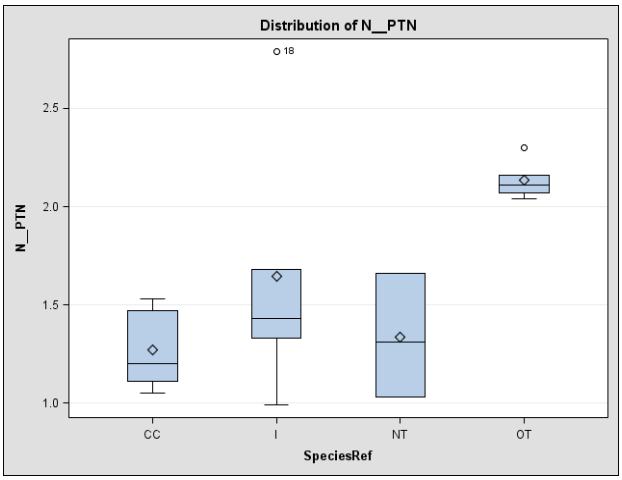
FIGURE B.17 BOX PLOT LOG TOTAL PHOSPHORUS MASS LEACHED (MG) VS. COLUMN



Graph is for visual reference only – text is not meant to be readable.

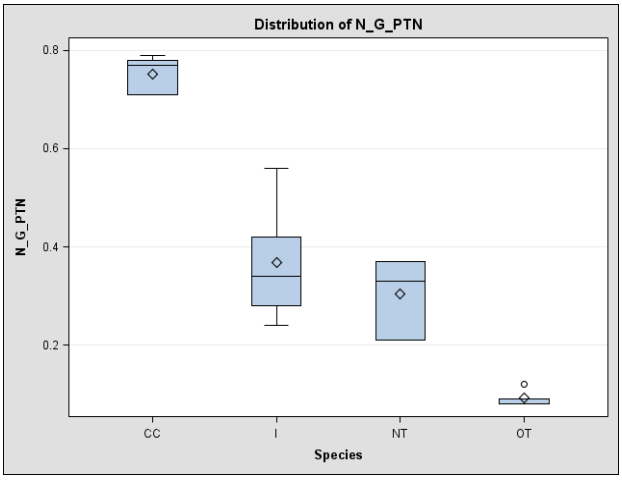
Plant Tissue

FIGURE B.18 BOX PLOT NITROGEN PLANT TISSUE (PPM) VS. VEGETATION SPECIES



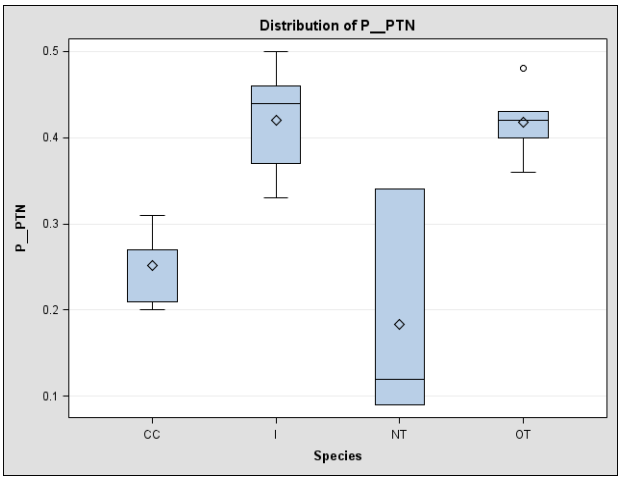
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.19 BOX PLOT NITROGEN PLANT TISSUE (GRAMS) VS. VEGETATION SPECIES



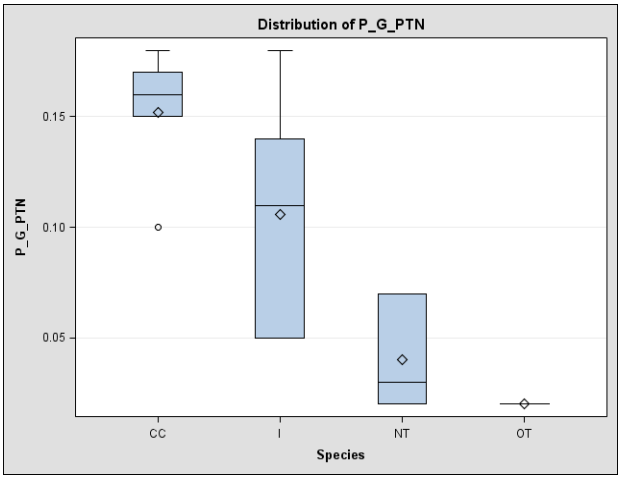
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.20 BOX PLOT PHOSPHORUS PLANT TISSUE (PPM) VS. VEGETATION SPECIES



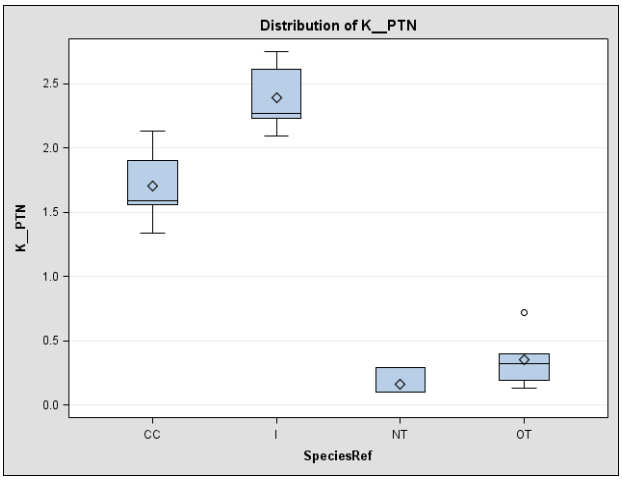
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.21 BOX PLOT PHOSPHORUS PLANT TISSUE (GRAMS) VS. VEGETATION SPECIES



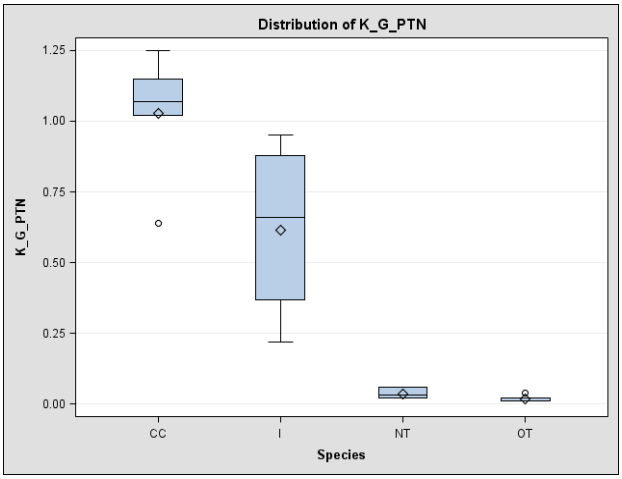
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.22 BOX PLOT POTASSIUM PLANT TISSUE (PPM) VS. VEGETATION SPECIES



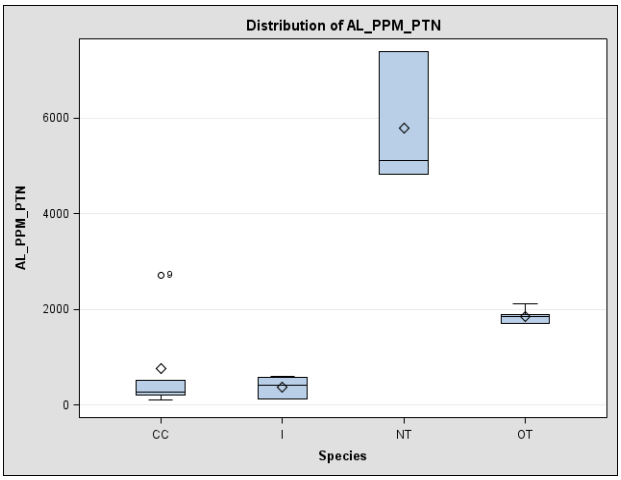
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.23 BOX PLOT POTASSIUM PLANT TISSUE (GRAMS) VS. VEGETATION SPECIES



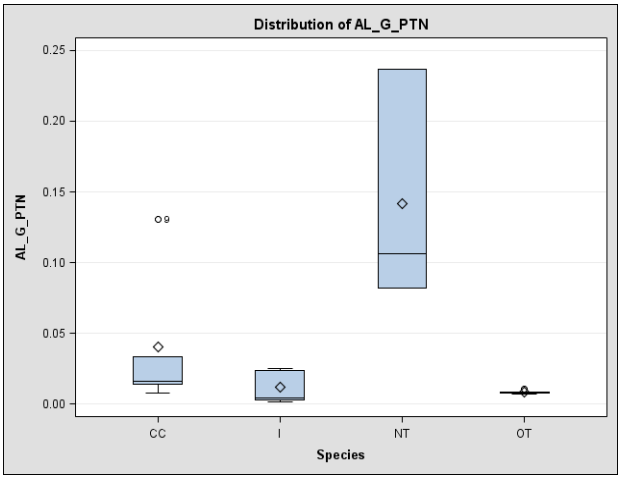
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.24 BOX PLOT ALUMINUM PLANT TISSUE (PPM) VS. VEGETATION SPECIES



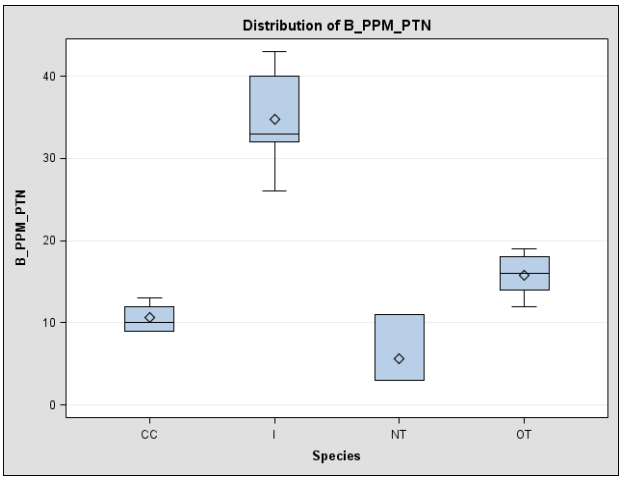
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.25 BOX PLOT ALUMINUM PLANT TISSUE (GRAMS) VS. VEGETATION SPECIES



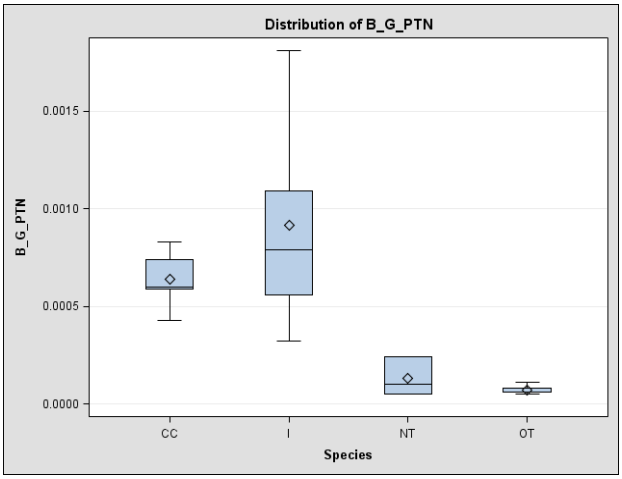
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.26 BOX PLOT BORON PLANT TISSUE (PPM) VS. VEGETATION SPECIES



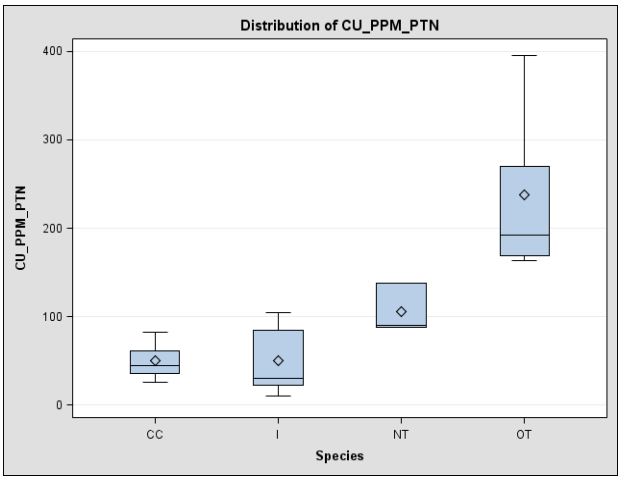
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.27 BOX PLOT BORON PLANT TISSUE (GRAMS) VS. VEGETATION SPECIES



