EVALUATION OF NATIVE AND ORNAMENTAL PLANT SPECIES FOR ESTABLISHMENT AND POLLUTANT CAPTURE IN BIORETENTION BASINS

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ABSTRACT

EVALUATION OF NATIVE AND ORNAMENTAL PLANT SPECIES FOR ESTABLISHMENT AND POLLUTANT CAPTURE IN BIORETENTION BASINS

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Stormwater runoff from urban environments can be mitigated by bioretention systems that capture stormwater and filter pollutants. Research has shown that vegetation improves the performance of these systems. Eight plant species were evaluated, four native to Michigan; *Calamagrostis canadensis, Carex stricta*, *Pycnanthemum virginianum, Rudbeckia hirta*, and four ornamental species; *Calamagrostis x acutiflora* 'Overdam', *Carex muskingumensis, Pycnanthemum muticum*, and *Rudbeckia fulgida* 'Goldsturm' for use in bioretention sites. The study coupled a column experiment to evaluate species capabilities in removing common stormwater pollutants with a field study to evaluate growth performance under bioretention conditions. In the column experiment, *Rudbeckia fulgida* 'Goldsturm' exhibited increased removal of nitrate, orthophosphate, total nitrogen, and total phosphorus over *Rudbeckia hirta*. *Calamagrostis, Carex,* and *Pycnanthemum*, native and ornamental species were similar in nutrient removal from stormwater. No differences were found between the native and ornamental species for metal uptake into plant tissue. The field study to determine percentage plant cover was conducted in 2012 and 2013 in a bioretention basin on the campus of Michigan State University East Lansing, MI. Both native and ornamental *Calamagrostis* and *Pycnanthemum* achieved 100% cover in all plots. The *Carex muskingumensis* outperformed *Carex stricta. Rudbeckia hirta* failed to reemerge in 2013 and *Rudbeckia fulgida* 'Goldsturm' was unable to survive a period of flooding. Overall, these results indicate that plant selection for performance in bioretention applications should not be based on native status.

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KEY TO SYMBOLS OR ABBREVIATIONS

BMPs	best management practices
cm	centimeter
Cu	copper
DS	diffuse source
g	gram
in	inch
L	liter
LID	low impact development
MDL	method detection limit
m	meter
mg	milligram
mL	milliliter
NPS	non-point source pollution
NH_4^+	ammonia
NO_3^-	nitrate
NO_2^-	nitrite
P	phosphorus
Pb	lead
PCBs	polychlorinated biphenyls
ppb	parts per billion
ppm	parts per million
PO_4^-	orthophosphate
PS	point source

st dev	standard deviation
TKN	total kjeldahl nitrogen
TN	total nitrogen
TP	total phosphorus
µg	microgram
Zn	zinc

CHAPTER 1: LITERATURE REVIEW

U.S. Stormwater Regulations

Pollution of waterways in the U.S. has been a concern for many years. In 1969 this problem came to the forefront with several highly publicized events: Hudson Bay bacteria levels reached levels 170 times greater than the safe limits; 41 million, a record number of fish kills were reported nationally; and surface oil on the Cuyahoga River caused a conflagration southeast of the city of Cleveland. Mounting concerns over water quality led to the establishment of the Environmental Protection Agency (EPA) in 1970. Quickly after, a succession of policies and regulations through the Clean Water Act (CWA) of 1972 were implemented to reduce the impairments of water bodies due to pollution caused by human activities. The goal of the CWA was to restore the nation's navigable waters to a condition that maintained 'chemical, physical, and biological integrity' with an end goal of making all water bodies 'fishable and swimmable'.

Initial investigations on the impairment of waterways focused on point source (PS) pollution stemming from industrial and municipal sources (USEPA, 1999). Point source pollution comes from a direct source with a discernible conveyance system into a receiving water body. Point source pollutants are typically easier to discern because they typically originate from a piped system or single property. Sources include: municipal and industrial wastewater effluent; runoff and leachate from solid waste disposal sites; runoff from industrial sites not connected to storm sewers; combined sewer overflows (CSOs); runoff and drainage from active mines and oil fields; discharges from vessels; damaged storage tanks; storage piles of chemicals; runoff from construction sites larger than 2 hectares; and finally, runoff or percolation from confined animal feeding operations (CAFOs). Through the years many of these sources were eliminated or impacts minimized. Today they represent only 10% of water body impairments (USEPA, 1999).

Present day challenges originate from non-point source pollution (NPS) and a more recently identified source known as diffuse source pollution (DS). Non-point pollution comes from a wide range of sources and is much more difficult to control due to the fact that it is typically from non-statutory points and caused by weather events (rainfall, snowmelt, etc.). Sources include: return flow from irrigated agriculture; runoff and percolation from unconfined pastures or rangelands; urban stormwater runoff from non-sewer system areas; septic tank leaks; atmospheric deposition on surface waters; runoff from abandoned mines; and land disturbance activities. Diffuse pollution is associated with non-point source pollution but is conceptual in nature and is influenced by some of the same characteristics such as atmospheric deposition and precipitation events. Diffuse pollution is always intermittent, from an extensive land area, strongly influenced by meteorological factors, and transported by land or air, making them extremely challenging if not impossible to treat at the source. The concept of diffuse pollution was developed because point source and non-point source pollution did not cover all aspects of environmental pollution. Diffuse source pollution allows for better understanding of what is actually occurring in the real world and leads to more effective treatments.

Stormwater in Michigan

The state of Michigan is known for its abundant fresh water resources. According to the *United States Geological Survey National Hydrography Dataset (USGS NHD)* there are approximately 46,000 inland lakes and freshwater reservoirs (>0.1 acres) with a total surface area of 872,109 acres. This does not include 76,439 miles of rivers and streams and 5,583,400 acres of wetlands (MIDEQ, 2012).

The Michigan Department of Environmental Quality (2012) submitted an integrated report titled WATER QUALITY AND POLLUTION CONTROL IN MICHIGAN 2012, SECTIONS 303(d), 305(b), AND 314 to the EPA, including a of list of water bodies not supporting their designated uses (DUs). The Michigan Environmental Protection Act (P.A. 451 Part 31, Ch.1) identified eight DUs from the state's water bodies that must be met between May 1st and October 31st, which included: agriculture; industrial water supply; public water supply; navigation; warm-water fishery; habitat for indigenous aquatic wildlife; partial body contact recreation; and total body contact recreation. In 2008, 4,532 causes of impairment were identified with over half due to Polychlorinated Biphenyls (PCBs) (2,966). During 2009 and 2010, 124 of the 730 public access inland lakes were monitored by the MDEQ. Twenty-five percent were found to be eutrophic (high nutrients) and 3% to be hypereutrophic (excessively high nutrients). The lakes with higher nutrient levels were typically associated with larger population centers of the Lower Peninsula.

Heavy Metal Pollution

There are many factors that have a degrading impact on water quality in urban environments (Holman-Dodds et al., 2003). Currently, there are 126 waterway pollutants on the EPA's Priority Pollution list including zinc, copper, and lead. These metals are byproducts of automobile exhaust and building decomposition (Sansalone & Teng 2004), (Davis et al. 2003). While zinc and copper are essential elements for plant and human growth, excess amounts of these pollutants are known to adversely affect human and environmental health. No levels of lead are found to be safe for human health.

Zinc is a common secondary contaminant that is limited in drinking water by the EPA (Davis et al. 2003); (Dietz & Clausen 2005). Levels have been found to be highest in stormwater runoff from parking lots and streets (Pitt et al., 1999). High zinc levels decrease the pH of waters and accumulate in soils on river banks. Zinc accumulation in soils slows the breakdown of organic matter by reducing the quantity and activity of microorganisms.

Copper in stormwater runoff is found on roadways and parking lots with moderate to high volumes of traffic. A report from the Clean Estuary Partnership (2005) reported that copper in urban runoff to San Francisco Bay comes from; vehicle brake pads, architectural copper from roofs, industrial copper use, soil erosion, fuel combustion, and vehicle fuel leaks. Copper in high doses is known to cause anemia as well as liver and kidney damage. In soil, copper contamination may reduce enzyme activity of microbes more than with other heavy metals (Wyszkowska et al., 2006).

Lead in stormwater is known to come from a range of sources. The LEAD Group Inc. (2002) found that urban buildings are a common source of lead in stormwater runoff. Leaded paint was banned from household use in 1978 but continues to be prevalent in the soil of many urban areas. Paint flakes or chalk from buildings is carried in stormwater during precipitation events. Also, lead dust freed during building demolition is moved with runoff. Automobiles are also still found to be a common source of lead in runoff from roads (Pitt et al. 1999) and parking areas (Popescu et al., 2011). Wheel weights falling from vehicles are ground into a fine powder by other traffic. Acute or chronic exposure to lead is known to severely impact human health. It has been known to cause mental lapses for adults at low dose exposure (NRCS, 2000); issues with kidney function; the synthesis of hemoglobin; and damage to the nervous system.

Excess Nutrients

Excess nutrients are a major non-point source pollutants and a continual challenge to stormwater managers. Nitrogen and phosphorus from lawn and agricultural fertilizers are the most frequently found nutrients in stormwater runoff (Kim et al., 2003). Nitrogen and phosphorus from stormwater runoff are linked to the eutrophication of water bodies. Eutrophication caused by excessive plant and algae growth in water ecosystems devastate biologic diversity by reducing available oxygen (Hsieh et al., 2007) (McDowell & Sharpley 2003). Consequently, controlling eutrophication requires reducing excess nutrient in surface waters. In regards to human health, high nitrate levels in drinking water (>10 ppm) are linked with health problems such as 'Blue Baby Syndrome'(methemoglobinemia) (Knobeloch et al., 2000). Epidemics of the dinoflagellate, *Pfiesteria piscicida*, in the eastern U.S. have been connected to excess nutrients in waters (Coyne et al., 2001). According to one study by Carpenter et al. (1998), neurological damage in people exposed to toxic chemicals produced by *Pfiesteria piscicida* has increased the public awareness of the human health issues related to water pollution.

Background of Bioretention Systems

Challenges with water quality issues have led some local and regional governments to discuss the reintroduction of biological systems for water filtration in urban areas. Bioretention basins gained appeal due to their ability to receive runoff from larger impervious surfaces, remove or retain pollutants, and provide beneficial green space in urban environments (Dietz & Clausen 2005). Bioretention basins are vegetated shallow depressions that are able to pond water from a typical depth of 15-45 centimeters and treat stormwater on site by utilizing a number of physical, chemical, and biological processes. Typical design manuals recommend a maximum of 5:1 ratio of runoff area to bioretention system. The runoff is treated in the bioretention system while allowing water to be drawn down into the soil profile within 24-48 hours. The infiltrated stormwater will enter sub-soil layers or be directed into an under drain to a storm drain system or receiving waters. The use of bioretention for stormwater management was initiated in Prince George's County, MD during the early 1990's.

Filtration & Capture of Pollutants

Bioretention systems utilize the biological processes of soils, microorganisms, and vegetation to treat stormwater runoff (Davis et al., 2003). Pollutants typically of concern are; heavy metals (lead, zinc, copper), excess nutrients (phosphorus & nitrogen), suspended solids, salts, and organic compounds (e.g. petroleum hydrocarbons).

Heavy metal pollutants typically bind to suspended solids in stormwater runoff (Davis et al. 2003). As a result, removing suspended solids from stormwater removes a large percentage of these metals bound to particles. In laboratory and field studies, lead, zinc, and copper have been removed from stormwater via infiltration through soils of bioretention systems. Studies have shown higher retention of heavy metals in laboratory studies over field experiments. Heavy metal retention was found to be (>90%) in a column study (Davis et al., 2003). Another column laboratory study found heavy metal removal efficiencies to be 94 to 97% (Sun and Davis, 2007).

Field studies, in general, have reported a greater range in heavy metal removal efficiencies. A field site was shown to have removal rates of; 80-98% lead, 64% of zinc, and 43% of copper (Davis et al., 2003). Davis (2003), Muthana (2007), Davis & Sun (2005) found that soil and mulch absorb the greatest percentage of metals from water as it passes through a bioretention system. Davis (2007) found that these metals not only are absorbed by the soil but are captured quickly, near the inlet source of the stormwater. Therefore, soil is a critical component when metal contamination of stormwater is one of the principal pollutants of concern.

Nitrogen and phosphorus present in stormwater can either be from natural or anthropogenic sources. As essential nutrients to plant growth and development their removal from stormwater can vary depending on the presence of vegetation in bioretention systems. Orthophosphate, the form of phosphorus most available to aquatic life, can be removed from stormwater through chemical adsorption onto soil particles by reacting with iron, calcium, or aluminum. Experimental results for phosphorus removal rates from stormwater have varied greatly with some results indicating the release of phosphorus from the system due to leaching. A column study by Davis (2001) found a 70% removal rate of phosphorus while in a study by Hsieh, et al., (2007) only had 41-48% phosphorus removal.

Depending on the source, nitrogen in stormwater is present in multiple forms. The most problematic is ammonia (NH_4^+) since it is known to be the most toxic to aquatic life. Nitrate (NO_3^-) and nitrite (NO_2^-) are two inorganic forms found in stormwater. Studies have shown a range of removal efficiencies for all three forms as well as for total nitrogen, measured as Total Kjeldahl nitrogen (TKN). Davis et al., (2001) found 65%- 75% removal of TKN and a 60% - 80% reduction of ammonia.

Nitrogen & Phosphorus Cycles

Nitrogen undergoes both chemical and biological reactions that affect both the movement and retention in soil. Nitrogen transformations are; mineralization, nitrification, immobilization, denitrification, and ammonia volatilization. Mineralization is the transformation of organic nitrogen to ammonium in the soil. This occurs when organic nitrogen, is slowly converted by microorganisms to ammonium, a form of nitrogen that is available for plant uptake. Mineralization is impacted by factors such as soil temperature, moisture levels, ratio of carbon to nitrogen, and compaction. A study by Zhang et al. (2011) on bioretention performance found that adding a carbon source to soil media increased nitrogen removal from stormwater. Nitrification is the conversion of ammonium to nitrate, which occurs in warm, well drained soils. Nitrate is a form of nitrogen taken up by plants, and also the form most easily leached due to its high solubility (Pitt et al. 1999) and negative ion charge, which does not bind to clay soil particles. Immobilization takes place when microorganisms use ammonium or nitrate for the decomposition of plant organic matter. This temporarily removes the nitrogen as an available source for plant uptake and occurs when carbon content is high in the soil. Denitrification takes place when soil air content is low enough to create anoxic conditions and microorganisms use oxygen in nitrate releasing nitrogen gas into the atmosphere. This typically takes two days of saturated soil to create these low oxygen conditions. Denitrification is one way that nitrogen can be removed from a bioretention system (Hatt et al. 2009). Ammonia volatilization occurs in high pH soil (>7.5) causing ammonia gas to be released from the soil. Volatilization was attributed to some of the nitrogen loss in a column study of bioretention plant species by Stuber (2012).

Different than nitrogen, phosphorus undergoes a sedimentary cycle therefore cannot be released back into the atmosphere or fixed by microorganisms in the soil. Inorganic phosphorus entering the soil is taken up by plants and converted into organic phosphorus. When plant tissue decomposes the organic phosphorus is converted by bacteria back into an inorganic form. While phosphorus is less soluble than other nutrients it can be dissolved and moved in water but is available to be bound by soil particles and taken up by plant tissue.

pH

Nitrogen and phosphorus cycles in soil are impacted by different pH levels. In acidic soils (pH <6) transformation of nitrogen through nitrification is slowed, and volatilization can increase. At a neutral pH soil microorganisms can convert ammonium to nitrate (nitrification) at a rapid rate. As pH increases ammonium NH_4^+, is converted to ammonia NH_3, which when dissolved in water is the form of nitrogen most available for algal growth in waterways.

Phosphorus is directly affected by change in soil pH levels, commonly binding with other nutrients to form less soluble compounds with limited mobility. In alkaline soils (pH >7.5) phosphate combines with calcium and magnesium. In acidic soils phosphate will also react with aluminum and iron. Phosphorus calcium compounds may become soluble again as available phosphorus is taken up by plants. Phosphorus bound to iron and aluminum is less available and to become mobile in acidic soils.

Urban Temperatures

Many bioretention facilities are designed to receive stormwater from urban environments with predominantly impervious surface areas. This impervious surface cover is known to cause increases in soil and air temperature. A study by Halverson and Heisler (1981) found monthly mean temperatures for soil in a street tree planting to be 4.1°C higher over that of a forested site at 10 cm depth. For air temperatures, Berdahl and Bretz (1997) recorded that during a hot summer day with clear skies, urban surfaces such as pavement can be 27–50°C hotter than the air in a non-urban environment. Since many temperate plants are already known to have a reduction in photosynthetic rate at 32–35°C, plant heat stress is something that must be considered for urban bioretention vegetation.