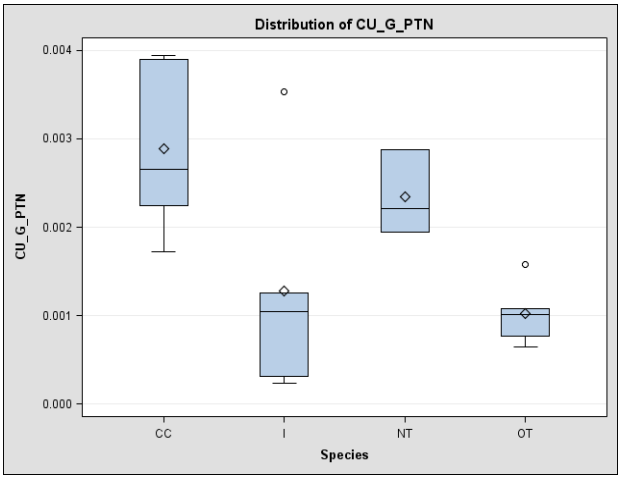
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.28 BOX PLOT COPPER PLANT TISSUE (PPM) VS. VEGETATION SPECIES



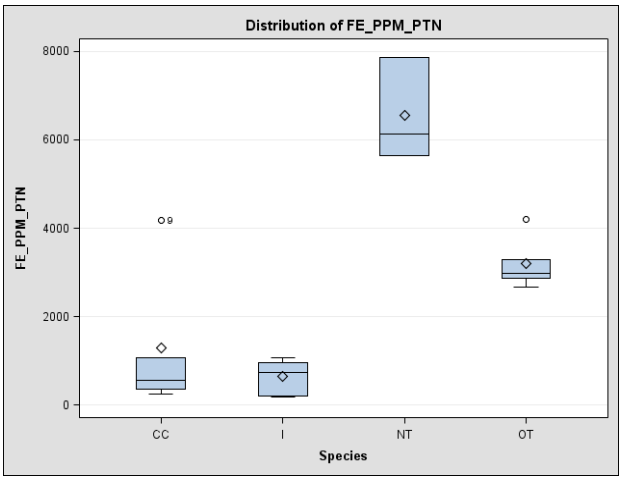
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.29 BOX PLOT COPPER PLANT TISSUE (GRAMS) VS. VEGETATION SPECIES



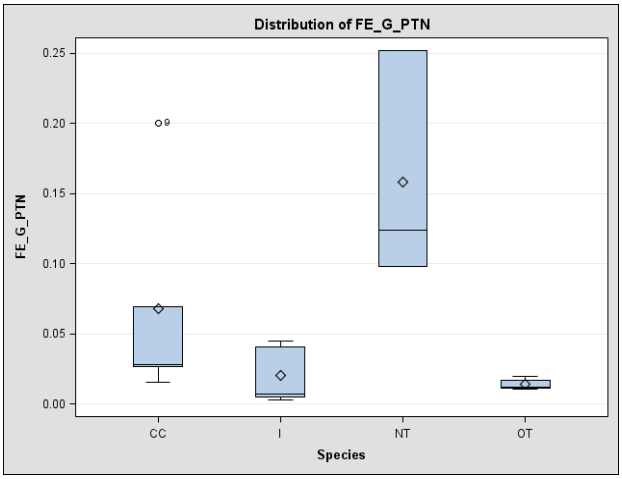
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.30 BOX PLOT IRON PLANT TISSUE (PPM) VS. VEGETATION SPECIES



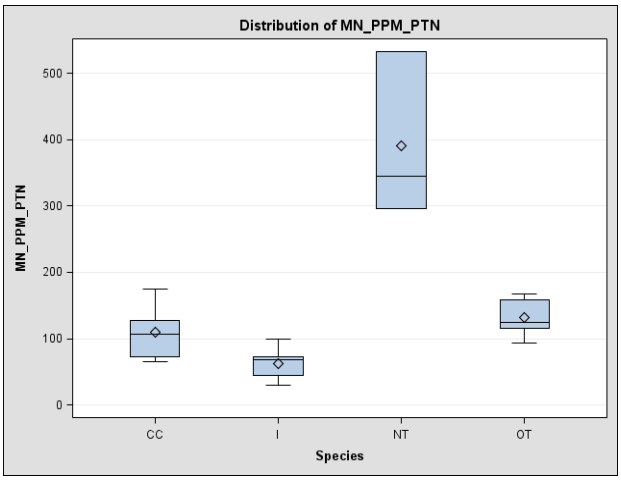
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.31 BOX PLOT IRON PLANT TISSUE (GRAMS) VS. VEGETATION SPECIES



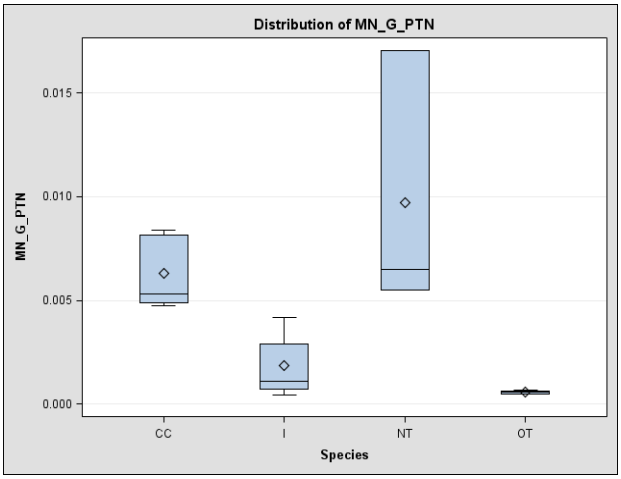
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.32 BOX PLOT MANGANESE PLANT TISSUE (PPM) VS. VEGETATION SPECIES



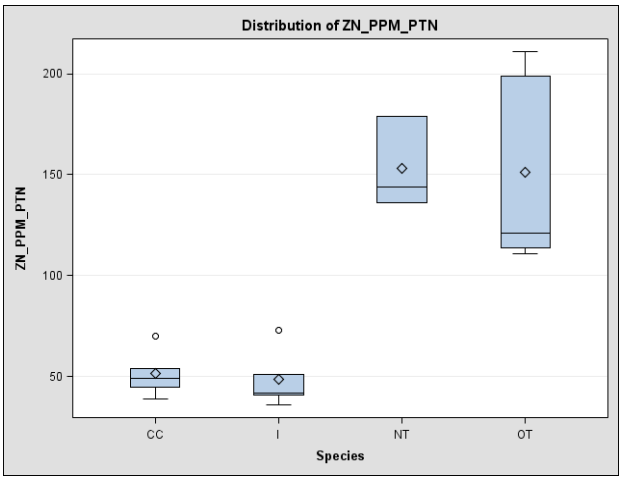
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.33 BOX PLOT MANGANESE PLANT TISSUE (GRAMS) VS. VEGETATION SPECIES



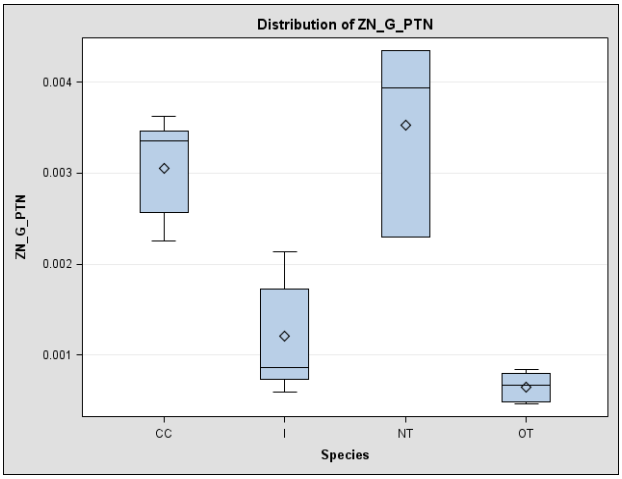
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.34 BOX PLOT ZINC PLANT TISSUE (PPM) VS. VEGETATION SPECIES



Graph is for visual reference only – text is not meant to be readable.

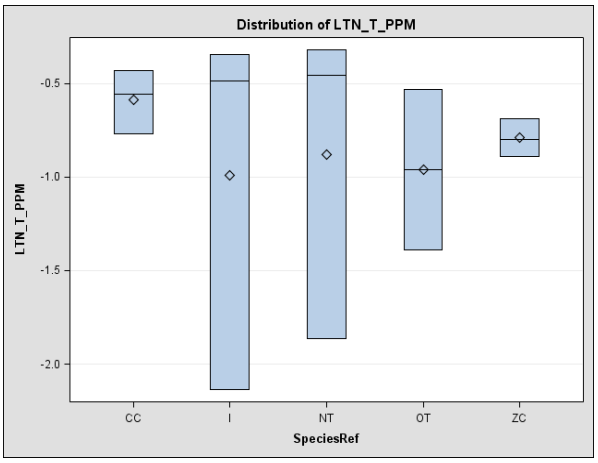
FIGURE B.35 BOX PLOT ZINC PLANT TISSUE (GRAMS) VS. VEGETATION SPECIES



Graph is for visual reference only – text is not meant to be readable.

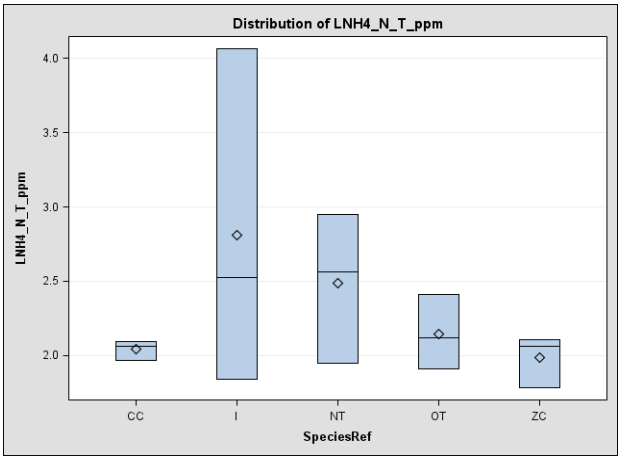
Potting Soil Mix

FIGURE B.36 BOX PLOT POTTING SOIL LOG NITRATE (PPM) VS. VEGETATION SPECIES



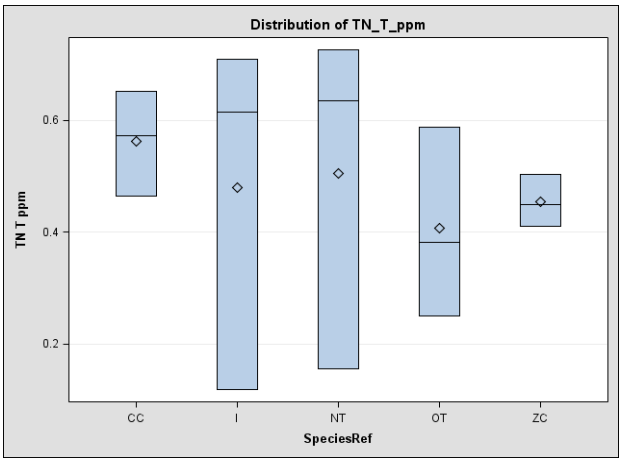
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.37 BOX PLOT POTTING SOIL LOG AMMONIA (PPM) VS. VEGETATION SPECIES



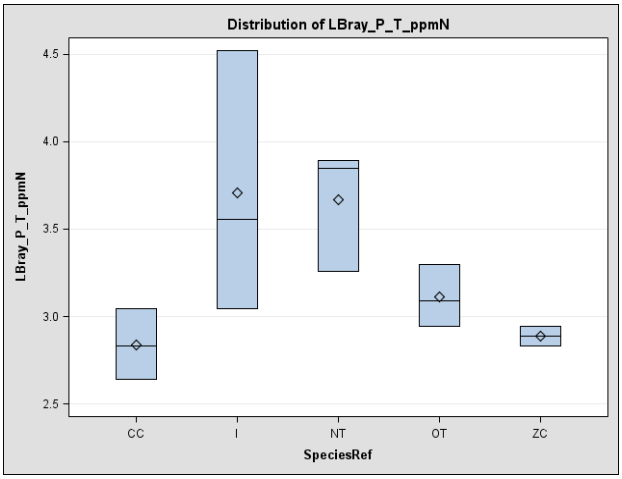
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.38 BOX PLOT POTTING SOIL TOTAL NITROGEN (%) VS. VEGETATION SPECIES



Graph is for visual reference only – text is not meant to be readable.

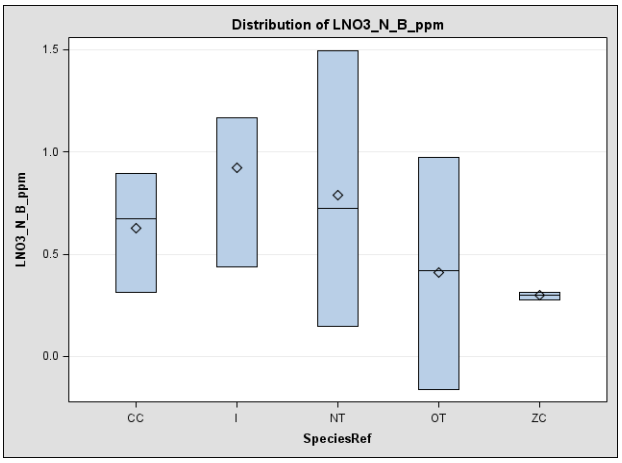
FIGURE B.39 BOX PLOT POTTING SOIL LOG BRAY PHOSPHORUS (PPM) VS. VEGETATION SPECIES



Graph is for visual reference only – text is not meant to be readable.

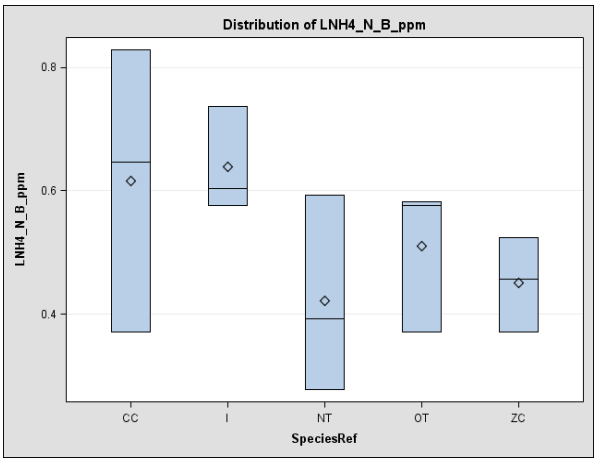
Bioretention Soil Mix

FIGURE B.40 BOX PLOT BIORETENTION SOIL LOG NITRATE (PPM) VS. VEGETATION SPECIES



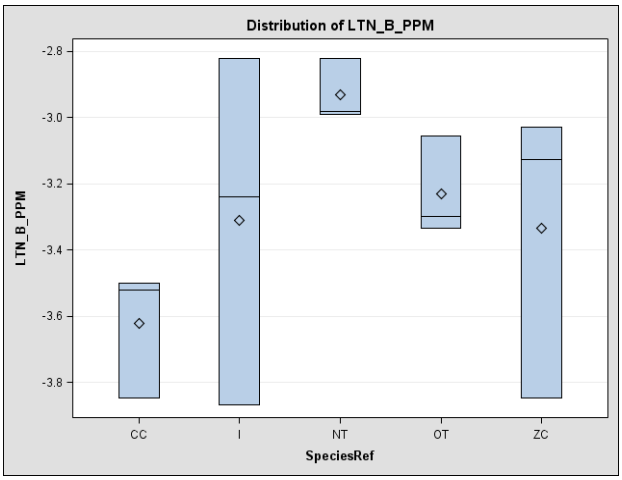
Graph is for visual reference only – text is not meant to be readable.

FIGURE B.41 BOX PLOT BIORETENTION SOIL LOG AMMONIA (PPM) VS. VEGETATION SPECIES



Graph is for visual reference only – text is not meant to be readable.

FIGURE B.42 BOX PLOT BIORETENTION SOIL TOTAL NITROGEN (%) VS. VEGETATION SPECIES



Graph is for visual reference only – text is not meant to be readable.

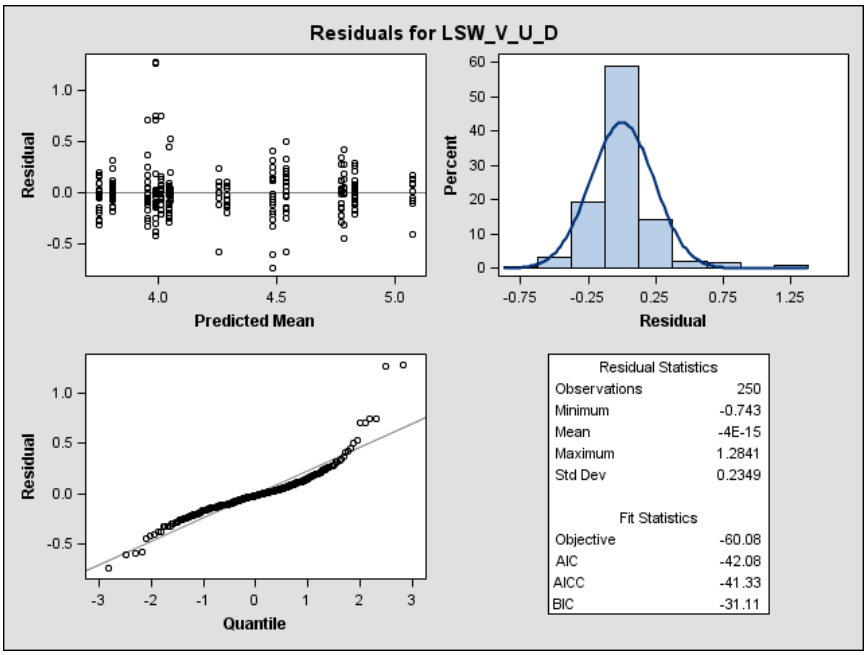
FIGURE B.43 BOX PLOT BIORETENTION LOG BRAY PHOSPHORUS (PPM) VS. VEGETATION SPECIES

Graph is for visual reference only – text is not meant to be readable.

Appendix C – Residual Statistics

Water Use

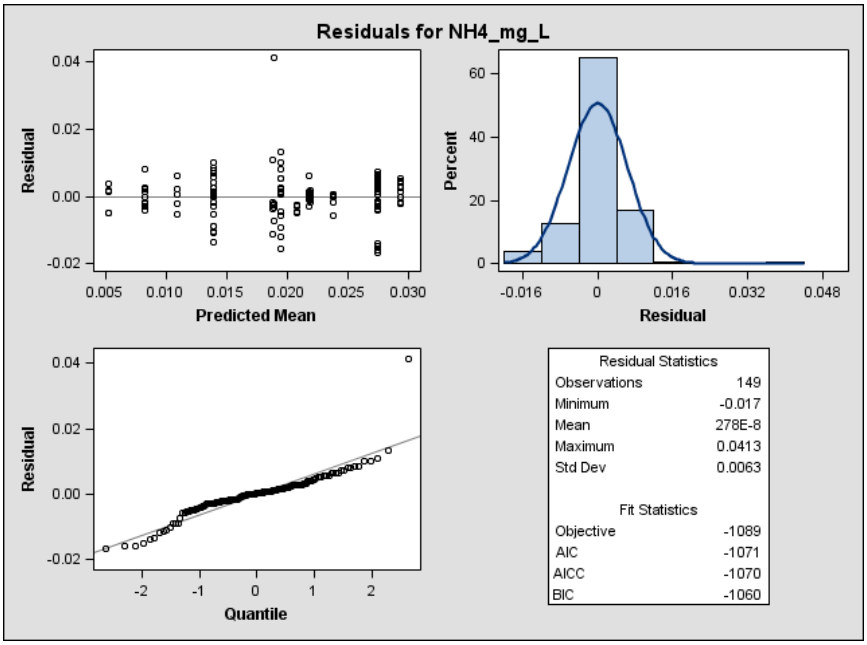
FIGURE C.1 LOG AVERAGE DAILY WATER USE RESIDUAL ANALYSIS



Graph is for visual reference only – text is not meant to be readable.

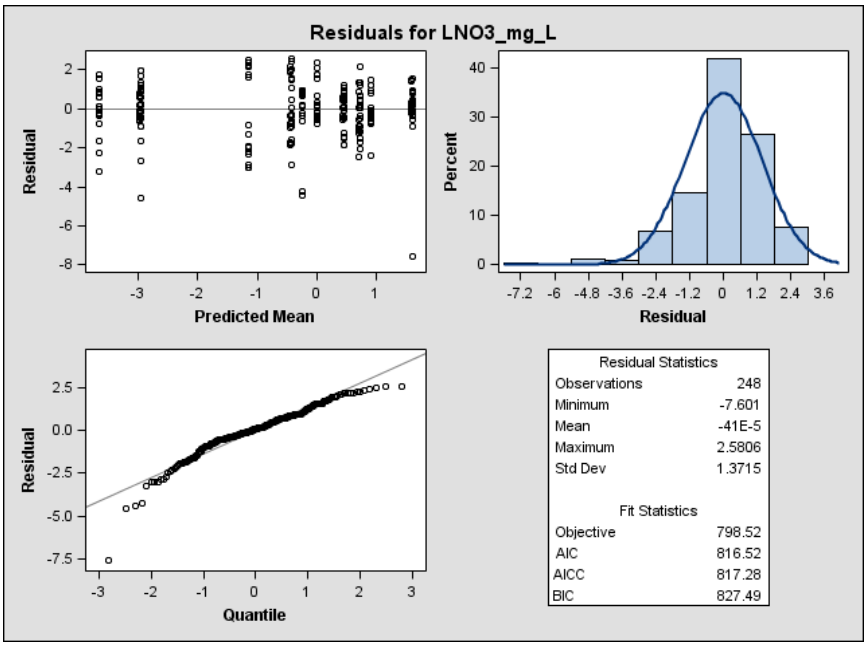
Nutrients

FIGURE C.2 AMMONIA MASS LEACHED (MG) RESIDUAL ANALYSIS



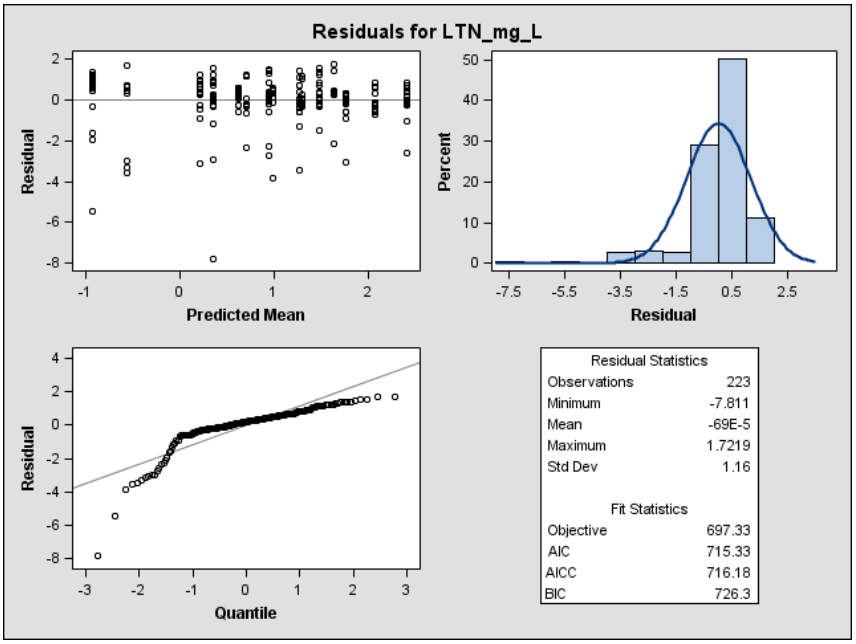
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.3 LOG NITRATE MASS LEACHED (MG) RESIDUAL ANALYSIS