Winter & Bioretention

There have been concerns with the use of bioretention systems in climates where the winter conditions create frozen soils and snow pack for a portion of the year. There is the additional concern of excessive road salt entering bioretention systems and creating salt stress on the plants. Salt causes a range of issues for vegetation including limiting water uptake and altering the soil structure.

There have been several studies on the effects of winter conditions on bioretention performance. LeFevre et al., (2009) concluded bioretention systems designed to perform in warm climates will also function in cold climate conditions when a well-draining soil media is used. It was stated that frost type played a role in bioretention performance. Concrete frost (saturated soils at freezing soil temperature) was found to have the greatest impact on infiltration impediment. While granular frost (unsaturated soils at soil freezing temperature) was found to have little to no impact on infiltration rates. In colder climates, designers have to take into consideration how snowpack and snowmelt, temperature changes, ion exchange, water storage capacity, and pollutant retention capabilities are all affected. Roseen et al., (2009) concluded that, evaluations of bioretention systems found high levels of functionality during the winter months and that frozen filter media did not cause a reduction in performance.

Regardless of plant dormancy, vegetation has an impact on the function of a bioretention facility even during winter. Muthanna et al., (2007) in their study on snowmelt pollutant removal in bioretention facilities found that while plants were found to only have taken up 2-8% of total metals they still played a role because root zone development and regeneration. Research concluded that bioretention facilities are still performing during the winter in cold climates even under snowpack and frost conditions. (LeFevre et al., 2009) (Roseen, et al., 2009)

Bioretention Soil

Due to different environmental conditions, soil media needed for successful treatment of stormwater in a bioretention system varies. Infiltration rates for soils in The Prince George's County Bioretention Manual (2007) was ≥2.54 cm/hr. This prevents the basins from overflowing during storm events but can affect pollutant treatment. Removal of nitrogen from runoff by soils has characteristics that differ from most bioretention systems. Soils that are effective for nitrogen removal have; rich organic matter of typically of decaying vegetation, and wet to hydric soils that are poorly drained enough to create anaerobic conditions to promote denitrification (Bentrup 2008).

Carpenter and Hallam (2009) stated that a majority of regulations require a mix of 30-60% sand, 20-40% compost, and 20-30% topsoil for bioretention basins and rain gardens. To test this ratio's treatment efficiency, Carpenter evaluated two full scale bioretention basins, one with a soil mix of 20% compost, 30% topsoil, 50% sand, and the other with a mix of 80% sand, 20% topsoil. The conclusions drawn were that the 80% sand 20% topsoil mix exhibited improved treatment efficiency over the other mix for larger storms.

Since critical function of bioretention basins is infiltration, the capacity of soils for capturing stormwater and not allowing it to escape is a key factor of system success (Davis, 2003). One characteristic of infiltration rates for soils is bulk density, the weight of soil for a given volume. It is a measure of porosity and specific gravity of the soil's organic and inorganic minerals (Holman-Dodds et al., 2003). Bulk density can vary greatly depending on previous land use. A lower bulk density is found in native and undisturbed soils as compared to levels in urban environments (Dierks, 2011). A low bulk density soil creates a diverse and healthy soil/plant community as well as relieves ecological degradation associated with compaction. Soil health and infiltration capacity are key components of vegetation establishment and bioretention function.

Phytoremediation

Phytoremediation utilizes vegetation to create a low-cost remediation (Raskin & Ensley 2000) processes using; rhizofiltration, phytostabilization, phytovolitization, and phytoextraction. Rhizofiltration is the use of the plant roots and microorganisms within the rhizosphere to absorb and precipitate pollutants, typically metals. Phytostabilization is the immobilization of pollutants by reducing solubility or bioavailability to the food chain. Phytovolatilization is the uptake by a plant of a pollutant which is then altered and is typically released through evaporation or vaporization. Phytoextraction is the accumulation and concentration of pollutants within the plant above ground tissue which is subsequently harvested and removed from the system. Plant species known for phytoremediation capabilities can be utilized in bioretention applications.

Vegetation Characteristics

Plant structure and growth characteristics play an integral part in vegetative stormwater management systems. Roots and root hairs have been studied for their effects in phytoremediation (Suza et al., 2008) (Agostini et al. 2013). Roots are the conduit by which certain pollutants are taken up and either retained in the plant tissue or in some cases broken down into less harmful compounds. The roots can play another role in pollutant removal by their relationship with microbes and mycorrhizal colonies through root exudates (Suza, et al., 2008). This relationship can increase growth of these microbes, which in turn, may break down certain pollutants through biodegredation or can increase the plant's ability to take up pollutants using phytoextraction.

Bioretention Vegetation Studies

Vegetation is known to remove pollutants from contaminated water through multiple biological processes (Lesage et al., 2007) (Cheng et al., 2002) (Yeh et al., 2009). However, there have been limited studies on plant species that improve pollutant removal efficiency from stormwater. Two studies conducted by Read (2008) & (2009) reported on plant effectiveness in stormwater pollutant removal. The 2008 study found that while plant size played a role in nitrogen and phosphorus removal efficiency for some plants, removal per unit plant mass depended on the species. The study concluded that root architecture played an important role in nutrient removal as well as impacting soil physiochemistry and microbial activity in the soil. Building upon the 2008 study, Read et al., (2009) deduced that the most important contributors to nitrogen (N) & phosphorous (P) removal from stormwater were length of longest root, root depth, total root length, and root mass. However, it could not be determined by the study as to which trait was the most influential since these characteristics typically correlate with above ground shoot growth characteristics. The study also concluded that plants with fine root structure such as Carex were found to have the best performance in regards to nutrient removal but were not as adept at improving water infiltration as plants with thicker root systems. It was concluded that for optimal performance efficiency, a bioretention facility may require a range of plant species with varying root structures.

Plant Stresses

The microclimate of a bioretention system can create a range of physiological stresses upon plants. Vegetation in bioretention basins undergo periods of soil saturation during rainfall events, as well as, extended periods of drought during dry periods. This is described by Braendle and Crawford (1999) as an “amphibian lifestyle”, where plants experience both flooding and arid environmental conditions. Plant species have a range of tolerances when it comes to flooding and hypoxic (dissolved oxygen is below the level necessary to sustain regular cellular respiration)or anoxic conditions (cellular respiration that is undergone in the absence of oxygen). Flooding tolerance can vary greatly from several hours to multiple weeks depending on species, the organs directly affected, stage of development, and environmental conditions (Vartapetian & Jackson 1997). It is common that plants for bioretention systems come from emergent wetland species which are adapted to periods of hypoxia and anoxia. In addition, Armstrong et al., (2009) found that pollution can cause damage to plants typically well adapted to flooding conditions. In their study on *Phragmities australis*, oils from contaminated flood water displaced surface gas films on the submerged plant organs. These oils also penetrated the leaf structure, sheaths and nodes which interfered with diffusion gas flows that are critical to sustaining roots and rhizomes while undergoing inundation. This indicates that even plants well suited to flooding conditions may have additional stress caused by stormwater pollution.

While much attention is paid to the ability of bioretention vegetation to tolerate water logged conditions, in most locations the plants undergo drought stress during the summer months. The engineered designs of bioretention systems focus on rapid water infiltration to prevent stormwater overflow outside of the basin. Most bioretention specifications typically call for no standing water 24-48 hours after a storm. The limit of soil water storage capacity reduces water availability for vegetation during the summer when transpiration rates will typically be at their highest. Carpenter and Hallam (2009) found that the infiltration rate of a well maintained bioretention basin was 5.1 cm/hr, which is substantially higher than the specified bioretention basin rate of 1.34 cm/hr. While high permeability of the soil mixes increase infiltration capabilities of a bioretention basin, this also has an adverse effect on the water holding capacity of the soil during periods of insufficient water.

Vegetation Rhizosphere & Microorganisms

In the study on 'Nutrient Retention in Vegetated and Nonvegetated Bioretention Mesocosms' Lucas and Greenway (2009) found a substantial increase in total phosphorous and nitrogen retention in the system over what was accounted for by the vegetation biomass. The researchers concluded that the useful life of a bioretention system could be significantly extended when the rhizosphere is well developed with mature vegetation. The plant rhizosphere improves the retention of pollutants from stormwater. The term rhizosphere is used to describe the plant root interface with the surrounding external environment. This zone surrounding the roots of plants and their surface contact with soil and soil organisms is the critical zone where contaminants can be bound and rhizodegredation processes occur (Hinsinger et al. 2009); (Susarla et al., 2002); (Lin & Mendelssohn 1998).Vegetation promotes conditions for microorgamisms, fungi, and the soil media to retain more total nitrogen & total phosphorus than would otherwise be possible. Soils with beneficial biota promote establishing healthy plant communities may be a key component to improved bioretention systems function. In Impacts of Biota on Bioretention Cell Function during Establishment in the Midwest, Greene (2008) found that "the interaction of plant roots and soil macrofauna over one growing season improved several aspects of bioretention cell function". The greatest increase in saturated hydraulic conductivity was in the treatment that included both plants and macrofauna. The presence of vegetation reduced ponding effects and increased water storage

Native vs. Ornamental Plants

Plant selection for bioretention applications must to take into account multiple factors, such as vigor, growth habit, function, and aesthetics (BES 2007). Vigor takes into account a plants ability to survive and thrive within the conditions presented within the bioretention facility. Growth habits of a plant are typically sizing such as mature height and spread. Function is the plants purpose within the bioretention system and will take into account if a plant is meant to filter or retain certain pollutants and provide weed suppression. Finally, aesthetic quality is the public perception of how the overall planting looks during different seasons. Public appeal is important to their acceptance as a common stormwater management tool.

The common practice for plant selection in bioretention basins is to utilize native plant species. Bioretention design and construction manuals recommended the use of native vegetation in bioretention basins or rain garden stormwater management systems. Sources commonly cite that; “Native plants don’t require fertilizer, have good root systems, and are better at utilizing the water and nutrients available in their native soils than non-native species.” http://www.groundwater.org/ta/raingardens.html. However, there has been limited research that has been able to study the veracity of these statements for use in bioretention systems. In the actual construction and maintenance of bioretention basins some practitioners are finding that this may be more of a challenge than previously thought. The Bureau of Environmental Services (BES) Report (2007) stated issues arose with the use of native plants. The city of Portland found that the use of native plants can actually limit the diversity of plants that can be used when the system require plants that are; low growing, primarily evergreen, and have drought and saturated water level tolerances. It was determined that “a mix of native and ornamental plant species was ideal in meeting specific site conditions.”

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CHAPTER 2: POLLUTANT REMOVAL BY NATIVE AND ORNAMENTAL PLANT SPECIES FROM SYNTHETIC STORMWATER UNDER CONTROLLED CONDITIONS

INTRODUCTION

Currently bioretention systems are being implemented as a best management practice (BMP) to reduce pollutant loads from stormwater in urban environments (Dietz & Clausen 2005). Typical stormwater pollutants of concern are; heavy metals (lead, zinc, copper), nutrients (phosphorus & nitrogen), suspended solids, salts, and organic compounds (e.g. petroleum hydrocarbons). Bioretention systems utilize soils, organic matter, and vegetation to treat runoff water (Davis et al. 2003a).

Vegetation is known to remove pollutants from polluted water through multiple biological processes (Lesage et al., 2007) (Cheng et al., 2002) (Yeh et al., 2009). However, there have been limited studies on plant species that improve pollutant removal efficiency from stormwater. Two studies conducted by Read et al. (2008) (2010) reported on plant effectiveness in stormwater pollutant removal. The 2008 study reported that, while plant size played a role in nitrogen and phosphorus removal efficiency for some plants, removal per unit plant mass depended on the species. The study concluded that root architecture played an important role in nutrient removal as well as impacting soil physiochemistry and microbial activity in the soil. Building upon the 2008 study, Read et al., (2010) deduced that the most important contributors to nitrogen (N) & phosphorous (P) removal from stormwater were length of longest root, root depth, total root length, and root mass. However, it could not be determined by the study as to which trait was the most influential since these characteristics typically correlate with above ground shoot growth characteristics. The study also concluded that plants species with fine root structure such as *Carex* were found to have the best performance in regards to nutrient removal but were not as adept at improving water infiltration as plants with thicker root systems. It was concluded that for optimal performance efficiency, a bioretention facility may require a range of plant species with varying root structures.

While several studies have reported that vegetation plays a critical role in pollutant removal efficiency (Read et al. 2008; Henderson et al., 2007; Zhang et al. 2010), there has not been a complete consensus on the impact plants have in bioretention function. Read et al. (2008) stated that the “choice of plant species may have marked effects on biofiltration effectiveness.” Pham et al. (2008) conducted a study to find plants that demonstrated an ability to maintain infiltration rates and minimize nitrogen outflows. Pham et al. therefore concluded that careful soil media selection allows for bioretention designers to “choose from a relatively wide range of plant species and still achieve effective nutrient removal.”

The selection of plant for bioretention applications must to take into account multiple factors, such as vigor, growth habit, function, and aesthetics (BES 2007). Vigor takes into account a plants ability to survive and thrive within the conditions presented within the bioretention facility. Growth habits of a plant are typically sizing such as mature height and spread. Function is the plants purpose within the bioretention system and will take into account if a plant is meant to filter or retain certain pollutants and provide weed suppression. Finally, aesthetic quality is the public perception of how the overall planting looks during different seasons. Public appeal is important to their acceptance as a common stormwater management tool.

The common practice for plant selection in bioretention basins is to utilize native plant species. In a review of 30 rain garden manuals created through 15 states, every manual recommended the use of native vegetation in bioretention basins or rain garden stormwater management systems. Sources commonly cite that; “Native plants don’t require fertilizer, have good root systems, and are better at utilizing the water and nutrients available in their native soils than non-native species.” http://www.groundwater.org/ta/raingardens.html. However, there has been limited research that has studied the veracity of these statements for use in bioretention systems. In the actual construction and maintenance of bioretention basins some practitioners are finding that this may be more of a challenge than previously assumed. The Bureau of Environmental Services (BES) Report (2007) stated issues arose with the use of only native plants. The city of Portland found that the use of only native plants can actually limit the diversity of plants that can be used when these stormwater systems require plants that are; low growing, primarily evergreen, and have drought and saturated water level tolerances. It was determined that “a mix of native and ornamental plant species was ideal in meeting specific site conditions.”

Bioretention systems are currently being installed throughout the Great Lakes region as a Low Impact Development (LID) practice that reduces the effect of stormwater runoff on natural waterway ecosystems. Extensive research on these systems has shown definitively that vegetation provides benefits such as, increased filtration capabilities and improved retention of many common water runoff pollutants. Vegetation also plays an important role in the perception of stormwater management systems by providing a visual aesthetic. Organizations have created numerous lists of plants for use within stormwater management systems. However while many different plant species are being used throughout the region, limited research links contaminant retention capabilities with plant growth and performance within a bioretention system.

MATERIALS & METHODS

This study compares performance of native and ornamental plant species for pollutant removal from synthetic stormwater. Eight plant species; *Calamagrostis canadensis*, *Calamagrostis x acutiflora* 'Overdam', *Carex stricta*, *Carex muskingumensis, Pycnanthemum virginianum*, *Pycnanthemum muticum*, *Rudbeckia hirta*, and *Rudbeckia fulgida* 'Goldsturm', were evaluated under controlled greenhouse conditions. A column study was conducted to evaluate the capability of each plant species to capture known pollutants from a synthetic stormwater. The objective is to determine if there is a difference in performance between native and ornamental plant species for bioretention function in stormwater treatment.

Native Plant Selection

Four native plant species were selected: two herbaceous perennials (*Rudbeckia* & *Pycnanthemum*), one grass (*Calamagrostis*), and sedge (*Carex*). The plant species selected using criteria listed:

1. Perennial, non-woody stemmed plants.
2. Species proven to exist in the USDA Planting Hardiness Zone 5.
3. Defined as a species for bioretention by the Southeastern Michigan Council of Governments (SEMCOG) *Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers* (SEMCOG) 2008) plant list, Appendix C.
4. Evaluated in a phytoremediation study previous to the start of this research project (Table 2.1).

TABLE 2.1 PHYTOREMEDIATION STUDIES OF PLANT SPECIES

Native Plant Species	Phytoremediation Study
Calamagrostis canadensis (Bluejoint Grass)	Fate of Naphthalene in Laboratory-Scale Bioretention Cells: Implications for Sustainable Stormwater Management (Lefevre et al. 2012)
Carex stricta (Tussock Sedge)	Greenhouse and Field Assessment of Phytoremediation for Petroleum Contaminants in a Riparian Zone (Euliss et al. 2008)
Pycnanthemum virginianum (Virginia Mountain Mint)	An Ecologically Engineered System for Remediation of Arsenic-Contaminated Water: Plant Species for Northwest (Rofkar, 2010*)*
Rudbeckia hirta (Black-eyed Susan)	Analysis of Arsenic Uptake by Plant Species Selected for Growth in Northwest Ohio by Inductively Coupled Plasma – Optical Emission Spectroscopy (Rofkar et al., 2007)

Ornamental Plant Selection

For each of the native plant species, an ornamental plant species counterpart was selected for comparison. These ornamental plant species were selected using the following criteria;

1. A non-native species from the native plant genera was selected.
2. Perennial non-woody stemmed plants.
3. Species proven to establish in the USDA Planting Hardiness Zone 5.
4. Display a distinct ornamental quality differing from the native plants (Table 2.2.

TABLE 2.2 ORNAMENTAL QUALITY OF PLANT SPECIES

Ornamental Plant Species	Ornamental Quality
Calamagrostis x acutiflora 'Overdam' (Feather Reed Grass)	"'Overdam' is a hybrid (*C. arundinacea* x *C. epigejos*) feather reed grass cultivar which is valued for its variegated foliage, early bloom, vertical lines and ability to grow in wet soils." **Missouri Botanical Garden**, http://www.missouribotanicalgarden.org/gardens-gardening/your-garden/plant-finder/plant-details/kc/n750/calamagrostis-x-acutiflora-overdam.aspx
Carex muskingumensis (Palm Sedge)	"Dense, clump-forming sedge which is grown for its foliage effect. Produces rigid, erect stems to 20" tall with 8" long, pointed, grass-like, light green leaves radiating from the stem tops. Commonly called palm sedge since the leaves somewhat superficially resemble miniature palm fronds." **Missouri Botanical Garden**, http://www.missouribotanicalgarden.org/gardens-gardening/your-garden/plant-finder/plant-details/kc/r390/carex-muskingumensis.aspx
Pycnanthemum muticum (Clustered Mountainmint)	"Silvery bracts highlight dense clusters of small pinkish flowers from summer to early fall. The flowers are an extraordinarily good source of nectar for smaller types of butterflies. The leaves smell strongly of spearmint when they are crushed." **American Beauties Native Plants** http://www.abnativeplants.com/index.cfm?fuseaction=plants.plantdetail&plant_id=72
Rudbeckia fulgida 'Goldsturm' (Goldsturm Blackeyed Susan)	"This coneflower cultivar is an upright, rhizomatous, clump-forming perennial which typically grows 2-3' tall. Features large, daisy-like flowers (3-4" across) with deep yellow rays and dark brownish-black center disks." **Missouri Botanical Garden,** http://www.missouribotanicalgarden.org/gardens-gardening/your-garden/plant-finder/plant-details/kc/i780/rudbeckia-fulgida-var.-sullivantii-goldsturm.aspx

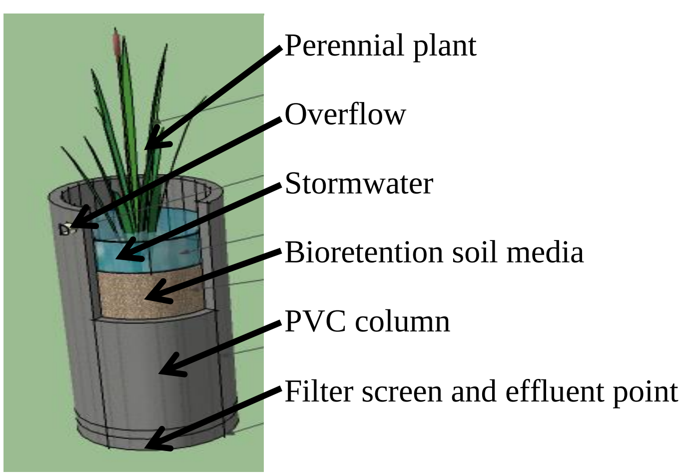
Experimental Design

The column study was designed to evaluate the removal and retention of pollutants from a synthetic stormwater. It was conducted as a completely randomized design experiment at the Plant Research Greenhouse, Michigan State University East Lansing, MI from 2-13-13 to 4-1-13. It consisted of 8 stormwater testing events, once per week. Sampling of the plant tissue and soil was taken at the beginning and end of the column study to determine the uptake of pollutants by plants and that retained by the soil.

Column Construction

Forty-five columns were constructed (40 cm tall with an interior diameter of 14.3 cm) from PVC schedule 40 pipes (Figure 2.1). The bottoms of the columns were covered with cheese cloth and 0.635 cm fiberglass screen lining, and secured in place using Oatey 8 oz. PVC Cement with 4, 20 cm Plastic Cable Zip Ties. All columns were cleaned with a bleach solution and scoured with sandpaper to reduce the chance of water channels being created between the column and the soil. Each column was rinsed with RO water and allowed to air dry.

FIGURE 2.1 COLUMN COMPONENTS



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

Plant Sources & Sizes

Plants were obtained for the study as follows: *Pycnanthemum virginianum* (38 cell plug), *Pycnanthemum muticum* (38 cell plug), *Calamagrostis canadensis* (32 square pots), came from Cardno JFNew Native Plant Nursery, Walkerton, Indiana; *Calamagrostis x acutiflora* 'Overdam' (32 square pots) was from Chief Mountain Farms, Port Deposit, MD; Carex stricta (32 square pots), *Carex muskingumensis* (32 square pots), *Rudbeckia hirta* (32 square pots), *Rudbeckia fulgita 'Goldsturm'* (32 square pots), were from Wildtype Native Plant Nursery, Mason, MI. Dimensions of pots are as follows; 32 square pots are 6.25 x 6.25 x 7.75 cm; the 38s are round-tapered plugs with open bottoms 5.71 x 5.71 x 12.7 cm, 50 cell plugs are 4.52 x 4.52 x 6.30 cm. Plants were placed into columns with bioretention media on October 4^{th} 2012 and allowed to establish before testing.

Column Soil and Plant Installation

The soil used for column study was taken from a bioretention site at Michigan State University. Before installation into the columns, the soil media was thoroughly mixed using a sanitized shovel to remove any buildup of settled particles and to avoid any potential layering within the columns. Columns were filled to a level 7.5 cm below the top to allow for water ponding, simulating bioretention conditions. Five columns were filled with bioretention soil only to serve as the non-vegetative control columns for the study.

One plant was placed in each column October 4th 2012, with 5 replicates of each of the species for a total of 40 plants. After receiving the plants from the nurseries, growth media was removed from the roots (Figure 2.2). Approximately 10 cm of the bioretention soil media was placed into the column around the plant root system, gradually building up to the predetermined soil level (Figure 2.3). The columns were placed in randomized order within the greenhouse benches (Figure 2.4).

FIGURE 2.2 COLUMN PLANTING STEPS (LEFT TO RIGHT): MATERIALS FOR PLANTING, REMOVAL OF SOIL FROM ROOTS, FILLING OF COLUMN

FIGURE 2.3 COLUMNS AFTER PLANTING

FIGURE 2.4 GREENHOUSE SETUP

Lighting Temperature & Watering

The column study used supplemental light to provide a 16 hour day using 8, 400 watt high pressure sodium bulbs in fixtures manufactured by P.L. Lighting Systems. A light bar was installed to record light levels in micromoles every 12 seconds for the duration of the experiment (Figure 2.5).

FIGURE 2.5 SUPPLEMENTAL LIGHTING AND LIGHT BAR

Day and night temperatures were regulated to keep the greenhouse at 24°C for the duration of the study.

Before the start of the stormwater testing all the columns received 925 mL of reverse osmosis (RO) water 2 times per week. During the study the columns received 300 mL of water 3-4 days prior to next stormwater testing.

Synthetic Stormwater

This study used a synthetic stormwater manufactured by using common pollutants (Table 2.3) typically found in urban environments (Stuber, 2012) (Read et al., 2008) (Figure 2.6).

TABLE 2.3 SYNTHETIC STORMWATER CONCENTRATIONS

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	100	0.79
Total Dissolved Phosphorus				*0.79*
Ammonia	Ammonium Chloride	8.20	100	0.82
Nitrogen Oxides	Potassium Nitrate	1.36	1000	1.36
Org. Nitrogen	Nicotinic Acid	3.47	1000	3.47
Total Dissolved Nitrogen				*5.65*
Copper	Copper Sulphate	1.30	1000	1.3
Lead	Lead Nitrate	1.50	100	0.15
Zinc	Zinc Chloride	2.40	1000	2.4
Total Metals				3.85

FIGURE 2.6 SYNTHETIC STORMWATER PRIOR TO TREATMENT

All of the columns received 925mL of synthetic stormwater, which simulates a 2” ponding depth for 5:1 ratio of bioretention to drainage area according to SEMCOG *Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers* (2008). Stormwater testing took place weekly for a total of 8 applications. The effluent water leached from the columns was collected in 5 quart, Mix n Measure plastic pails and the volume recorded.

Sample Preparation

Water samples were analyzed four hours after stormwater application to the columns. Each water sample was filtered using a 0.45 µm syringe filter prior to analysis. Two mL of each sample was digested using potassium persulfate ($K_2S_2O_8$) in accordance with Standard Methods for the Examination of Water and Wastewater for analysis of total nitrogen and total phosphorus content. Ten mL of each sample was also acidified using nitric acid (HNO_3) to <2.0 pH, and stored in a freezer at -18 °C until analysis.

Ammonium

For each sample 100 µL was added to a Costar 96-Well Microplate Assay. Forty µL of reagent ammonium cynurate was added to each well followed by 40 µL of reagent ammonium salicylate. A plate reader was used with a filter set at 630nm to determine ammonium concentration content.

Nitrate, Phosphate, Total Nitrogen, Total Phosphorus, Lead, Zinc, & Copper

A Dionex ICS-5000 utilized ion chromatography (IC) was used to analyze samples. Three milliliters of sample was placed in polystyrene vials and injected by AS-AP Autosampler. Nitrate, phosphate, total nitrogen, and total phosphorus were separated using an IonPac AS22 Carbonate Eluent Anion-Exchange Column. Lead, zinc, and copper were separated using an IonPac CS5A Transition Metal Column.

Cation & 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. 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. Anion quantification was performed using linear point to point calibration of 10 calibration levels, 6 lower level calibration levels and 4 high range calibration levels.

Method Detection Limits (MDLs)

For each pollutant of interest, a Method Detection Limit was determined to reduce the chance of presenting concentrations at low levels of instrument noise as actual values. While not used for accuracy or precision of the actual quantity, the MDL does allow for a 99 percent confidence that the observed value was greater than zero (Table 2.4). As described by the EPA 40 CFR part-136 the MDL was calculated.

Table 2.4 STORMWATER METHOD DETECTION LIMITS

Method Detection Limits	
Target Parameter	MDL MDL (mg/L)
Nitrate	0.025
Ammonia	0.015
Total Nitrogen	0.2
Orthophosphate	0.09
Total phosphate	0.4
Copper	0.1
Zinc	0.1

ICS-5000 Program

The minimum and maximum pressure limit on the ICS-5000 was 200 and 2900 psi. A 100 ml volume of epure water flush was utilized prior to each sample. Sample injection into the column was 1 mL for anions. Flow rate during anion analysis was 1.2 ml/min.

Plant Tissue Testing

Prior to the start of the study, three randomly selected plants from each species were analyzed for: TKN, P, Zn, Cu, Pb. These plants were prepared using the techniques established in <u>Plant analysis handbook II: A practical sampling, preparation, analysis, and interpretation guide</u> (Mills, H., & Jones, J., 1997). Washing consisted of removing soil surrounding the roots by hand (Figure 2.7). Retention of the fine roots was done by running the soil through using a #10 screen. After removing most of the soil, samples were finished by gently washing the surface of the plant material with reverse osmosis (RO) water. The plant samples were divided between shoots/leaves and roots, which then had fresh & dried weights recorded. These samples were dried at 60°C in an oven for 54 hours and ground using a Wiley mill with a 60 mesh screen. A minimum of two grams dry ground weight was required for tissue analysis. Samples were analyzed by the Missouri University Soil Testing Laboratory; Columbia, MO. Analysis was conducted for: TKN, P, Zn, Cu, Pb. At the conclusion of the column study all plants were harvested and evaluated following the previously described procedure.

FIGURE 2.7 POST STUDY PLANT HARVEST

Soil Samples

Soil samples were taken from each column at the end of the study. The was homogenized to create a representative mix. A total of 45 soil samples were evaluated in the Soil and Plant Nutrient Laboratory East Lansing, MI for; TKN, ammonium, nitrate, P, Cu, Zn. Soil samples were also tested for Pb at the Missouri University Soil Testing Laboratory; Columbia, MO.

Water Samples

Water samples were analyzed as duplicates for each run for each pollutant. Quality assessment in the Anion system used a linear point to point calibration of 10 calibration levels, 6 lower level calibration levels and 4 high range calibration levels. A standard calibration curve was run 3 times; 2/7/13, 3/3/13, and 3/15/13. During the 8 sample runs, 3 standards were also analyzed to compare with standard calibration curves

Statistical Analysis

Statistical analysis was performed using SAS 9.3 (2011). Statistical evaluation of data was conducted for effluent concentrations for each of the water quality parameters; water use, nitrate, ammonium, orthophosphate, total nitrogen, total phosphorus, copper, lead, and zinc. Plant tissue content and soil was analyzed for; change in mass, percent nitrogen, percent phosphorus, copper, zinc, and lead content. Data normality was tested using the Shapiro-Wilk test, after which data was analyzed using analysis of variance (ANOVA). Upon finding differences between groups the data was then analyzed using Tukey's HSD Post-hoc test with significance between data indicated for the p-value of less than 0.05. After which variables were tested using Pearson's Correlation Coefficient.

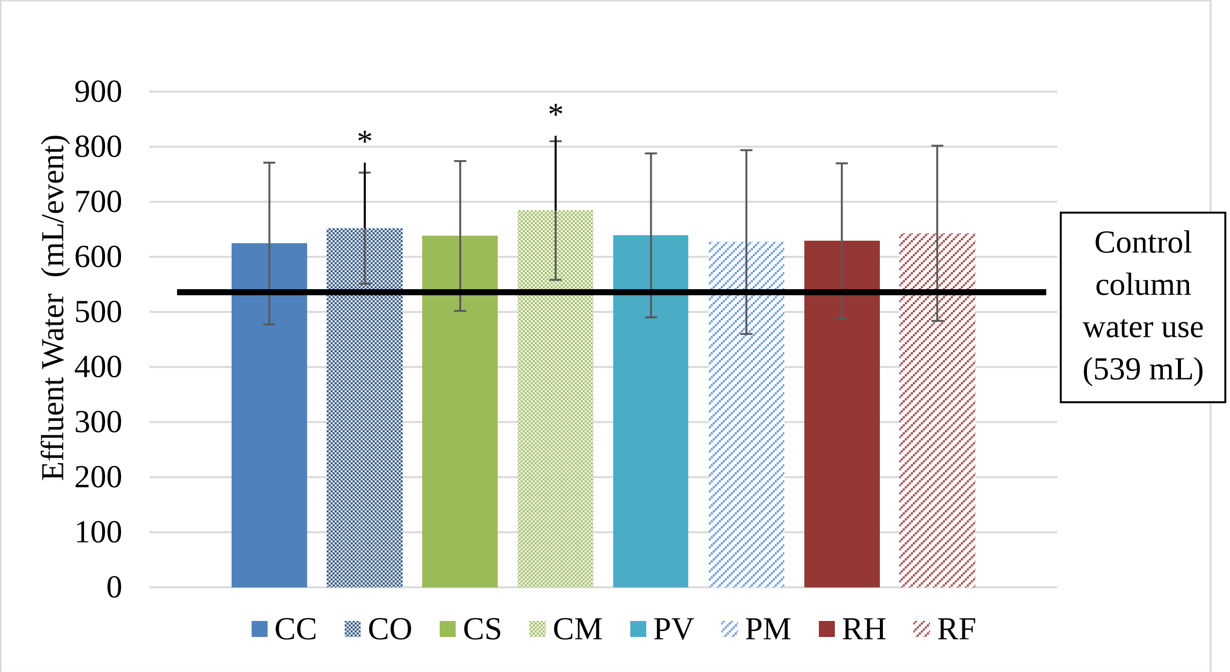
RESULTS

Water Use

Effluent water was collected and volume measured (mL) for each column to determine water use following each stormwater treatment.

No differences were found between the four genera. *Carex muskingumensis* and *Calamagrostis x acutiflora* 'Overdam' were the only species to exhibit differences in water use from the control column. The highest water usage (Figure 2.8) was by, *Carex muskingumensis* (684.25 [±126.15] mL/run) followed by; *Calamagrostis x acutiflora* 'Overdam' (652.0 [±144.27] mL/run), *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(642.63 [±159.28] mL/run), *Pycnanthemum virginianum* (639.13 [±149.65] mL/run), *Carex stricta* (638 [±136.83] mL/run), *Rudbeckia hirta* (628.88 [±141.27] mL/run), *Pycnanthemum muticum* (626.88 [±167.29] mL/run, *Calamagrostis canadensis* (624.25 [±147.50] mL/run), and the control column (539.75 [±151.65] mL/run).