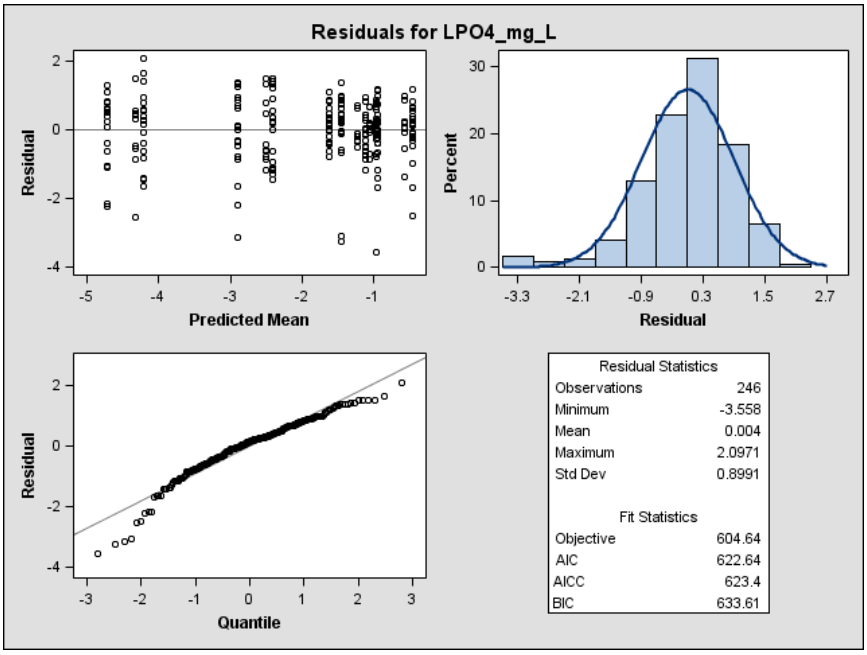
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.4 LOG TOTAL NITROGEN MASS LEACHED (MG) RESIDUAL ANALYSIS



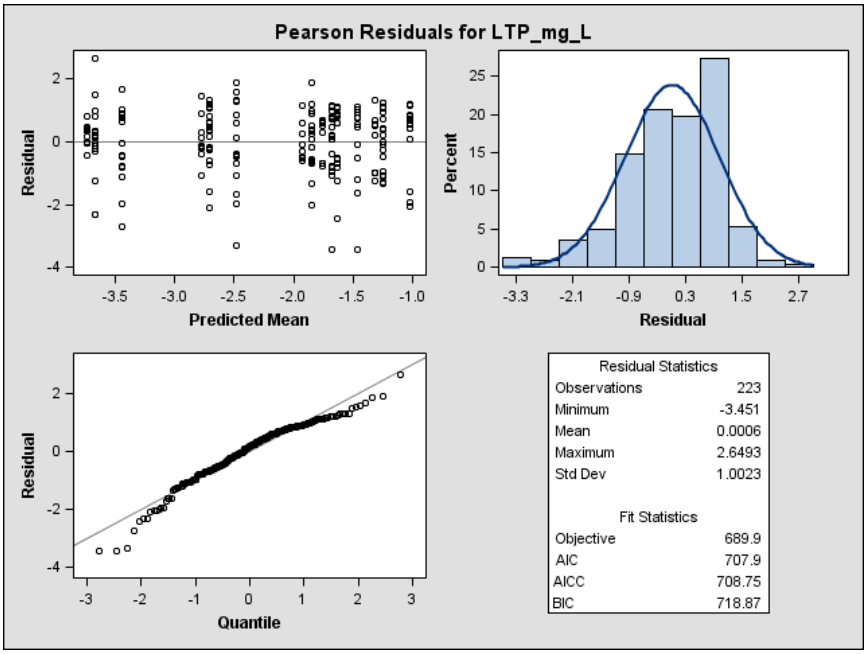
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.5 LOG ORTHOPHOSPHATE MASS LEACHED (MG) RESIDUAL ANALYSIS



Graph is for visual reference only – text is not meant to be readable.

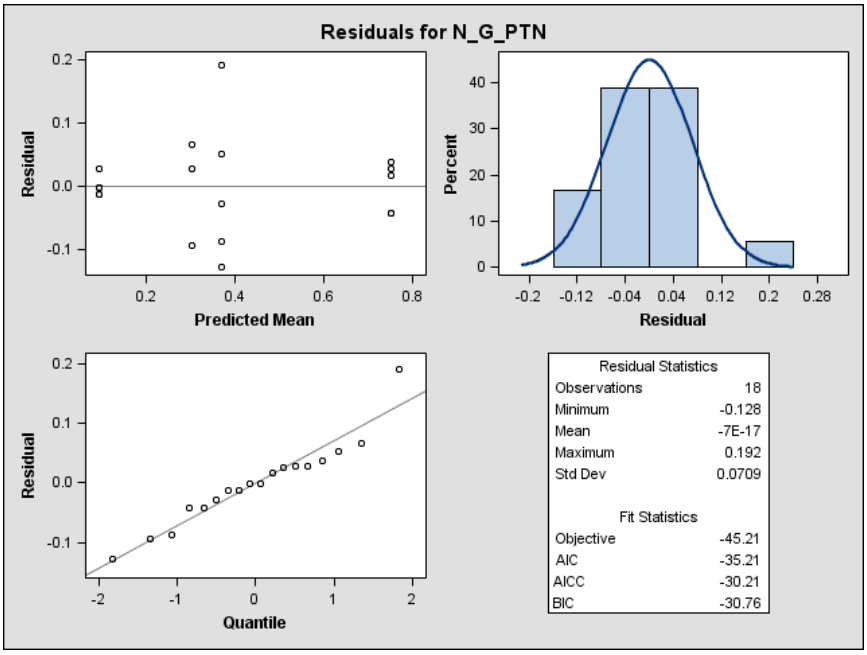
FIGURE C.6 LOG TOTAL PHOSPHORUS MASS LEACHED (MG) RESIDUAL ANALYSIS



Graph is for visual reference only – text is not meant to be readable.

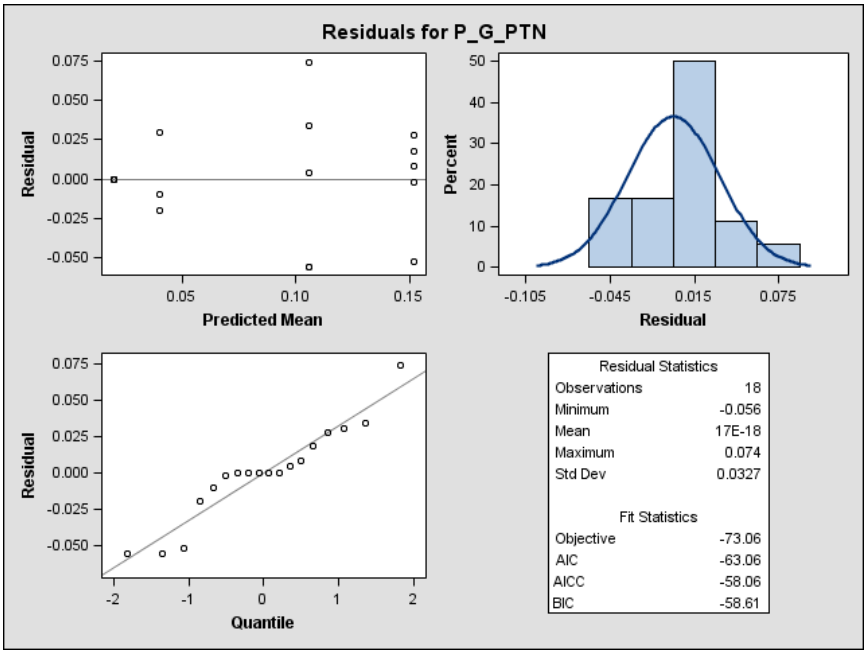
Plant Tissue

FIGURE C.7 NITROGEN PLANT TISSUE (GRAMS) RESIDUAL ANALYSIS



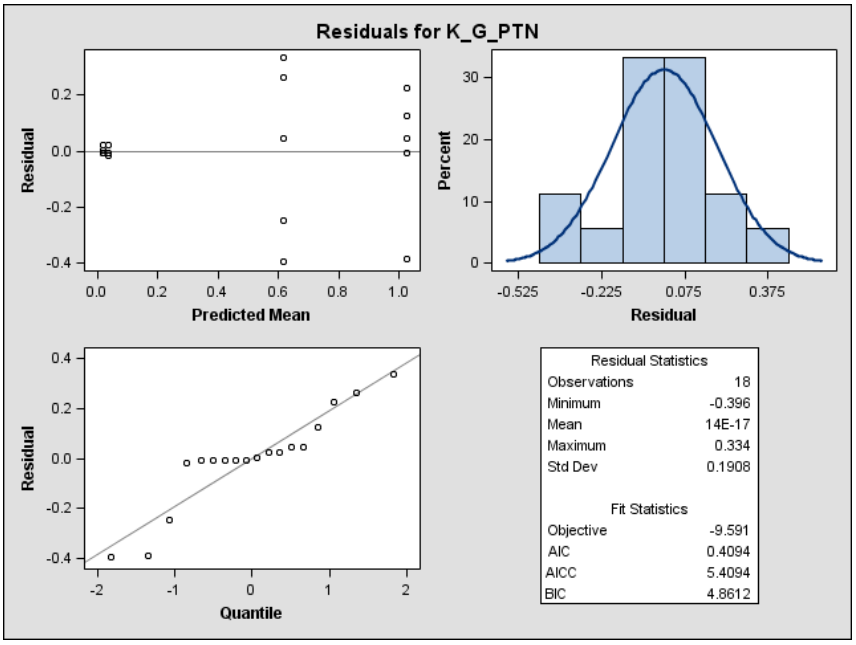
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.8 PHOSPHORUS PLANT TISSUE (GRAMS) RESIDUAL ANALYSIS



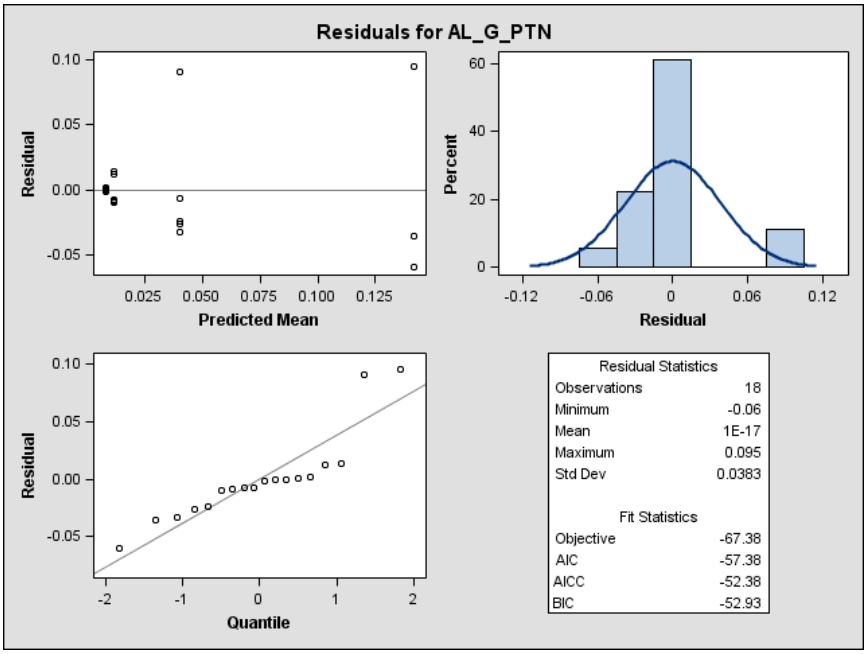
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.9 POTASSIUM PLANT TISSUE (GRAMS) RESIDUAL ANALYSIS