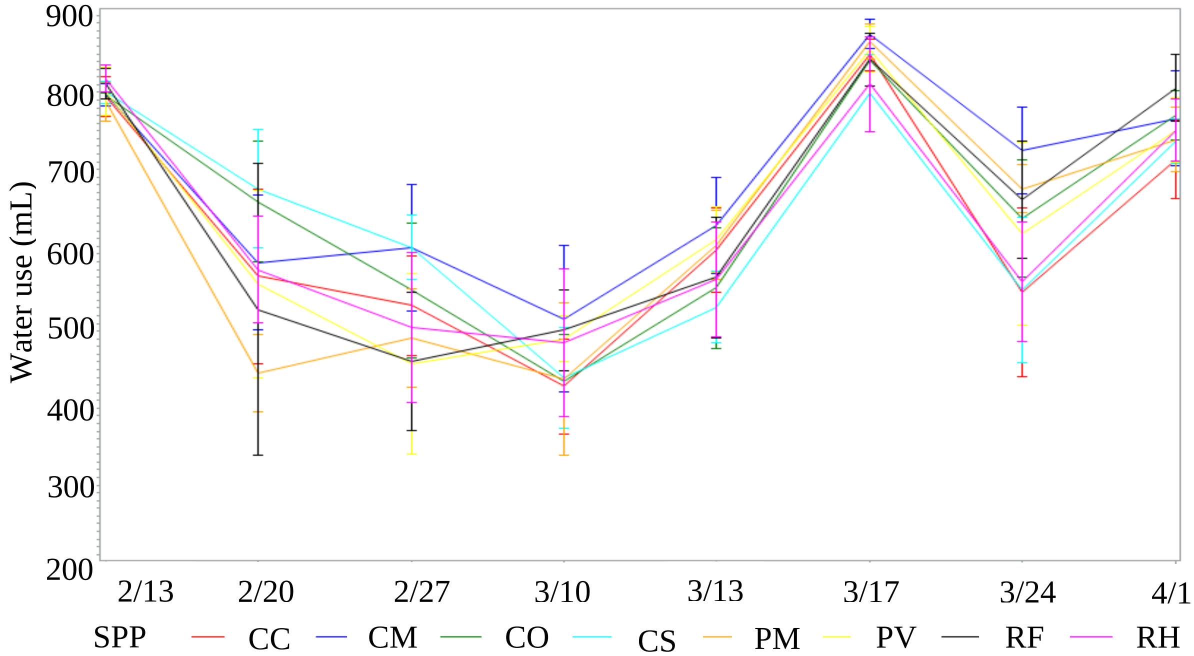
FIGURE 2.8 WATER USE BY SPECIES



Data represent means ± SD. (*) Indicates significant difference from the control column (p<.05).
CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm'

There were variations in water use evident between dates as shown in Figure 2.9.

FIGURE 2.9 TREATMENT WATER USE BY DATE



Data represent means ± SD. CC-Calamagrostis canadensis, CM- Carex muskingumensis, CO-Calamagrostis x acutiflora 'Overdam', *CS-Carex stricta, PM-Pycnanthemum muticum, PV-Pycnanthemum virginianum, RF-Rudbeckia fulgida, RH-Rudbeckia hirta*

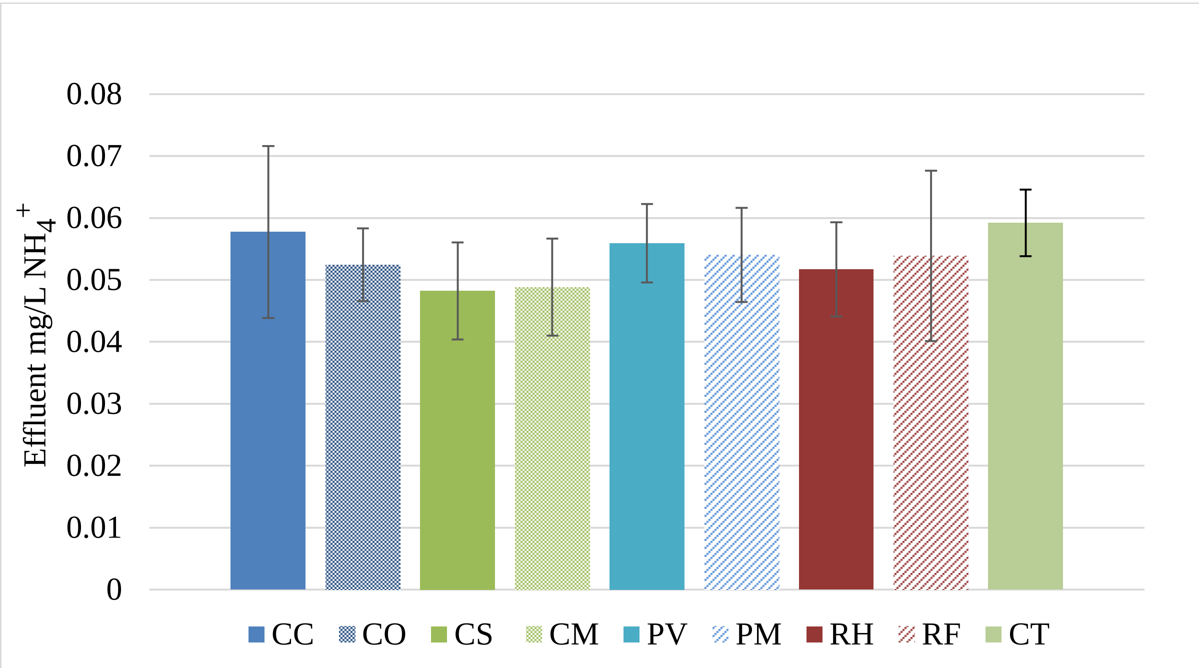
Effluent

Leachate from each column was collected and analyzed as described in materials and methods to determine mass and concentrations of ammonium, nitrate, orthophosphate, total nitrogen, and total phosphorus. Data recorded was the concentration (mg/L) of nutrient and the mass (mg) of nutrient in the effluent. Mass was determined by the concentration of the nutrient multiplied by the volume of collected stormwater.

Ammonium (NH_4^+)

The mass of ammonium detected in the effluent were low for all of the columns (Figure 2.10). No significant differences in effluent ammonium mass were found. The lowest mean effluent mass was found in *Carex stricta* (.0482 [±0.004] mg/event), followed by; *Carex* *muskingumensis* (.0488 [±0.007] mg/event), *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(.0517 [±0.013] mg/event), *Calamagrostis x acutiflora* 'Overdam' (.0524 [±0.005] mg/event), *Rudbeckia hirta* (.0538 [±0.001] mg/event), *Pycnanthemum muticum* (.0540 [±0.007] mg/event), *Pycnanthemum virginianum* (.0559 [±0.006] mg/event), *Calamagrostis canadensis* (.0577 [±0.013] mg/event), and the Control Column (.0591 [±0.005] mg/event).

FIGURE 2.10 MASS OF NH_4^+ WITHIN EFFLUENT BY SPECIES



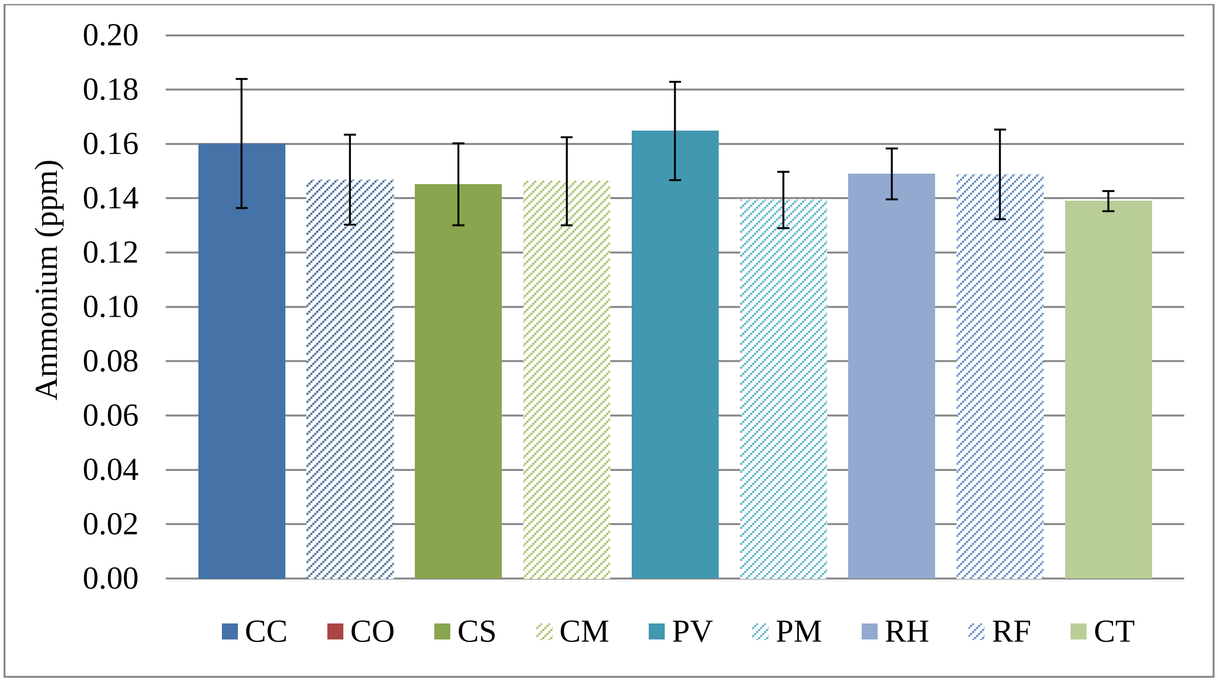
Data represent means ± SD. (*) Indicates significant difference from the control column (p<.05). CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum,* RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm', CT-Control column

The ammonium concentrations (ppm) in effluent (Figure 2.11) were correlated with the mass effluent (mg/event) (Table 2.5). Since mass and concentration are significantly correlated; the remaining analysis of dates and correlation to water use, were completed using mass of ammonium leached.

TABLE 2.5 AMMONIUM MASS & CONCENTRATION CORRELATION

Pearson Correlation Coefficients, N = 40	
Prob > |r| under H0: Rho=0	
	NH_4^+ Conc
NH_4^+ Mass	0.62828
	<.0001

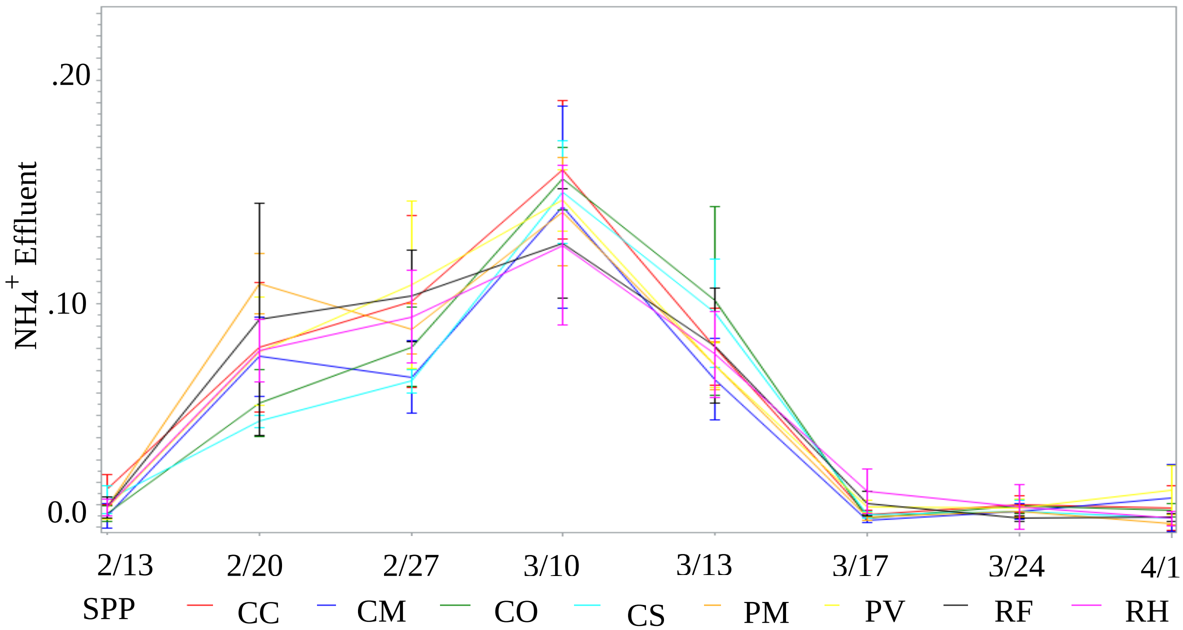
FIGURE 2.11 CONCENTRATION OF NH_4^+ EFFLUENT BY SPECIES



Data represent means ± SD. CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* ‘Overdam’, CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* ‘Goldsturm’, CT-Control column

There were variations between the treatment dates for ammonium effluent as shown in Figure 2.12. A steady increase in the mass of ammonium in the effluent was exhibited by all species and control until 3-10-13.

FIGURE 2.12 MASS OF NH_4^+ WITHIN EFFLUENT BY DATE



Data represent means ± SD. CC-*Calamagrostis canadensis,* CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta,* CM- *Carex muskingumensis,* PV-*Pycnanthemum virginianum,* PM-*Pycnanthemum muticum,* RH-*Rudbeckia hirta,* RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm'

A negative correlation was found between water use and ammonium effluent (Table 2.6). The mass of nitrogen leaching as ammonium was lower with higher water use volumes.

TABLE 2.6 CORRELATION BETWEEN WATER USE AND AMMONIUM MASS

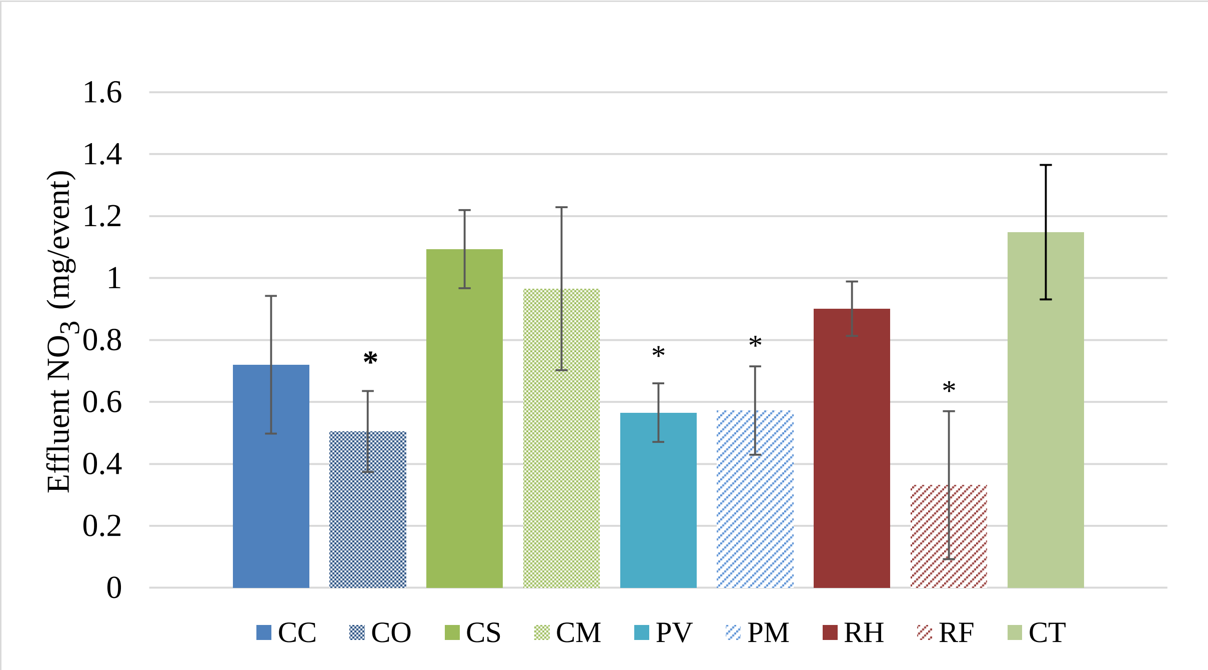
Pearson Correlation Coefficients, N = 40	
Prob > |r| under H0: Rho=0	
	H_2O Use
NH_4^+	-0.78596
	<.0001

Nitrate (NO_3^-)

Pycnanthemum muticum, Pycnanthemum virginianum, Calamagrostis x acutiflora 'Overdam', *and Rudbeckia fulgida var. sullivantii* 'Goldsturm' exhibited significant differences from the control column for nitrate in the effluent (Figure 2.13). The lowest effluent mass was found in *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(0.331 [±0.238] mg/event), followed by; *Calamagrostis x acutiflora* 'Overdam' (0.504 [±0.130] mg/event), *Pycnanthemum virginianum* (0.564 [±0.094] mg/event), *Pycnanthemum muticum* 0.572 [±0.142] mg/event), *Calamagrostis canadensis* (0.719 [±0.222] mg/event), *Rudbeckia hirta* (0.901 [±0.088] mg/event), *Carex muskingumensis* (0.965 [±0.263] mg/event), *Carex stricta* at (1.09 [±0.126] mg/event), and the Control Column (1.14 [±0.217] mg/event).