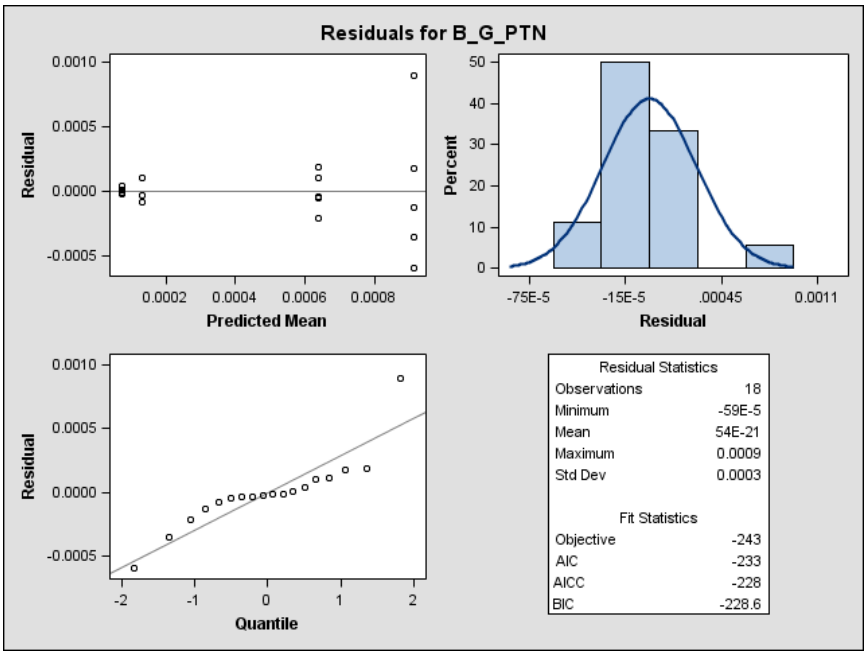
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.10 ALUMINUM PLANT TISSUE (GRAMS) RESIDUAL ANALYSIS



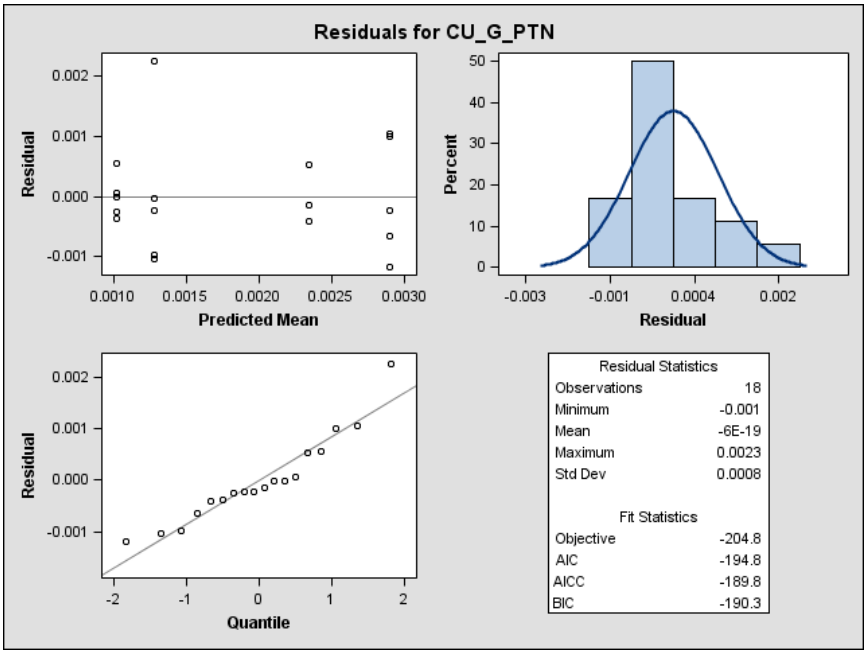
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.11 BORON PLANT TISSUE (GRAMS) RESIDUAL ANALYSIS



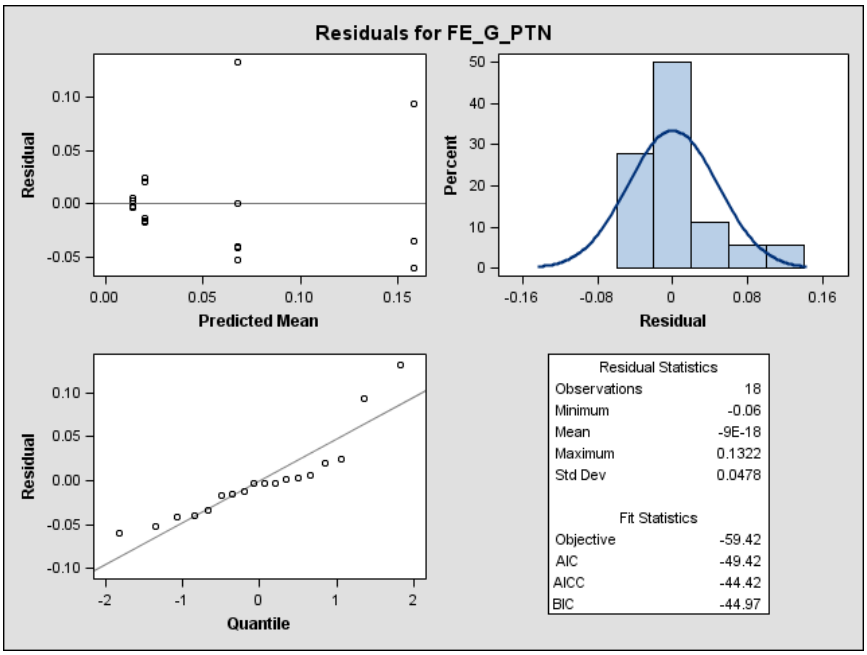
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.12 COPPER PLANT TISSUE (GRAMS) RESIDUAL ANALYSIS



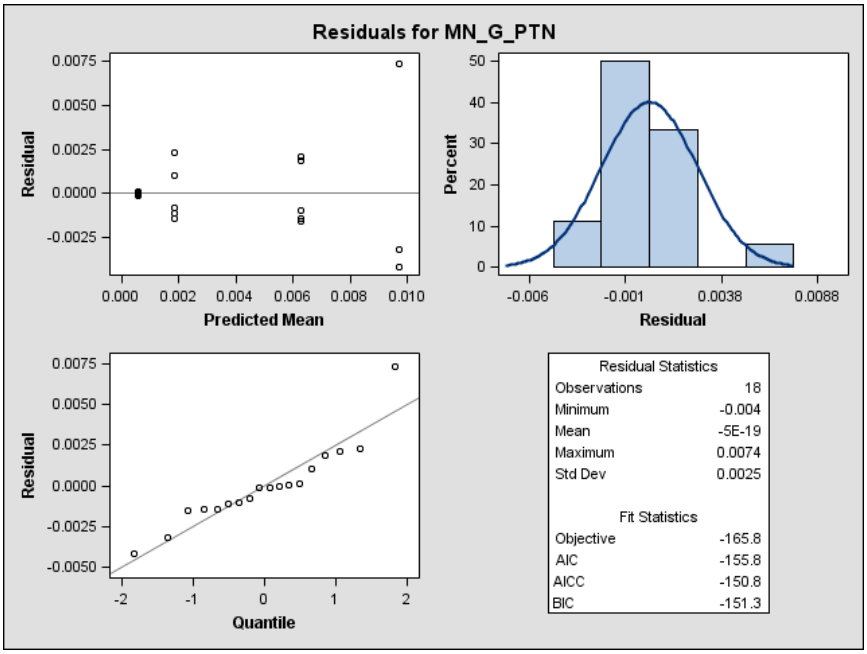
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.13 IRON PLANT TISSUE (GRAMS) RESIDUAL ANALYSIS



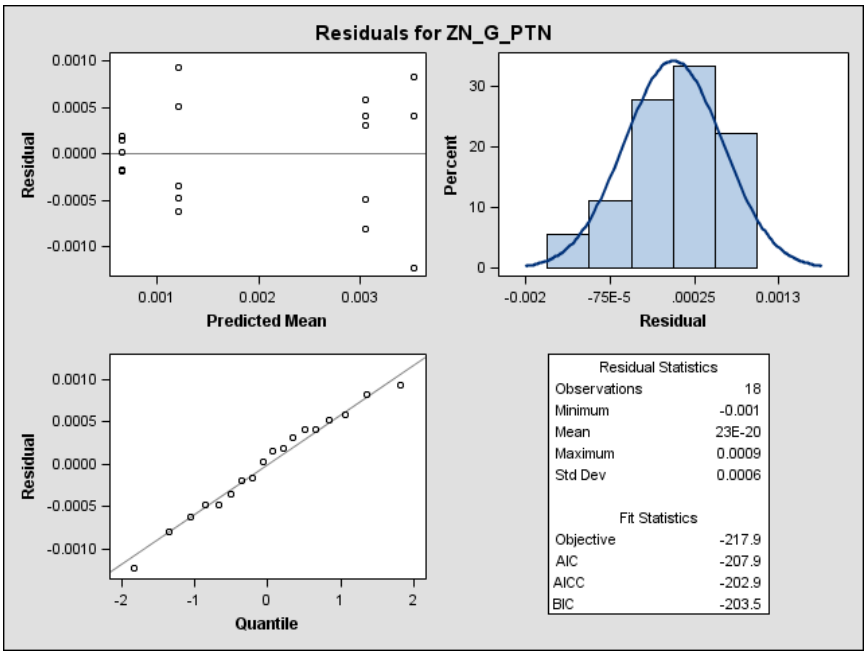
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.14 MANGANESE PLANT TISSUE (GRAMS) RESIDUAL ANALYSIS



Graph is for visual reference only – text is not meant to be readable.

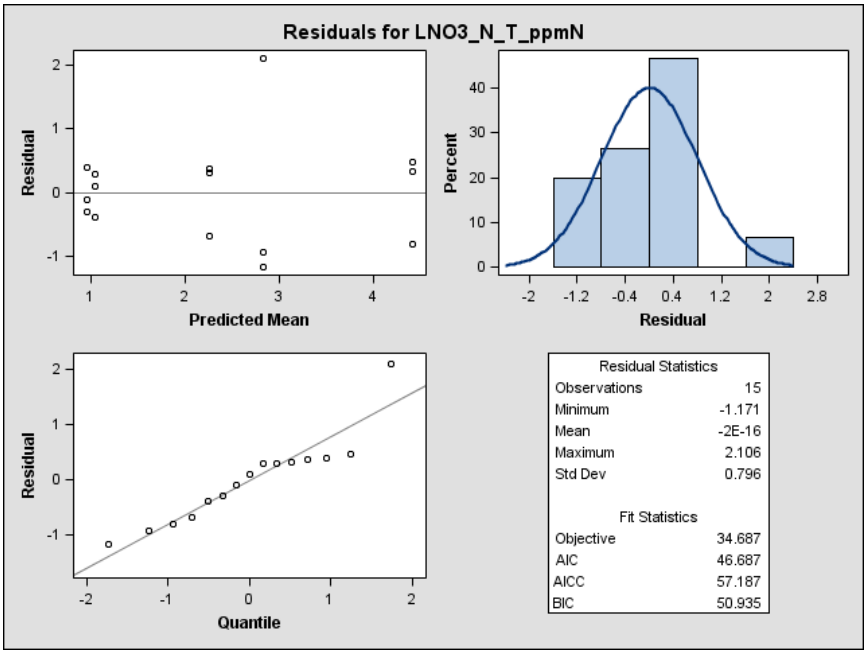
FIGURE C.15 ZINC PLANT TISSUE (GRAMS) RESIDUAL ANALYSIS



Graph is for visual reference only – text is not meant to be readable.

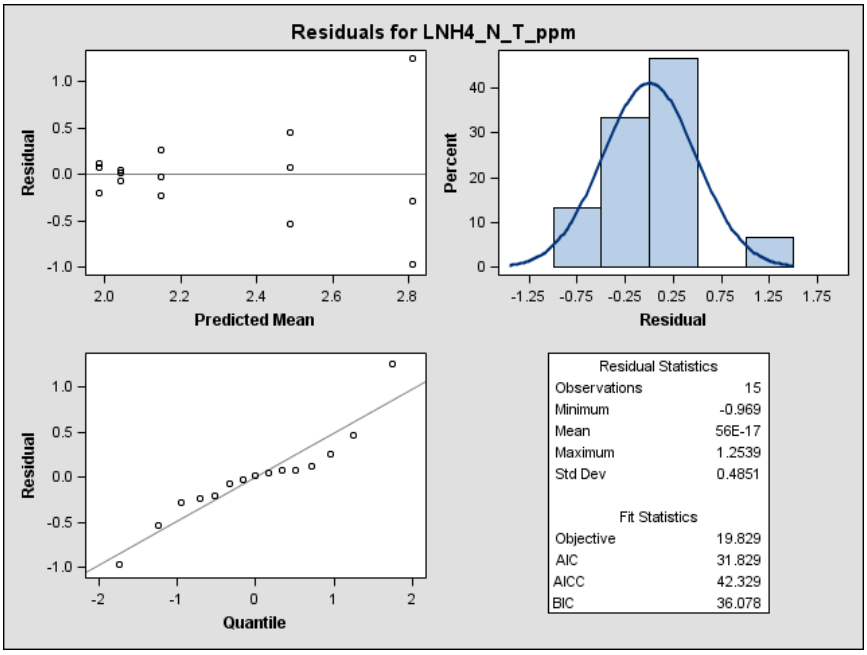
Potting Soil Mix

FIGURE C.16 POTTING SOIL LOG NITRATE (PPM) RESIDUAL ANALYSIS



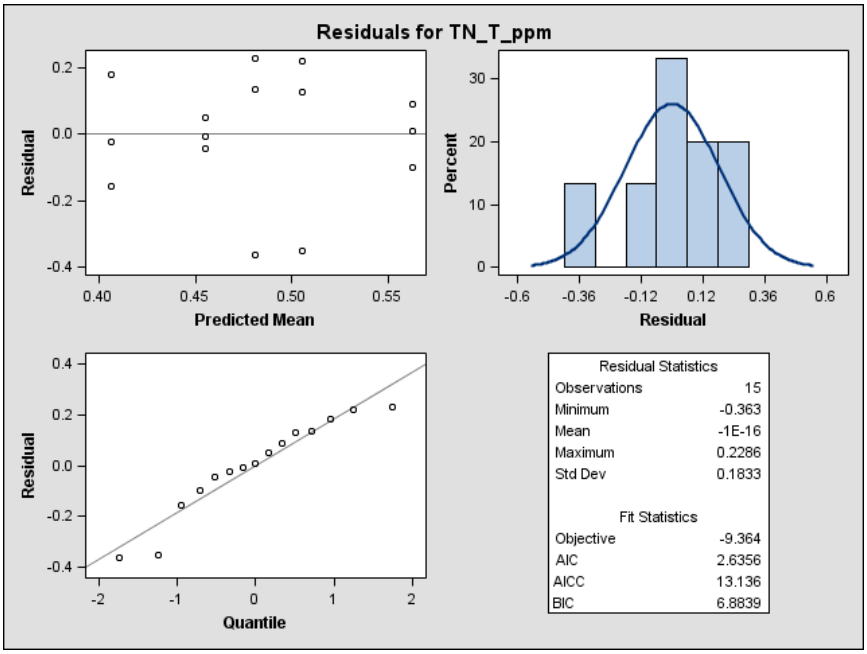
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.17 POTTING SOIL LOG AMMONIA (PPM) RESIDUAL ANALYSIS



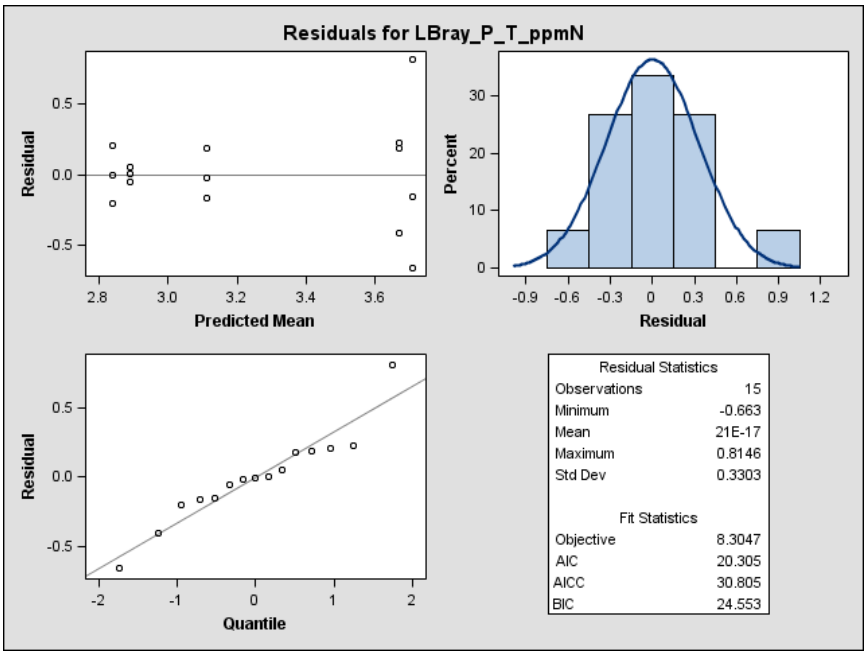
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.18 POTTING SOIL TOTAL NITROGEN (%) RESIDUAL ANALYSIS



Graph is for visual reference only – text is not meant to be readable.

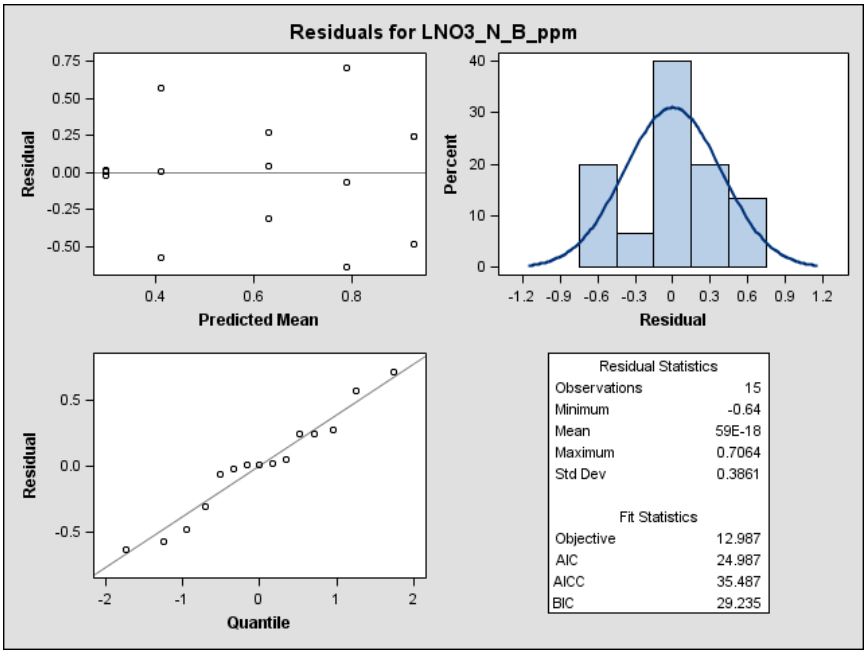
FIGURE C.19 POTTING SOIL LOG BRAY PHOSPHORUS (PPM) RESIDUAL ANALYSIS



Graph is for visual reference only – text is not meant to be readable.

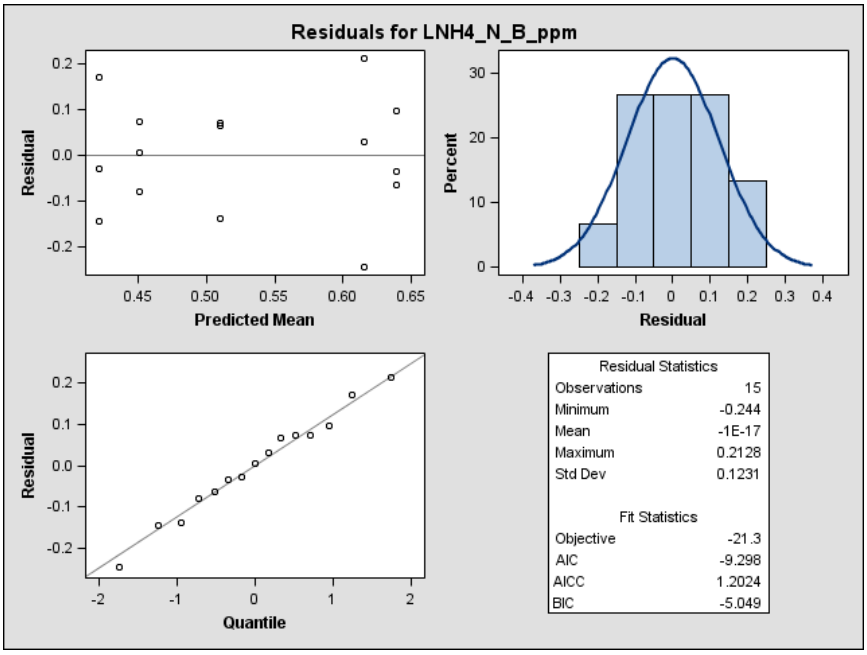
Bioretention Soil Mix

FIGURE C.20 BIORETENTION SOIL LOG NITRATE (PPM) RESIDUAL ANALYSIS



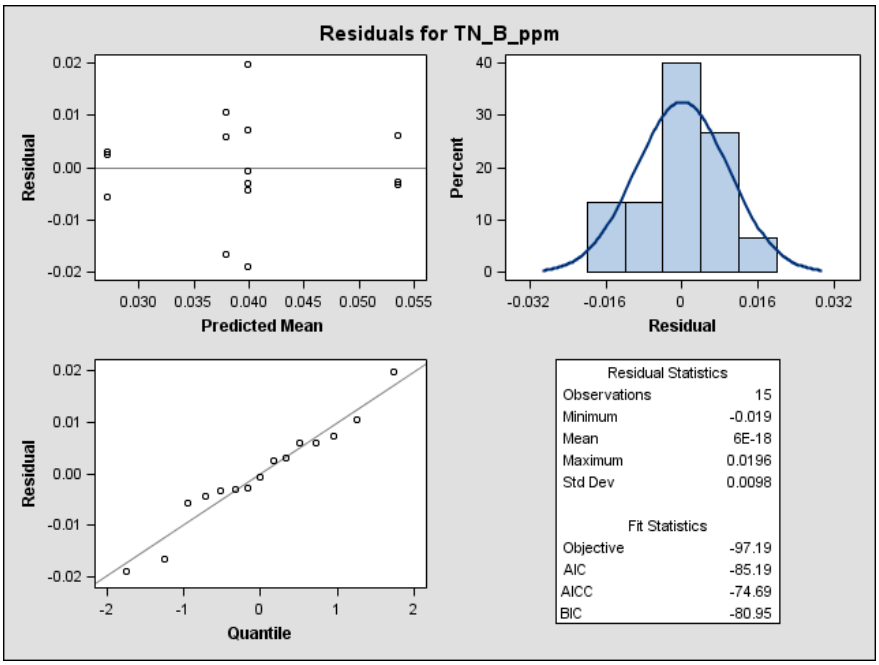
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.21 BIORETENTION SOIL LOG AMMONIA (PPM) RESIDUAL ANALYSIS



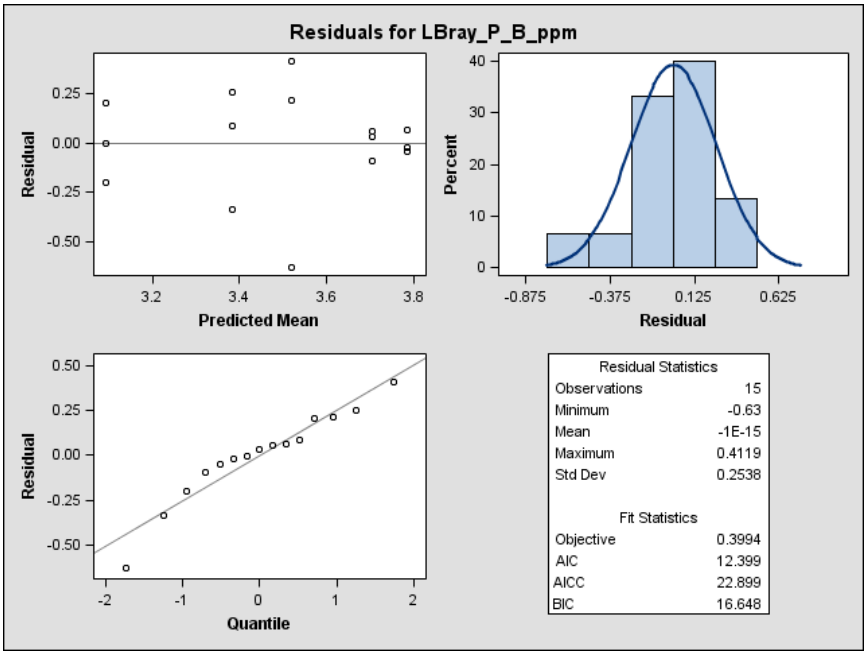
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.22 BIORETENTION SOIL TOTAL NITROGEN (PPM) RESIDUAL ANALYSIS



Graph is for visual reference only – text is not meant to be readable.