The effluent nitrate mass leached from columns was not different between ornamental and native plant species for *Calamagrostis, Carex*, or *Pycnanthemum*. *Rudbeckia* species displayed a difference in mass, with greater leached nitrate detected in the effluent from native *Rudbeckia hirta* column (P-value 0.001).

FIGURE 2.13 MASS OF NO_3^- WITHIN EFFLUENT BY SPECIES



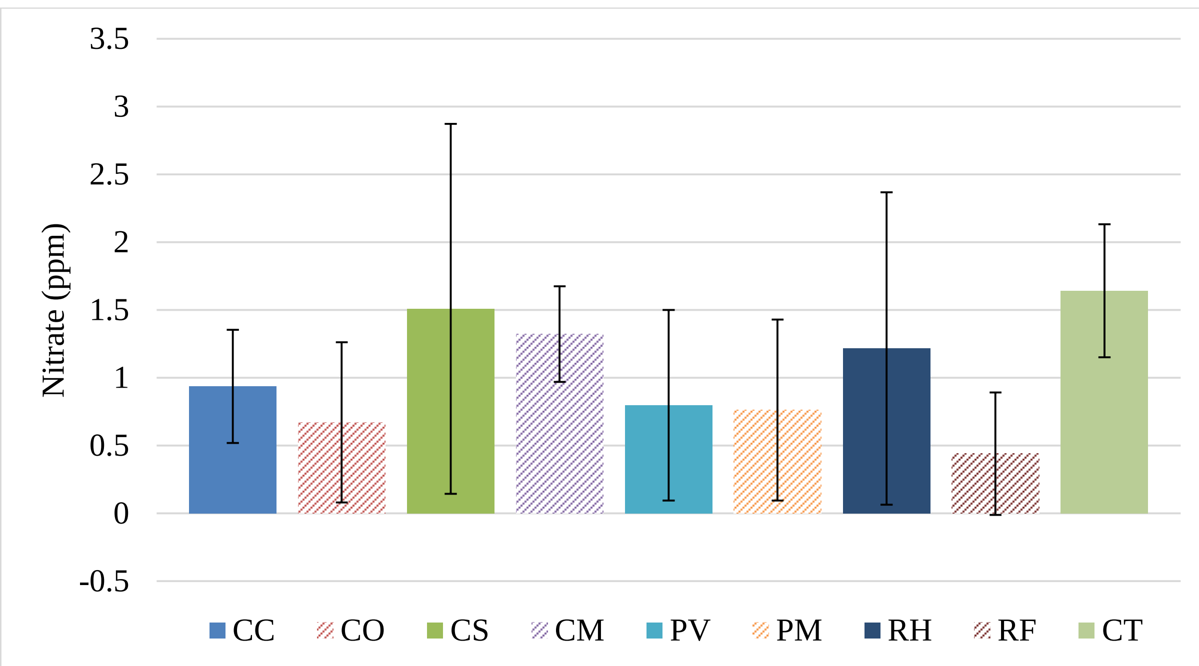
Data represent means ± SD. (*) Indicates significant difference from the control column (p<.05).
CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm' CT-Control column

The nitrate concentrations (ppm) in effluent (Figure 2.14) were correlated with the mass effluent (mg/event) (Table 2.7). Since mass and concentration are significantly correlated; the remaining analysis of dates and correlation to water use were completed using mass of nitrate leached.

Table 2.7 NITRATE MASS & CONCENTRATION CORRELATION

Pearson Correlation Coefficients, N = 40	
Prob > |r| under H0: Rho=0	
	NO_3^- Conc
NO_3^- Mass	0.64365
	<.0001

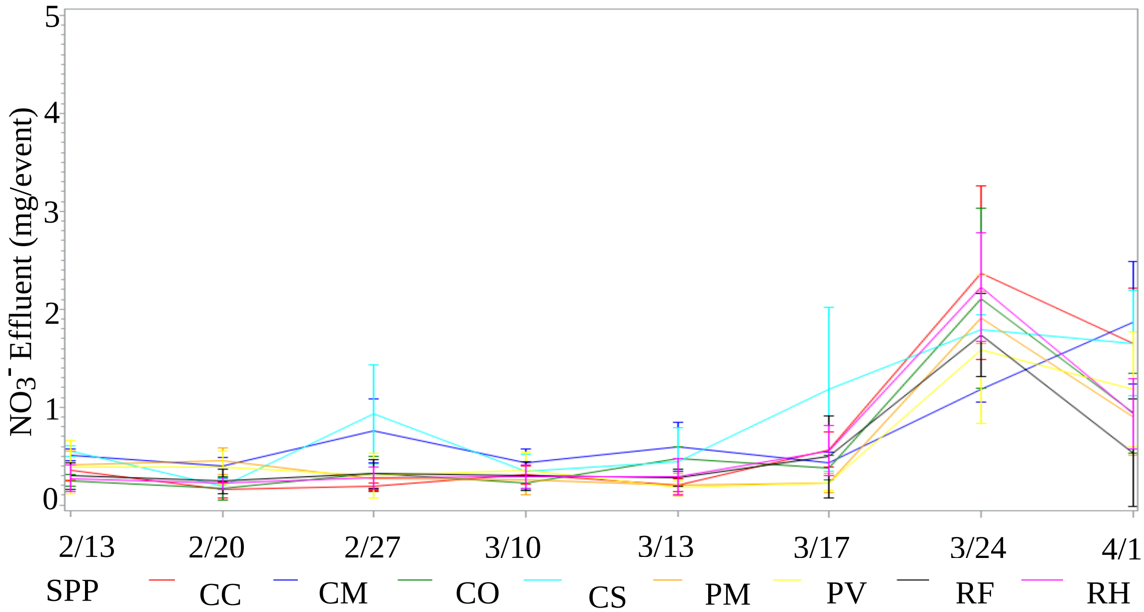
FIGURE 2.14 CONCENTRATION OF NO_3^- EFFLUENT BY SPECIES



Data represent means ± SD. CC-*Calamagrostis canadensis*, CM- *Carex muskingumensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, PM-*Pycnanthemum muticum*, PV-*Pycnanthemum virginianum*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm', RH-*Rudbeckia hirta*, CT-Control

There were variations between the treatment dates for nitrate effluent as shown (Figure 2.15). The effluent variations on 3/24 and 4/1 treatment dates was due to a spiking of stormwater nitrate from 1.4 (ppm/run) to 3.2 (ppm/run).

FIGURE 2.15 MASS OF NO_3^- IN EFFLUENT BY DATE



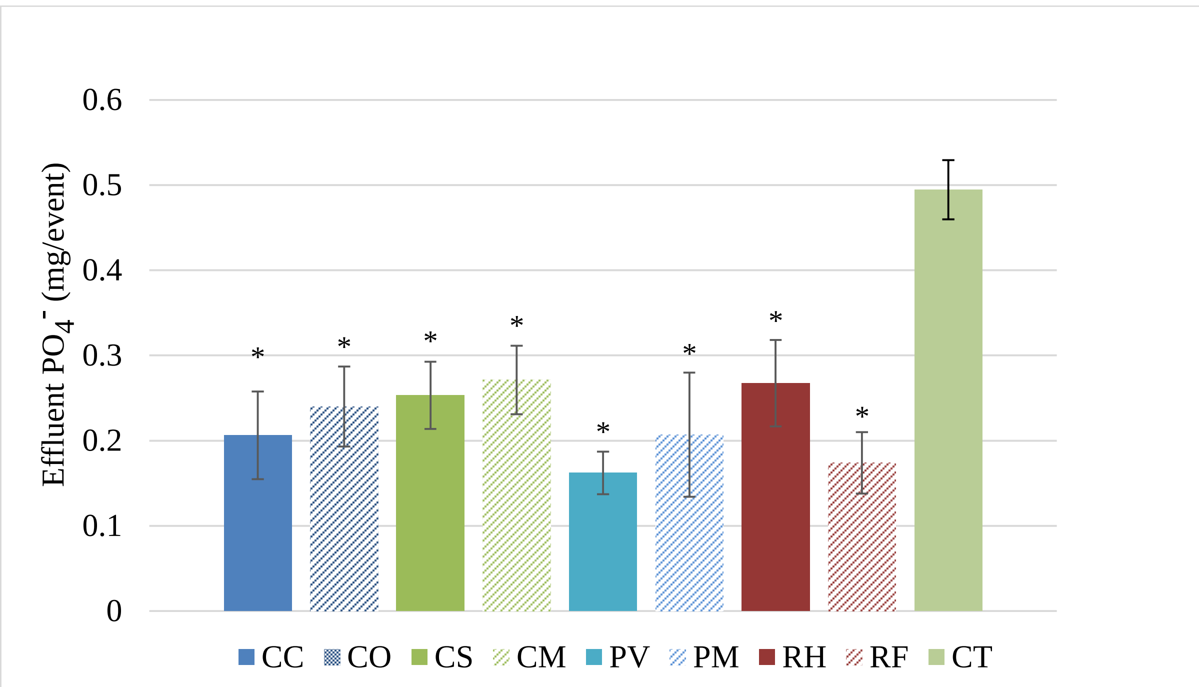
Data represent means ± SD. CC-Calamagrostis canadensis, CM- Carex muskingumensis, CO-Calamagrostis x acutiflora 'Overdam', *CS-Carex stricta, PM-Pycnanthemum muticum, PV-Pycnanthemum virginianum, RF-Rudbeckia fulgida, RH-Rudbeckia hirta*

Orthophosphate

All species exhibited a difference in orthophosphate mass from the control column. The lowest mean effluent concentration (Figure 2.16) was found in *Pycnanthemum virginianum* (0.162 [±0.025] mg/event), followed by; *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(0.173 [±.035] mg/event), *Calamagrostis canadensis* (0.206 [±0.051] mg/event), *Pycnanthemum muticum* (0.207 [±0.072] mg/event), *Calamagrostis x acutiflora* 'Overdam' (0.240 [±0.047] mg/event), *Carex stricta* at (0.253 [±0.039] mg/event), *Rudbeckia hirta* (0.267 [±0.051] mg/event), *Carex muskingumensis* (0.271 [±0.040] mg/event), and the Control Column (0.494 [±0.034] mg/event).

The effluent orthophosphate leached from columns was not different between the ornamental and native plant species for *Calamagrostis*, *Carex*, or *Pycnanthemum*. *Rudbeckia* species showed a difference in mass, with greater leached orthophosphate detected in the native *Rudbeckia hirta* effluent (P-value 0.022).

FIGURE 2.16 MASS OF ORTHOPHOAPHATE WITHIN EFFLUENT BY SPECIES



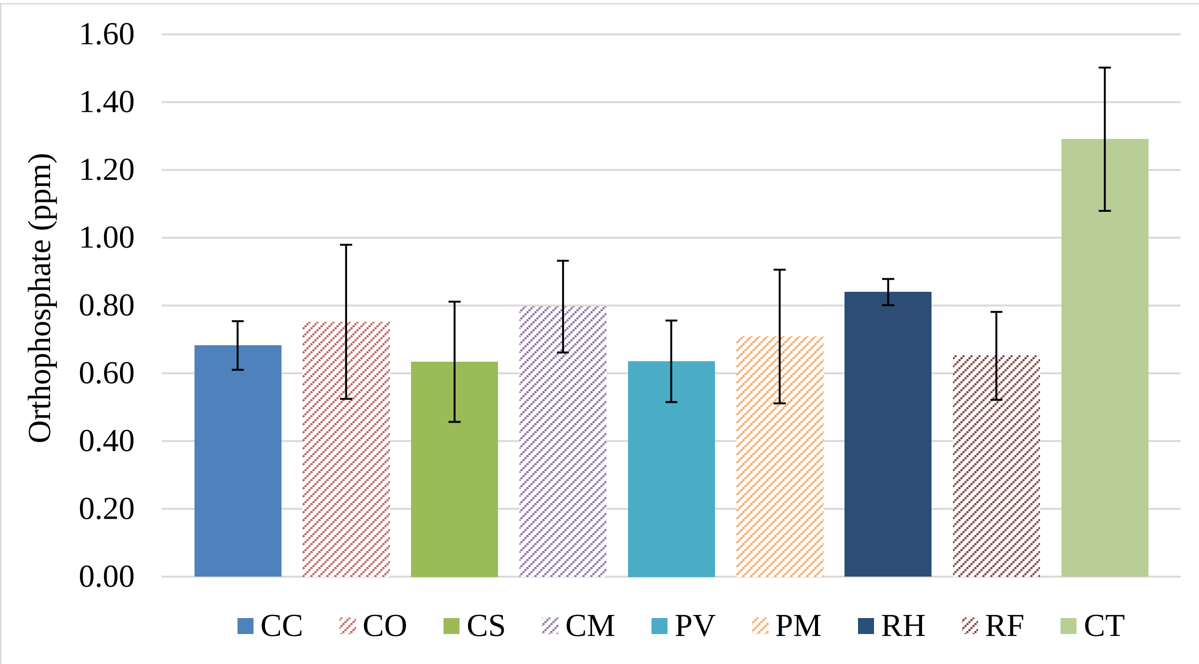
Data represent means ± SD. (*) Indicates significant difference from the control column (p<.05).
CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm', CT-Control column

The orthophosphate concentrations (ppm) in effluent results (Figure 2.17) were correlated with the mass effluent (mg/event) (Table 2.8). Since mass and concentration are significantly correlated; the remaining analysis of dates and correlation to water use were completed using mass of orthophosphate leached.

TABLE 2.8 ORTHOPHOSPHATE MASS & CONCENTRATION CORRELATION

Pearson Correlation Coefficients, N = 40	
Prob > |r| under H0: Rho=0	
	PO_4^- Conc
PO_4^- Mass	0.71365
	<.0131

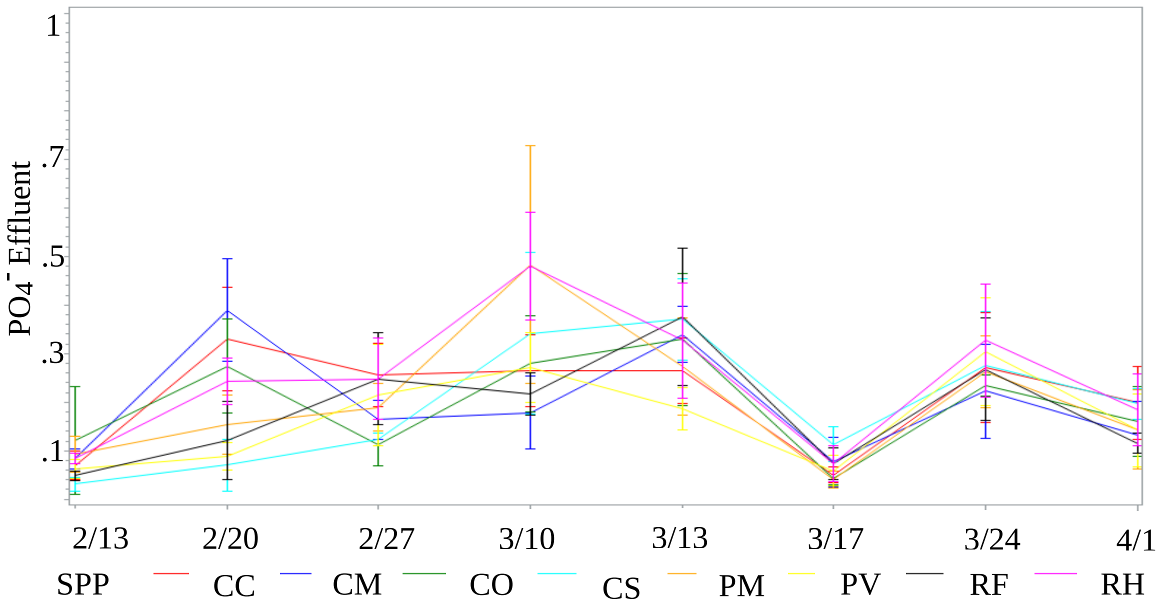
FIGURE 2.17 CONCENTRATION OF PO_4^- EFFLUENT BY SPECIES



Data represent means ± SD. CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* ‘Overdam’, CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum,* PM-*Pycnanthemum muticum,* RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* ‘Goldsturm’, CT-Control column

There were variations between the treatment dates for orthophosphate effluent as shown (Figure 2.18).

FIGURE 2.18 MASS OF PO_4^- WITHIN EFFLUENT BY DATE



Data represent means ± SD. CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* ‘Overdam’, CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* ‘Goldsturm’

A negative correlation existed between water use and orthophosphate effluent (Table 2.9). The mass of phosphorus leaching as orthophosphate was lower with higher water use volumes.