FIGURE C.23 BIORETENTION SOIL LOG BRAY PHOSPHORUS (PPM) RESIDUAL ANALYSIS

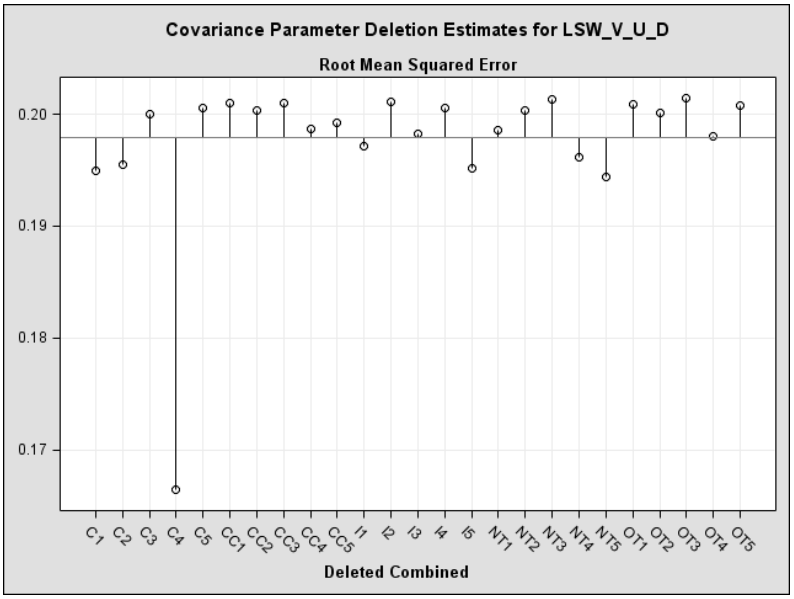


Graph is for visual reference only – text is not meant to be readable.

Appendix D

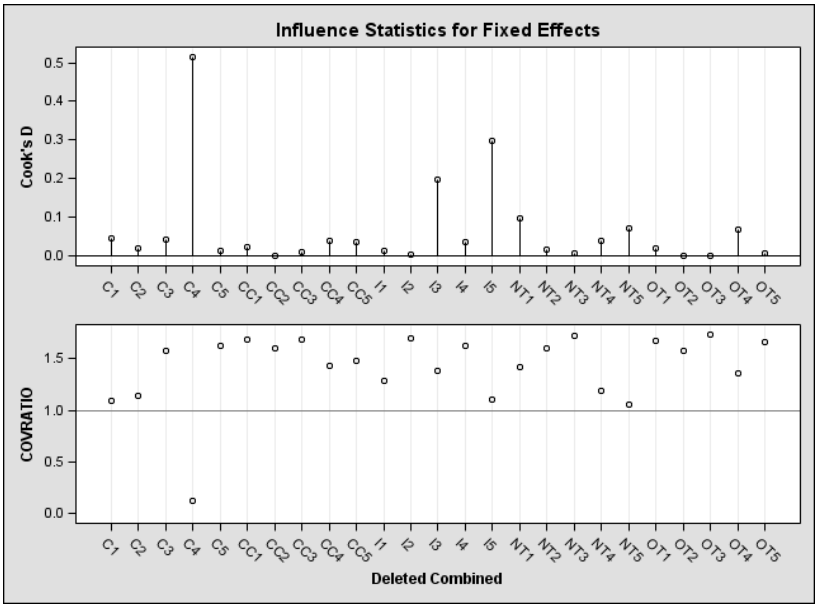
Influence Statistics

FIGURE C.24 LOG AVERAGE DAILY WATER USE ROOT MEAN SQUARED ERROR BY COLUMN



Graph is for visual reference only – text is not meant to be readable.

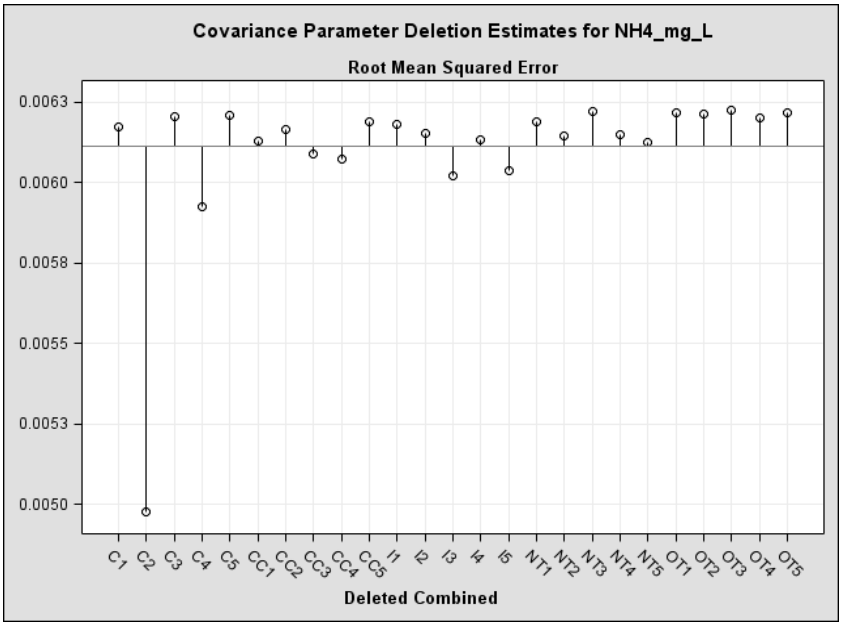
FIGURE C.25 LOG AVERAGE DAILY WATER USE INFLUENCE STATISTICS BY COLUMN



Graph is for visual reference only – text is not meant to be readable.

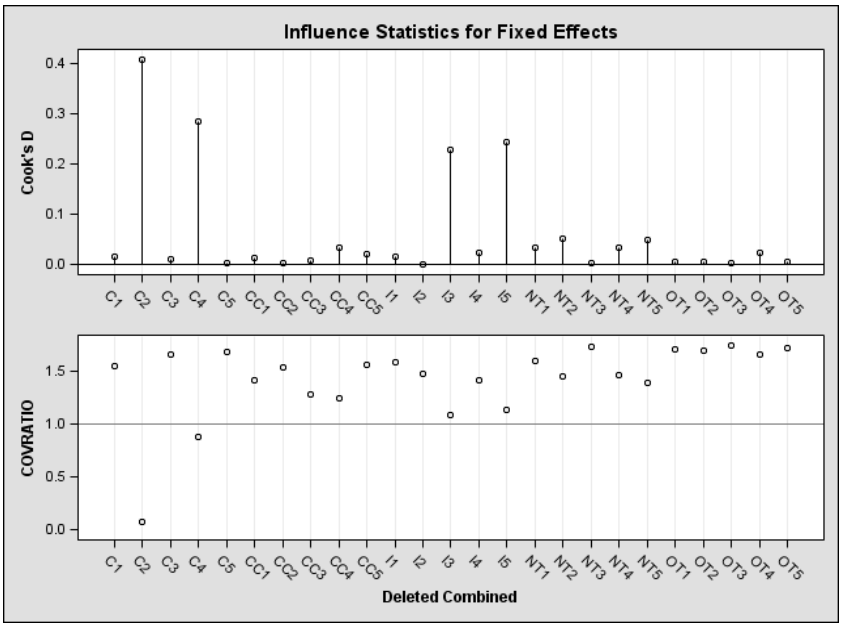
Nutrients

FIGURE C.26 AMMONIA MASS LEACHED (MG) ROOT MEAN SQUARED ERROR BY COLUMN



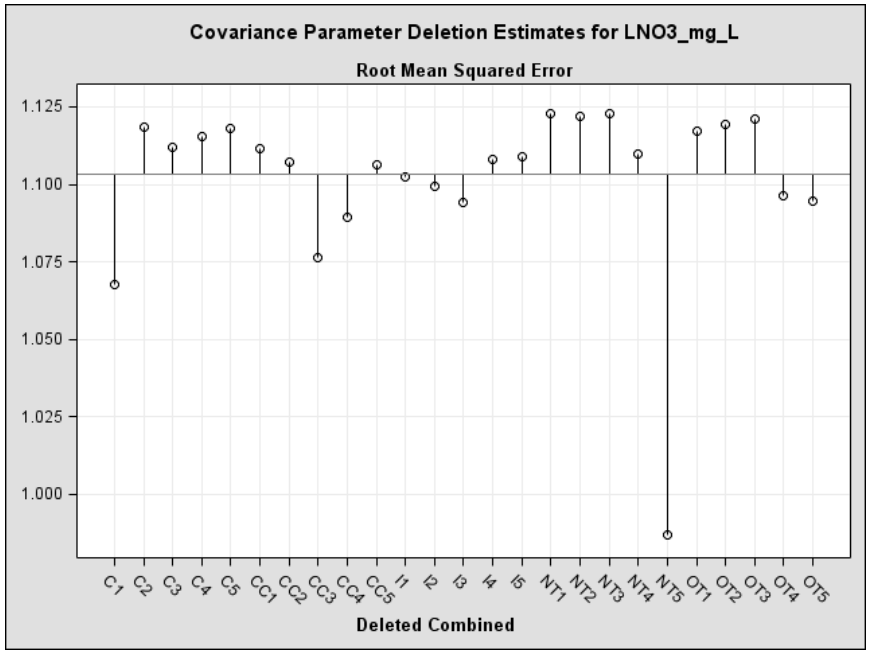
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.27 AMMONIA MASS LEACHED (MG) INFLUENCE STATISTICS BY COLUMN



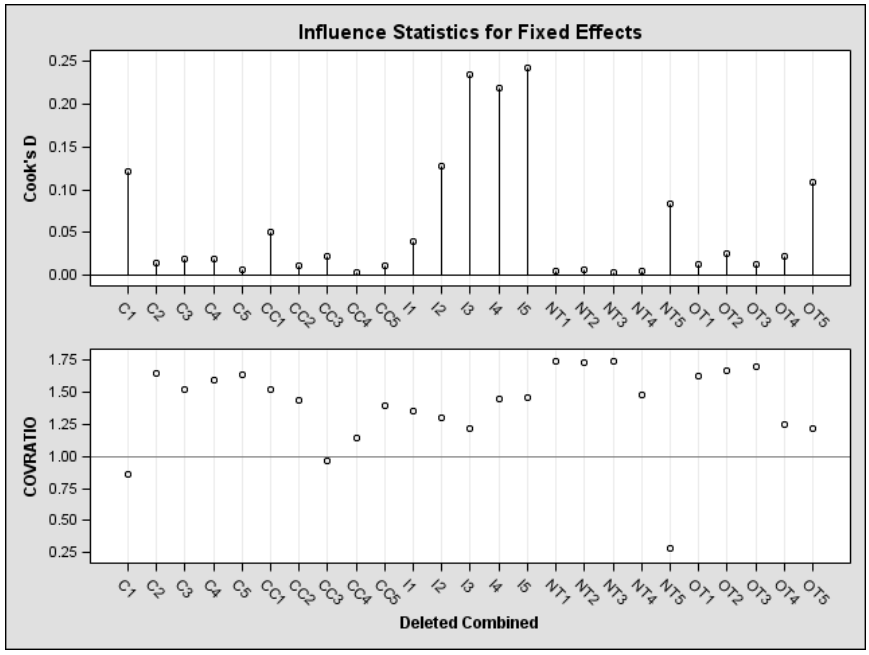
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.28 LOG NITRATE MASS LEACHED (MG) ROOT MEAN SQUARED ERROR BY COLUMN



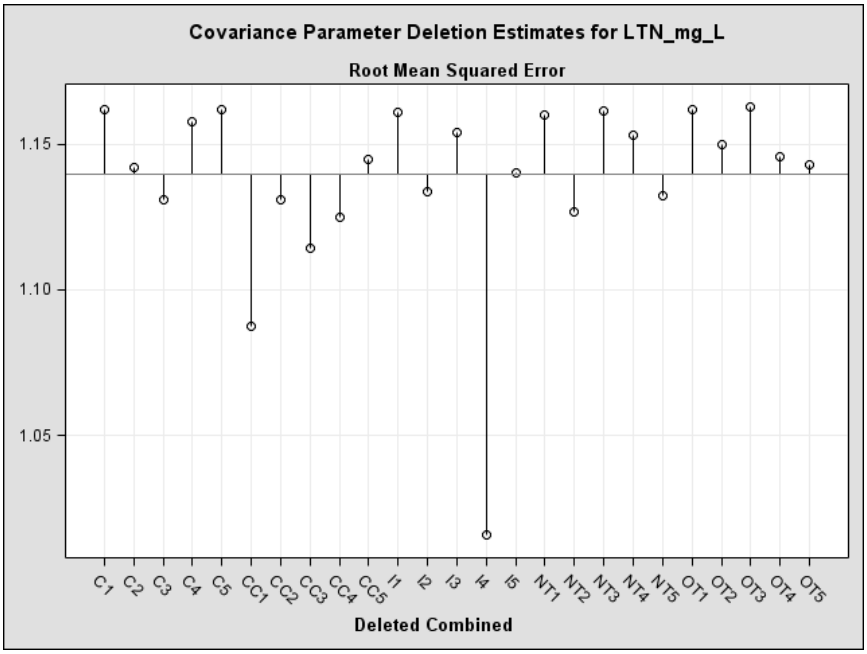
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.29 LOG NITRATE MASS LEACHED (MG) INFLUENCE STATISTICS BY COLUMN



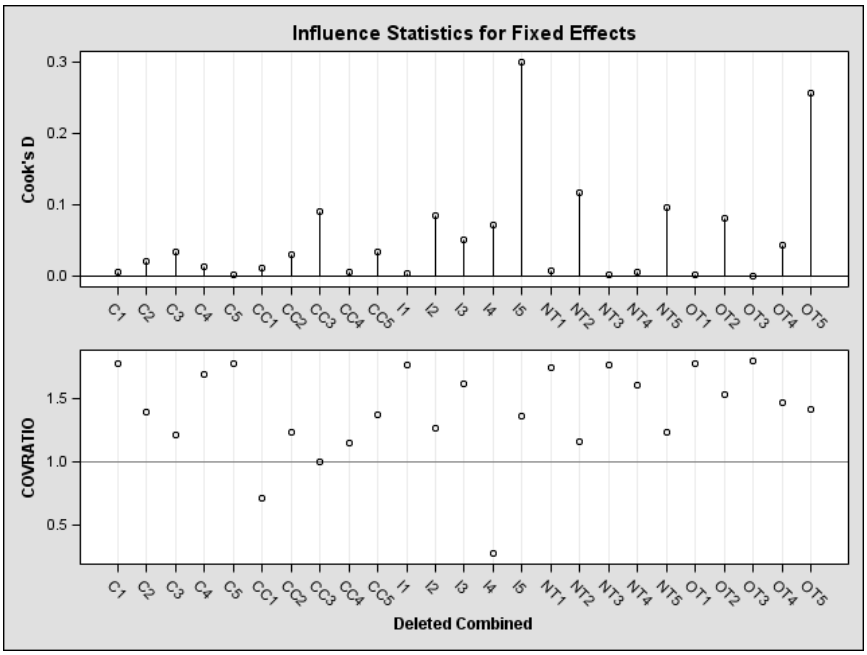
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.30 LOG TOTAL NITROGEN MASS LEACHED (MG) ROOT MEAN SQUARED ERROR BY COLUMN



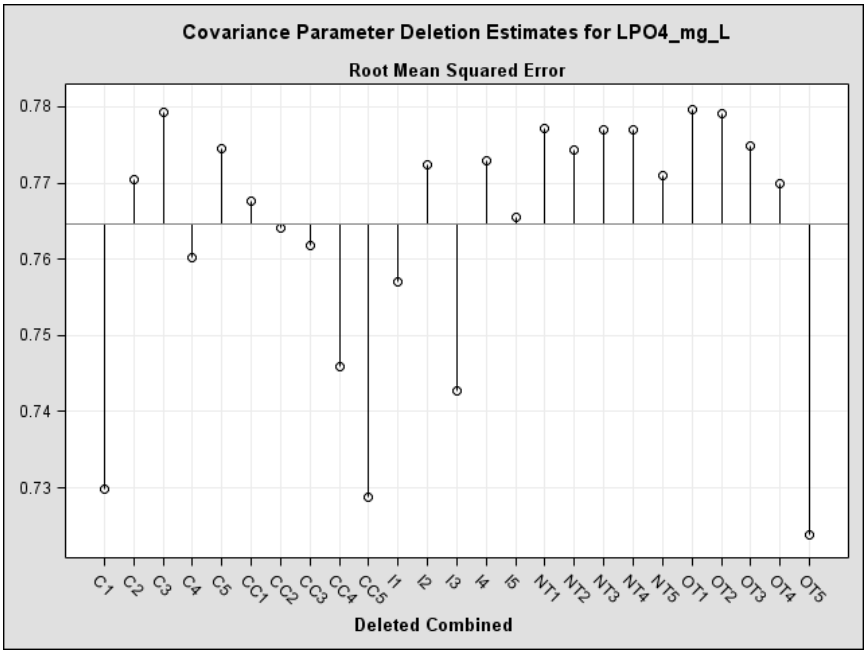
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.31 LOG TOTAL NITROGEN MASS LEACHED (MG) INFLUENCE STATISTICS BY COLUMN



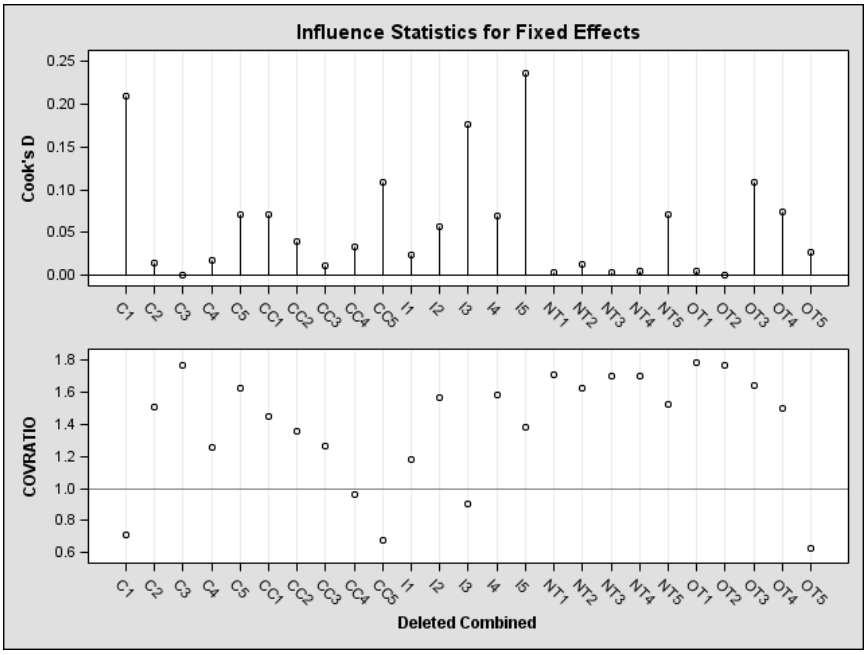
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.32 LOG ORTHOPHOSPHATE MASS LEACHED (MG) ROOT MEAN SQUARED ERROR BY COLUMN



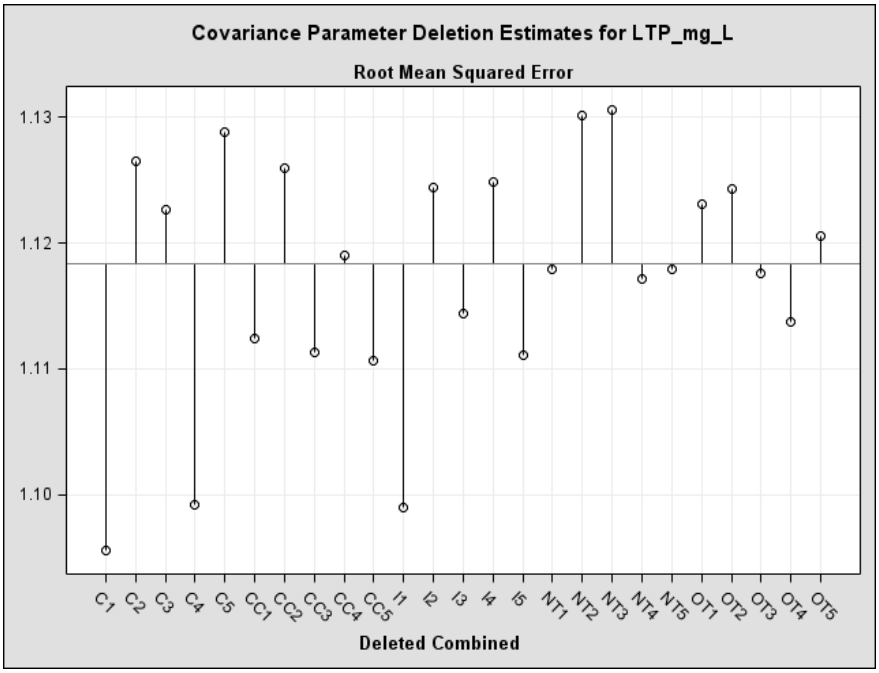
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.33 LOG ORTHOPHOSPHATE MASS LEACHED (MG) INFLUENCE STATISTICS BY COLUMN



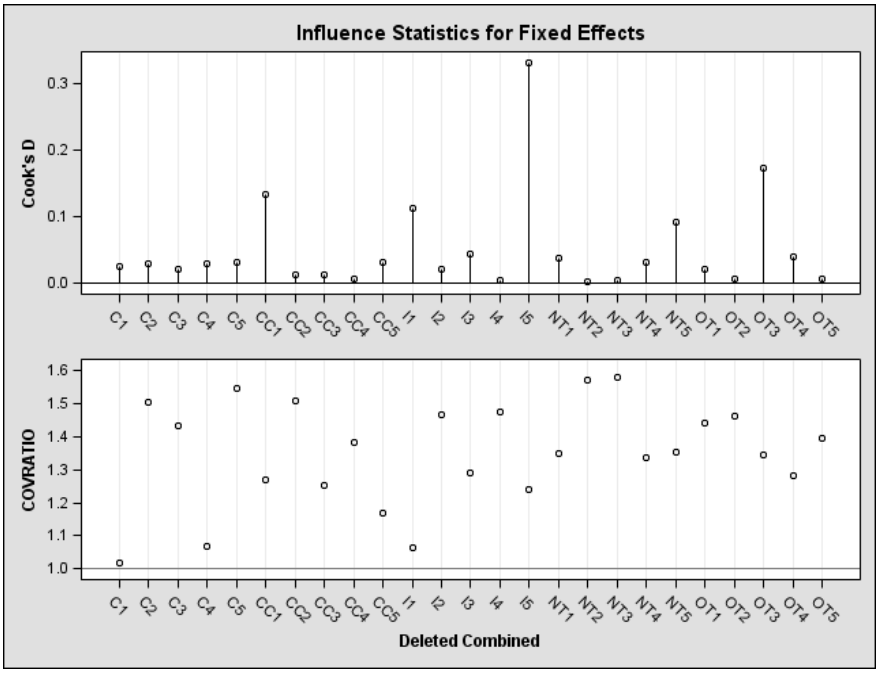
Graph is for visual reference only – text is not meant to be readable.

FIGURE C.34 LOG TOTAL PHOSPHORUS MASS LEACHED (MG) ROOT MEAN SQUARED ERROR BY COLUMN



Graph is for visual reference only – text is not meant to be readable.

FIGURE C.35 LOG TOTAL PHOSPHORUS MASS LEACHED (MG) INFLUENCE STATISTICS BY COLUMN



Graph is for visual reference only – text is not meant to be readable.

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