TABLE 2.9 CORRELATION BETWEEN WATER USE AND ORTHOPOSPHATE

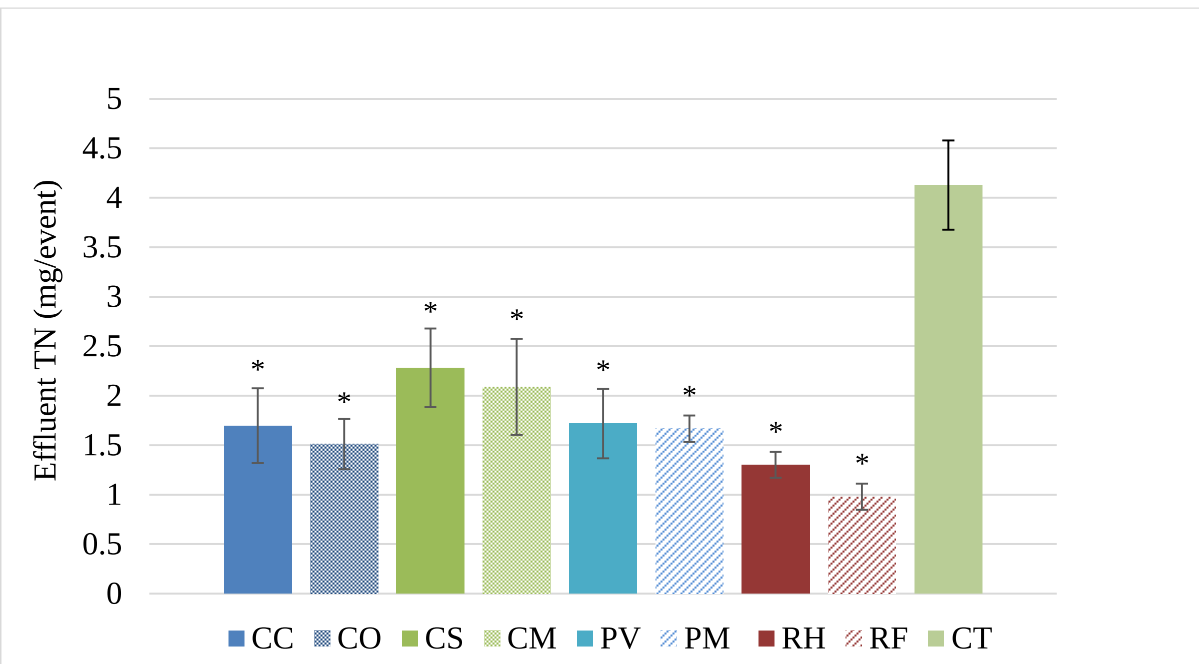
Pearson Correlation Coefficients, N = 40	
Prob > |r| under H0: Rho=0	
	H2O Use
PO_4^-	-0.48854
	<.0001

Total Nitrogen (TN)

All plant species were found to have different mass effluent from the control column for total nitrogen (Figure 2.19). The lowest mean effluent concentration was found in *Rudbeckia* *fulgida var. sullivantii* 'Goldsturm'(0.978 [± 0.132] mg/event), followed by; *Rudbeckia hirta* (1.29 [±0.130] mg/event), *Calamagrostis x acutiflora* 'Overdam' (1.51 [±0.253] mg/event), *Pycnanthemum muticum* (1.66 [±0.135] mg/event), *Calamagrostis canadensis* (1.69 [±0.378] mg/event), *Pycnanthemum virginianum* (1.71 [±0.351] mg/event), *Carex muskingumensis* (2.08 [±0.486] mg/event), *Carex stricta* at (2.28 [±0.398] mg/event), and the Control Column (4.12 [±0.450] mg/event).

The effluent total nitrogen leached from columns was not different when comparing the ornamental and native plant species for *Calamagrostis*, *Carex*, or *Pycnanthemum*. *Rudbeckia* species showed a difference in masses, with greater leached total nitrogen detected in the native, *Rudbeckia hirta* effluent (P-value 0.022).

FIGURE 2.19 MASS OF TN WITHIN EFFLUENT BY SPECIES



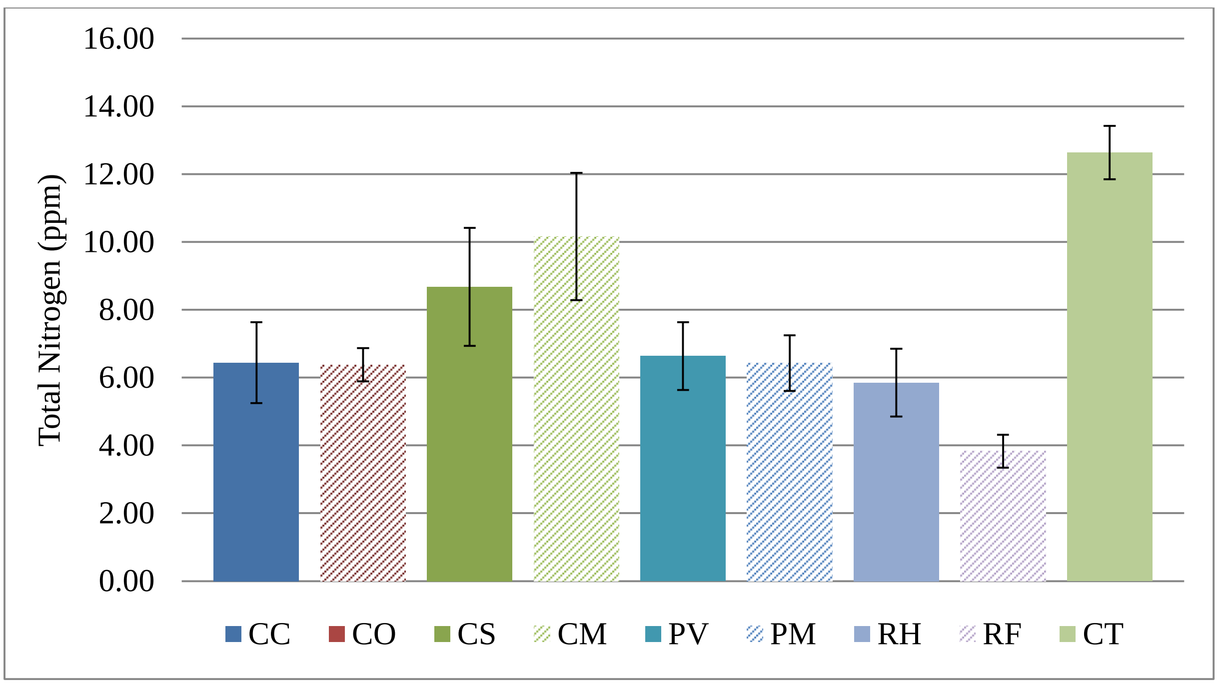
Data represent means ± SD. (*) Indicates significant difference from the control column (p<.05). CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm', CT-Control column

The total nitrogen concentrations (ppm) in effluent (Figure 2.20) were correlated with the mass effluent (mg/event) (Table 10). Since mass and concentration are significantly correlated; the remaining analysis of dates was completed using mass of total nitrogen leached.

TABLE 2.10 TOTAL NITROGEN MASS & CONCENTRATION CORRELATION

Pearson Correlation Coefficients, N = 40	
Prob > |r| under H0: Rho=0	
	TN Conc
TN Mass	0.57656
	<.0001

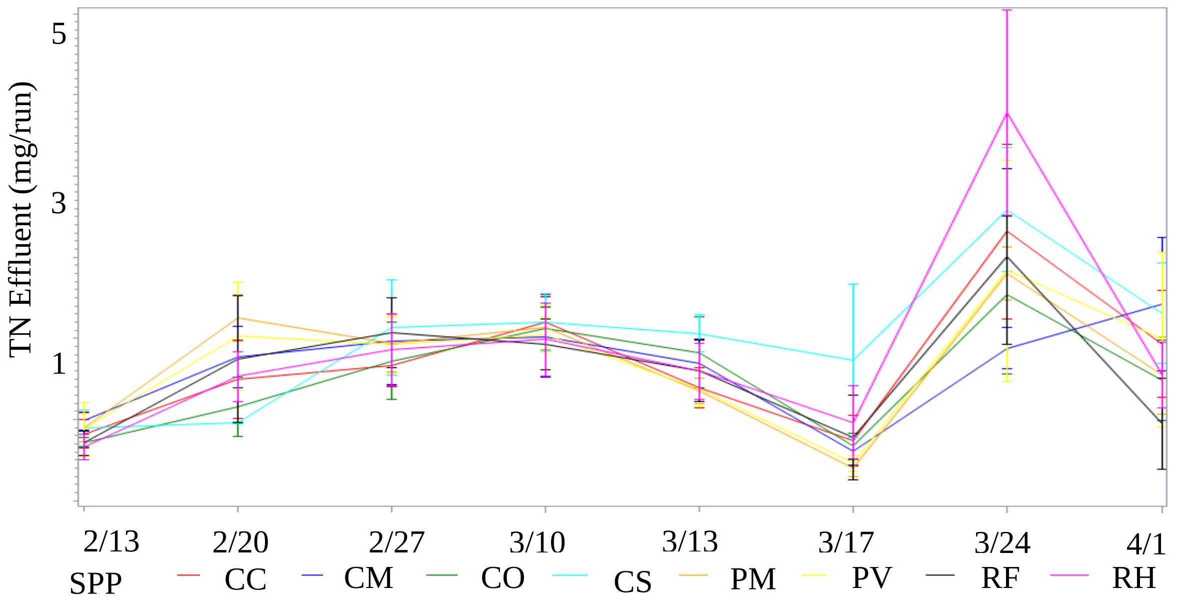
FIGURE 2.20 CONCENTRATION OF TN EFFLUENT BY SPECIES



Data represent means ± SD. CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm', CT-Control column

There were variations between the treatment dates for total nitrogen effluent as shown (Figure 2.21). The effluent variation on 3/24 and 4/1 treatment dates was due to the spiking of stormwater total nitrogen from 5.8 mg/L to 8.2 mg/l.

FIGURE 2.21 MASS OF TN WITHIN EFFLUENT BY DATE



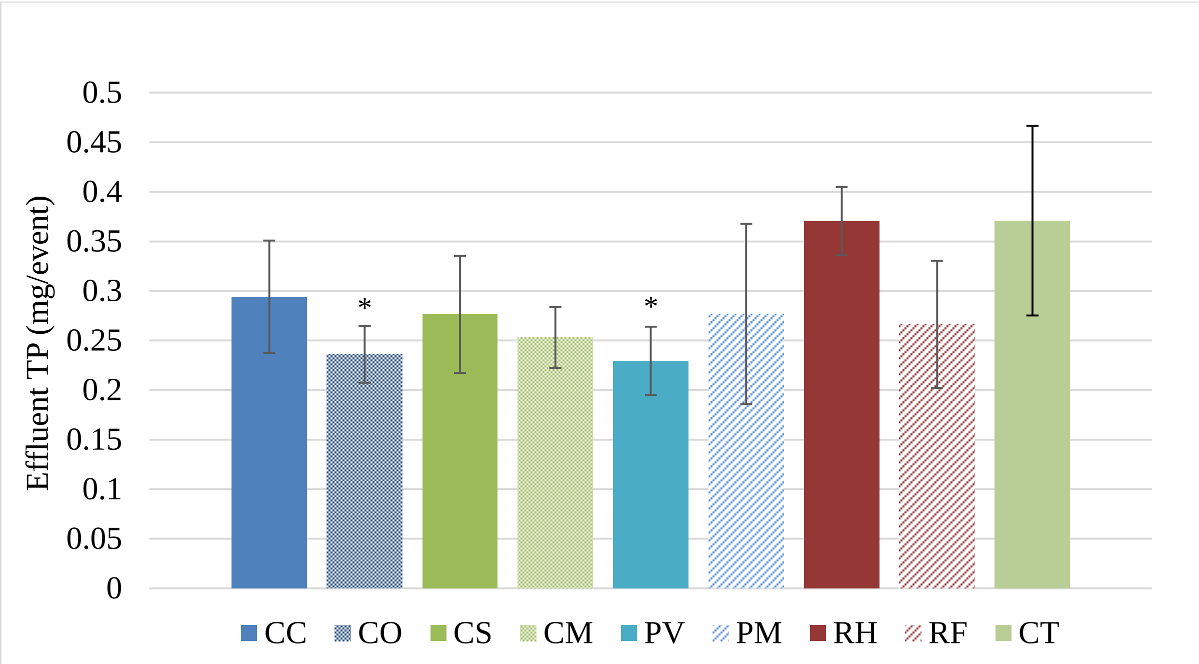
Data represent means ± SD. CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm'

Total Phosphorus (TP)

The mass of total phosphorus for *Calamagrostis x acutiflora* 'Overdam' and *Pycnanthemum virginianum* columns were different from the control column (Figure 2.22). The lowest mean effluent concentration was found in *Pycnanthemum virginianum* (0.229 [± 0.034] mg/event), *Calamagrostis x acutiflora* 'Overdam' (0.235 [± 0.028] mg/event), *Carex muskingumensis* (0.252 [± 0.030] mg/event), *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(0.266 [± 0.064] mg/event), *Carex stricta* at (0.276 [± 0.0591] mg/event), *Pycnanthemum muticum* (0.277 [± 0.091] mg/event), *Calamagrostis canadensis* (0.294 [± 0.056] mg/event), *Rudbeckia hirta* (0.370 [± 0.034] mg/event), and the Control Column (0.371 [± 0.095] mg/event).

The effluent total phosphorus leached from columns was not different when comparing the ornamental and native plant species for *Calamagrostis*, *Carex*, or *Pycnanthemum*. *Rudbeckia* species showed a difference in masses, with greater leached total phosphorus detected in the native, *Rudbeckia hirta* effluent (P-value 0.0127).

FIGURE 2.22 MASS OF TP WITHIN EFFLUENT BY SPECIES



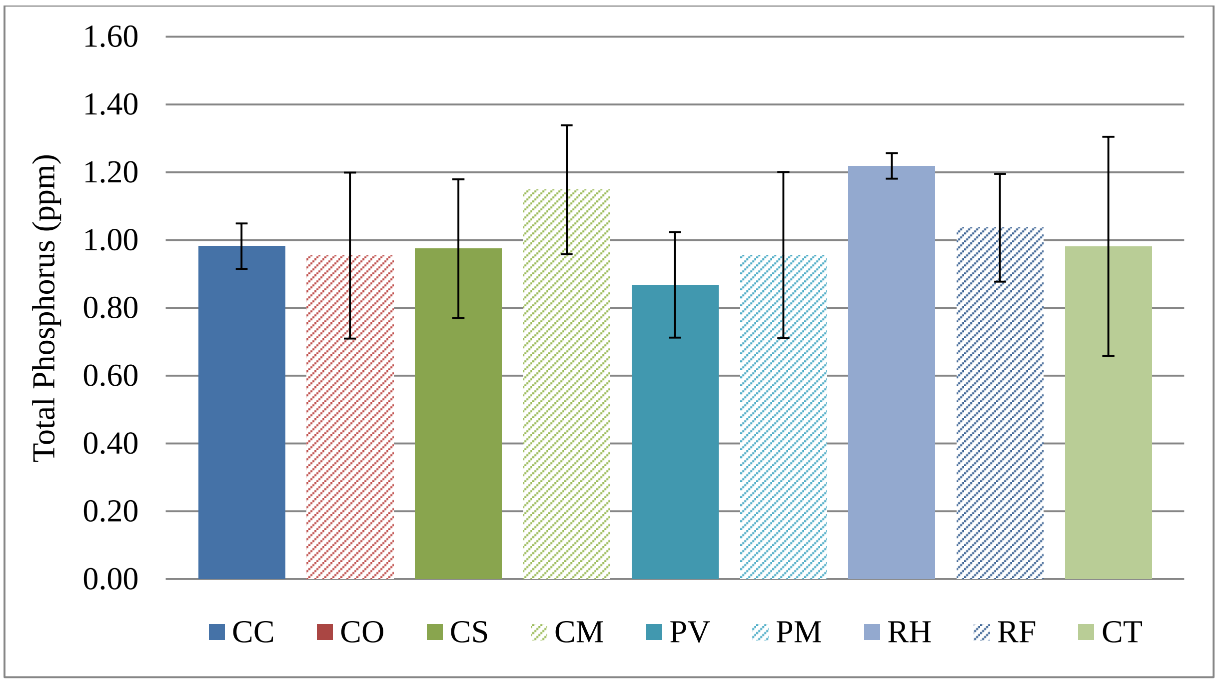
Data represent means ± SD. (*) Indicates significant difference from the control column (p<.05).
CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm', CT-Control column

The total phosphorus concentration (ppm) in effluent (Figure 2.23) was correlated with the mass effluent (mg/event) (Table 2.11). Since mass and concentration are significantly correlated; the remaining analysis of dates and correlation to water use were completed using mass of total phosphorus leached.

TABLE 2.11 TOTAL PHOSPHORUS MASS & CONCENTRATION CORRELATION

Pearson Correlation Coefficients, N = 40	
Prob > |r| under H0: Rho=0	
	TP Conc
TP Mass	0.41365
	<.0131

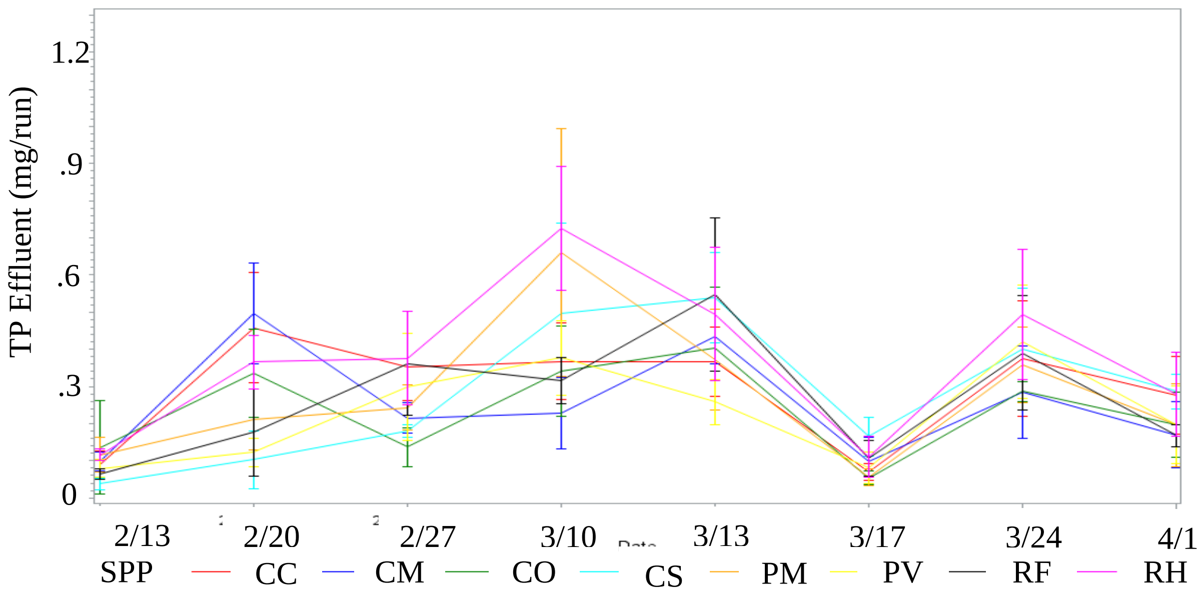
FIGURE 2.23 CONCENTRATION OF TP EFFLUENT BY SPECIES



Data represent means ± SD. CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm', CT-Control column

There were variations between the treatment dates for total phosphorus effluent as shown (Figure 2.24).

FIGURE 2.24 MASS OF TP WITHIN EFFLUENT BY DATE



Data represent means ± SD. CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm'

A negative correlation existed between water use and total phosphorus effluent (Table 2.12). The mass of total phosphorus leached was lower with higher water use volumes.

TABLE 2.12 CORRELATION BETWEEN WATER USE AND TOTAL PHOSPHORUS

Pearson Correlation Coefficients, N = 40	
Prob > |r| under H0: Rho=0	
	H2O Use
TP	-0.53807
	<.0003

Shoot, Root & Total Plant Mass

All plants were removed and dried at the conclusion of the experiment to determine the change from initial shoot, root, and total mass.

Calamagrostis and *Carex* showed differences in shoot and total mass when compared to *Pycnanthemum* and *Rudbeckia* (Table 2.13). The ornamental species of *Carex* and *Rudbeckia* exhibited greater shoot and root mass increases over the native species (Figure 2.25).

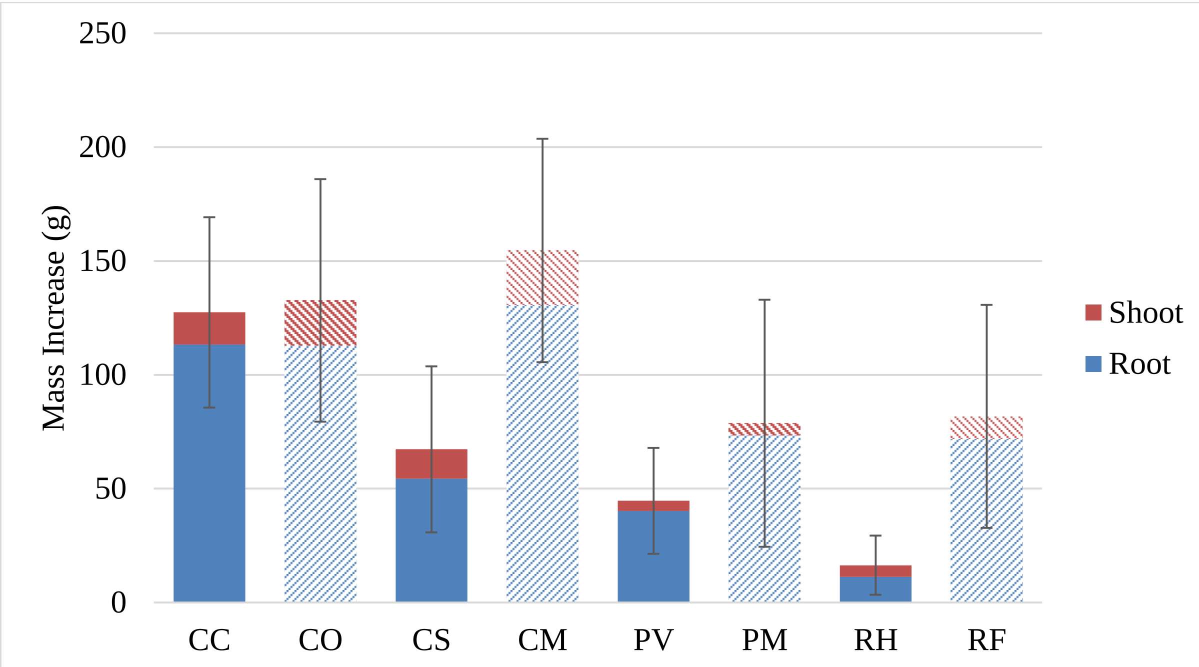
Table 2.13 GROUPING OF PLANT TOTAL MASS CHANGE BY GENUS

Tukey	**Mean**	**N**	**Genus**
A	130.09 (g)	10	Calamagrostis
A			
A	110.93 (g)	10	Carex
B	61.7 (g)	10	Pycnanthemum
B			
B	40.05 (g)	10	Rudbeckia

Means with the same letter are not significantly different.

The highest total mass was found in *Carex muskingumensis* (154.59 [± 49.08] g), followed by, *Calamagrostis x acutiflora* 'Overdam' (132.7 [± 53.24] g), *Calamagrostis canadensis* (127.47 [± 41.80] g), *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(81.73 [± 48.98] g), *Pycnanthemum muticum* (78.74 [± 54.24] g), *Carex stricta* at (67.27 [± 36.51] g), *Pycnanthemum virginianum* (44.64 [± 23.26] g), *Rudbeckia hirta* (16.36 [±13.04] g).

FIGURE 2.25 INCREASE IN PLANT TISSUE MASS



Data represent means ± SD. CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm'

Table 2.14 shows the percent change in plant mass from the initial mass over the course of the experiment.

TABLE 2.14 PERCENT CHANGE IN MASS OVER INITIAL MASS

	Root Mass	**Shoot Mass**	**Total Mass**
Calamagrostis canadensis	257.67%	330.58%	264.19%
Calamagrostis x acutiflora 'Overdam'	301.98%	377.97%	311.28%
Carex stricta	172.92%	230.28%	181.62%
Carex muskingumensis	436.19%	549.86%	450.57%
Pycnanthemum virginianum	173.07%	168.28%	172.59%
Pycnanthemum muticum	353.29%	106.51%	304.85%
Rudbeckia hirta	98.93%	59.46%	82.07%
Rudbeckia fulgida 'Goldsturm'	319.84%	144.16%	279.42%

Water use exhibited a positive correlation (Table 2.15) with shoot mass. As shoot mass increased so did water use.

TABLE 2.15 CORRELATION BETWEEN WATER USE AND SHOOT MASS

Pearson Correlation Coefficients, N = 40	
Prob > |r| under H0: Rho=0	
	H2O Use
Shoot Mass	0.32550
	<.0404

Plant Pollutant Uptake

Nitrogen (N)

There were differences between genera (Table 2.16) with *Calamagrostis* and *Carex* exhibiting a higher uptake of nitrogen than *Pycnanthemum* and *Rudbeckia*. No differences were exhibited in plant tissue nitrogen concentration between native and ornamental plants of each genus (Figure 2.26).

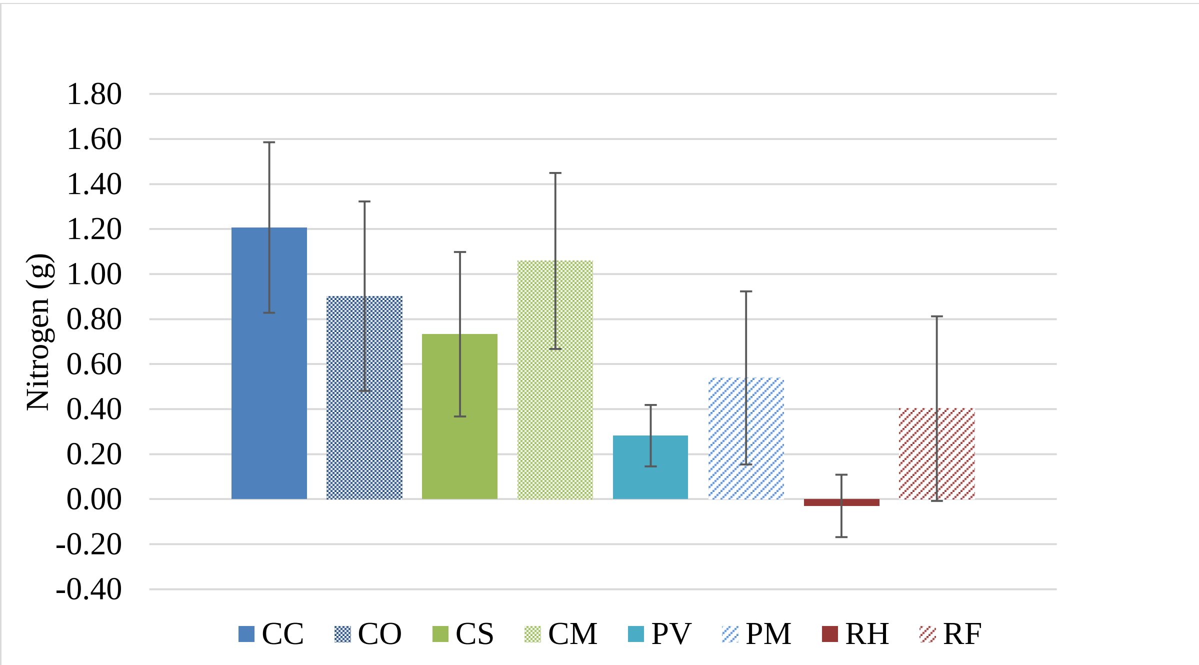
TABLE 2.16 GROUPING OF PLANT NITROGEN CHANGE BY GENUS

Tukey	Mean (g)	N	Genus
A	1.05	10	Calamagrostis
A			
A	0.89	10	Carex
B	0.41	10	Pycnanthemum
B			
B	0.18	10	Rudbeckia

Means with the same letter are not significantly different.

The highest total nitrogen uptake (Figure 2.26) was found in *Calamagrostis canadensis* (1.21 [± 0.38] g), followed by, *Carex muskingumensis* (1.06 [± 0.39] g), *Calamagrostis x* *acutiflora* ‘Overdam’ (0.90 [± 0.42] g), *Carex stricta* at (0.73 [± 0.37] g), *Pycnanthemum muticum* (0.54 [± 0.38] g), *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’(0.40 [± 0.41] g), *Pycnanthemum virginianum* (0.28 [± 0.14] g), *Rudbeckia hirta* (-0.02 [±0.13] g).

FIGURE 2.26 PLANT TISSUE UPTAKE OF NITROGEN



Data represent means ± SD. CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* ‘Overdam’, CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* ‘Goldsturm’

A positive correlation was found between nitrogen uptake and shoot, root and total mass for all plant species (Table 2.17). The total plant mass for the genus *Calamagrostis* (130.08 g) and *Carex* (110.931 g) were greater than *Pycnanthemum* (61.695 g), and *Rudbeckia* (49.047 g).

TABLE 2.17 CORRELATION BETWEEN NITROGEN AND PLANT TISSUE MASS

Pearson Correlation Coefficient Prob > |r| under H0: Rho=0			
	Total Mass	Root Mass	Shoot Mass
N	0.8813 <.0001	0.88009 <.0001	0.51205 0.0007

Phosphorus (P)

Differences were found in phosphorus uptake (Table 2.18) with *Calamagrostis* exhibiting higher uptake than *Carex*, *Pycnanthemum*, and *Rudbeckia*. The uptake of phosphorus (Figure 2.27) into the plant tissue was different for the genus *Rudbeckia* when comparing the ornamental and native plant species.

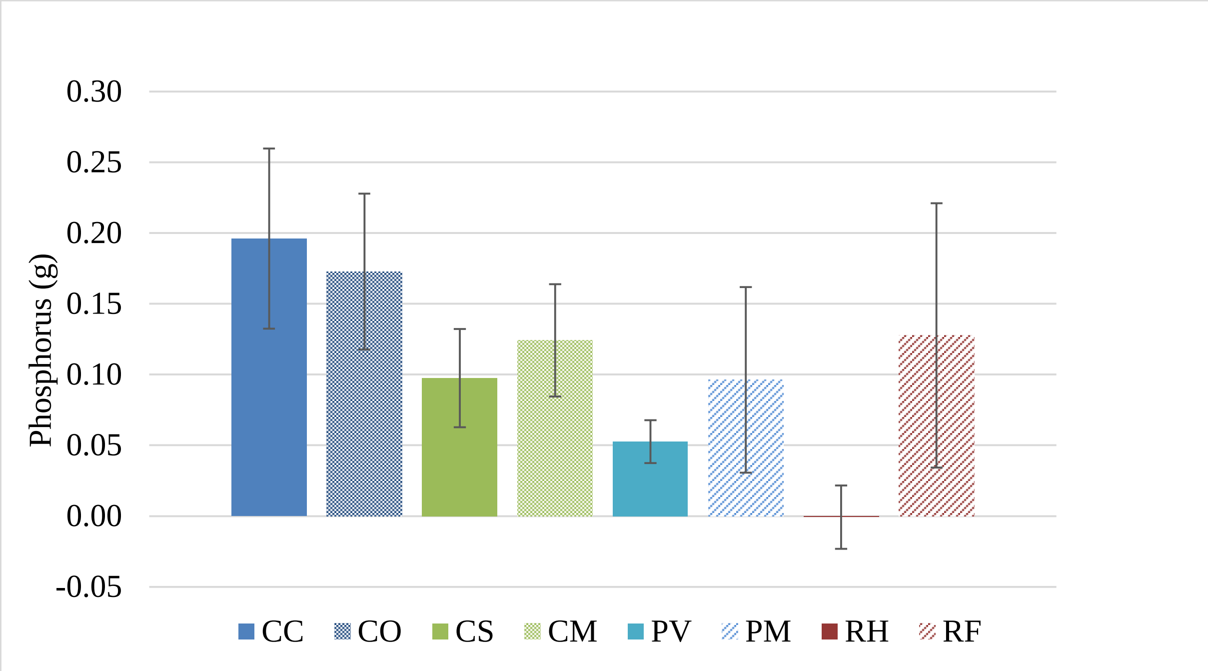
TABLE 2.18 GROUPING OF PLANT PHOSPHORUS CHANGE BY GENUS

Tukey	**Mean (g)**	**N**	**Genus**
A	0.18	10	Calamagrostis
B	0.11	10	Carex
B			
B	0.074	10	Pycnanthemum
B			
B	0.063	10	Rudbeckia

Means with the same letter are not significantly different.

The highest phosphorus uptake was found in *Calamagrostis canadensis* (0.19 [± 0.06] g), followed by, *Calamagrostis x acutiflora* 'Overdam' (0.17 [± 0.05] g), *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(0.13 [± 0.09] g), *Carex muskingumensis* (0.12 [± 0.04] g), *Carex stricta* at (0.10 [± 0.03] g), *Pycnanthemum muticum* (0.10 [± 0.07] g), *Pycnanthemum virginianum* (0.05 [± 0.02] g), *Rudbeckia hirta* (0.00 [±0.02] g).

FIGURE 2.27 PLANT TISSUE UPTAKE OF PHOSPHORUS



Data represent means ± SD. CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* ‘Overdam’, CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* ‘Goldsturm’

There was a positive correlation between phosphorus uptake and shoot, root, and total mass (Table 2.19).

TABLE 2.19 CORRELATION OF PHOSPHORUS UPTAKE AND PLANT TISSUE MASS

Pearson Correlation Coefficient Prob > |r| under H0: Rho=0			
	Total Mass	Root Mass	Shoot Mass
P	0.77988 <.0001	0.786429 <.0001	0.40490 0.0096

Copper (Cu)

Plant uptake of copper (Table 2.20) was higher in the genus *Pycnanthemum* when compared to *Carex* but not between the other genera. The native *Calamagrostis canadensis*, *Carex stricta*, and *Pycnanthemum virginianum* had higher uptake of Cu than their ornamental plant counterparts, while *Rudbeckia* species exhibited no difference (Figure 2.28).

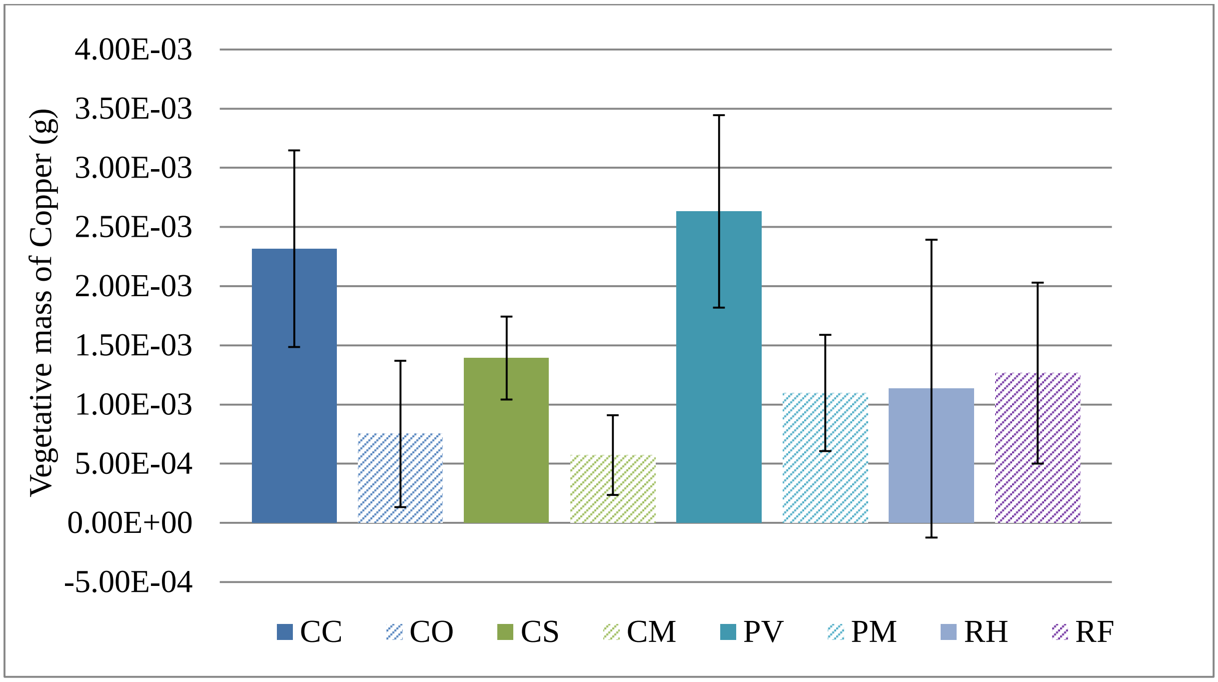
TABLE 2.20 PLANT COPPER UPTAKE CHANGE BY GENUS

Tukey		**Mean (g)**	**N**	**Genus**
	A	0.0018	10	Pycnanthemum
	A			
B	A	0.0012	10	Rudbeckia
B	A			
B	A	0.0007	10	Calamagrostis
B				
B		0.0004	10	Carex

Means with the same letter are not significantly different.

The highest uptake of Cu was by *Pycnanthemum virginianum* (2.63E-03 [±1.08E-03] g), closely followed by, *Calamagrostis canadensis* (2.32E-03 [±1.11E-03] g), Carex stricta (1.39E-03 [±4.68E-04] g), *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(1.27E-03 [±7.64E-04] g), *Rudbeckia hirta* (1.13E-03 [±1.26E-04] g), *Pycnanthemum muticum* (1.10E-03 [±1.08E-04] g), *Calamagrostis x acutiflora* 'Overdam' (7.51E-04 [±1.12E-03] g), *Carex muskingumensis* (5.72E-04 [±4.50E-03] g).

FIGURE 2.28 PLANT TISSUE UPTAKE OF COPPER



Data represent means ± SD. CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm'

Zinc (Zn)

No differences zinc uptake was found between the genera (Table 2.21). The native *Pycnanthemum virginianum* had higher uptake than ornamental *Pycnanthemum muticum* (Figure 2.29).

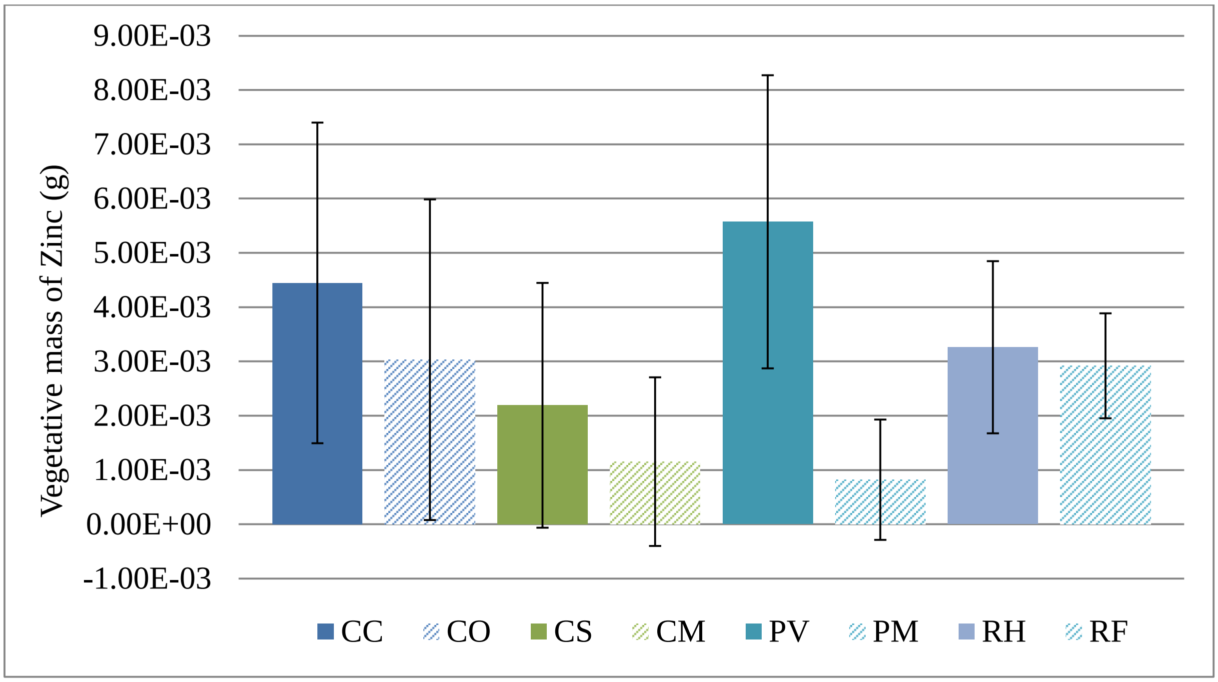
TABLE 2.21 PLANT ZINC UPTAKE CHANGE BY GENUS

Tukey	Mean	N	Genus
A	0.003739	10	Calamagrostis
A	0.003198	10	Pycnanthemum
A	0.003091	10	Rudbeckia
A	0.001673	10	Carex

Means with the same letter are not significantly different.

The highest uptake of Zn was by *Pycnanthemum virginianum* (5.57E-03 [±2.70E-03] g), followed by, *Calamagrostis canadensis* (4.44E-03 [±2.95E-03] g), *Rudbeckia hirta* (3.26E-03 [±1.58E-03] g), *Calamagrostis x acutiflora* 'Overdam' (3.03E-03 [±2.95E-03] g), *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(2.92E-03 [±9.67E-04] g), *Carex stricta* (2.19E-03 [±2.95E-03] g), Carex muskingumensis (1.15E-03 [±1.55E-03] g), *Pycnanthemum muticum* (8.20E-04 [±1.11E-03] g).

FIGURE 2.29 PLANT TISSUE UPTAKE OF ZINC



Data represent means ± SD. CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm'

Lead (Pb)

The genus *Pycnanthemum* was greater in lead uptake (Table 2.22) than *Carex* and *Calamagrostis*. There were no differences in lead uptake between native and ornamental species of each genera.

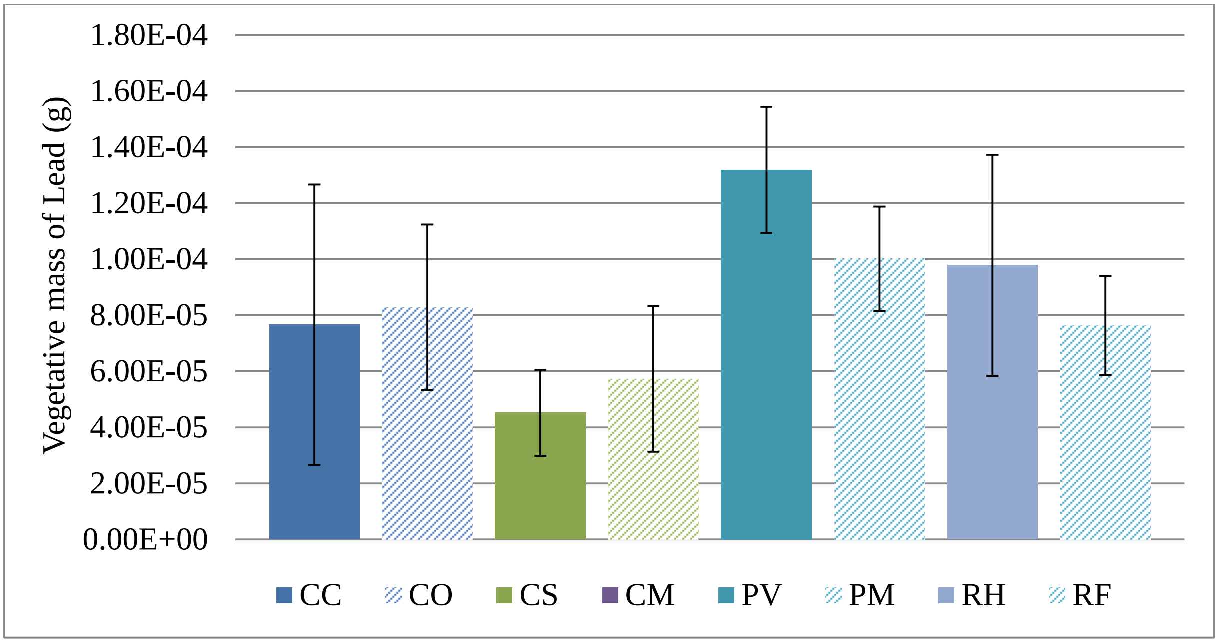
TABLE 2.22 PLANT LEAD UPTAKE CHANGE BY GENUS

Tukey		Mean	N	Genus
	A	0.00018654	10	Pycnanthemum
B	A	0.00011999	10	Rudbeckia
B		0.00007824	10	Calamagrostis
B		0.00004104	10	Carex

Means with the same letter are not significantly different.

The highest lead uptake (Figure 2.30) was by *Pycnanthemum virginianum* (1.32E-04 [±2.25E-05] g), followed by, *Pycnanthemum muticum* (1.00E-04 [±1.87E-05] g), *Rudbeckia hirta* (9.78E-05 [±3.94E-05] g), *Calamagrostis x acutiflora* 'Overdam' (8.28E-05 [±2.96E-05] g), *Calamagrostis canadensis* (7.66E-05 [±5.00E-05] g), *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(7.62E-05 [±1.77E-05] g), *Carex muskingumensis* (5.72E-05 [±2.60E-05] g) *Carex stricta* (4.52E-05 [±1.54E-05] g).

FIGURE 2.30 PLANT TISSUE UPTAKE OF LEAD



Data represent means ± SD. CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm'

Soil Retention

Soil concentrations presented are the change in concentrations that occurred over the course of the study.

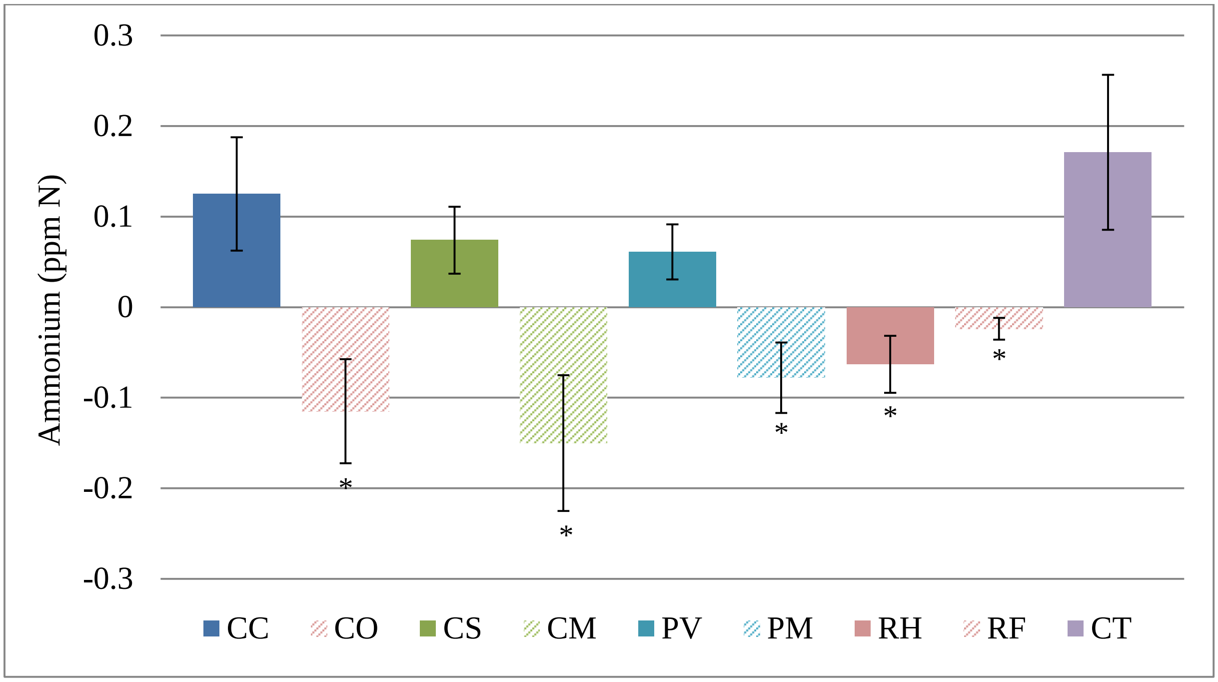
Ammonium

Differences were found in the soil ammonium content between the control column and *Calamagrostis x acutiflora* 'Overdam', *Carex muskingumensis, Pycnanthemum muticum, Pycnanthemum virginianum*, *Rudbeckia hirta,* and *Rudbeckia fulgida var. sullivantii* 'Goldsturm'.

The highest soil retention of ammonium concentration (Figure 2.31) was by the Control Column (0.171 [±0.085] mg/L), followed by *Calamagrostis canadensis* (0.125 [±0.062] mg/L), *Carex stricta* (0.074 [±0.037] mg/L), *Pycnanthemum virginianum* (0.061 [±0.031] mg/L), *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(-0.024 [±0.012] mg/L), *Rudbeckia hirta* (-0.063 [±0.031] mg/L), *Pycnanthemum muticum* (-0.078 [±0.039] mg/L), *Calamagrostis x acutiflora* 'Overdam'(-0.115 [±0.057] mg/L), *Carex muskingumensis* (-0.15 [±0.075] mg/L).

Differences were found between the native and ornamental *Calamagrostis, Carex* and *Pycnanthemum*, with all 3 native species (*Calamagrostis canadensis*, *Carex stricta*, and *Pycnanthemum virginianum*) exhibiting higher soil ammonium content over their respective ornamental counterparts.

FIGURE 2.31 AMMONIUM SOIL CONCENTRATION



Data represent means ± SD. (*) Indicates significant difference from the control column (p<.05).
CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta,* CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum,* RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm', CT-Control column

Nitrate

There were differences found in soil nitrate concentration between all plant species and the control column. *Carex* and *Calamagrostis* exhibited different nitrate concentrations (Table 2.23) from the other genera. *Rudbeckia* and *Pycnanthemum* were not found to be different. *Calamagrostis*, *Carex*, *Pycnanthemum*, exhibited differences between native and ornamental plant species (Figure 2.32).

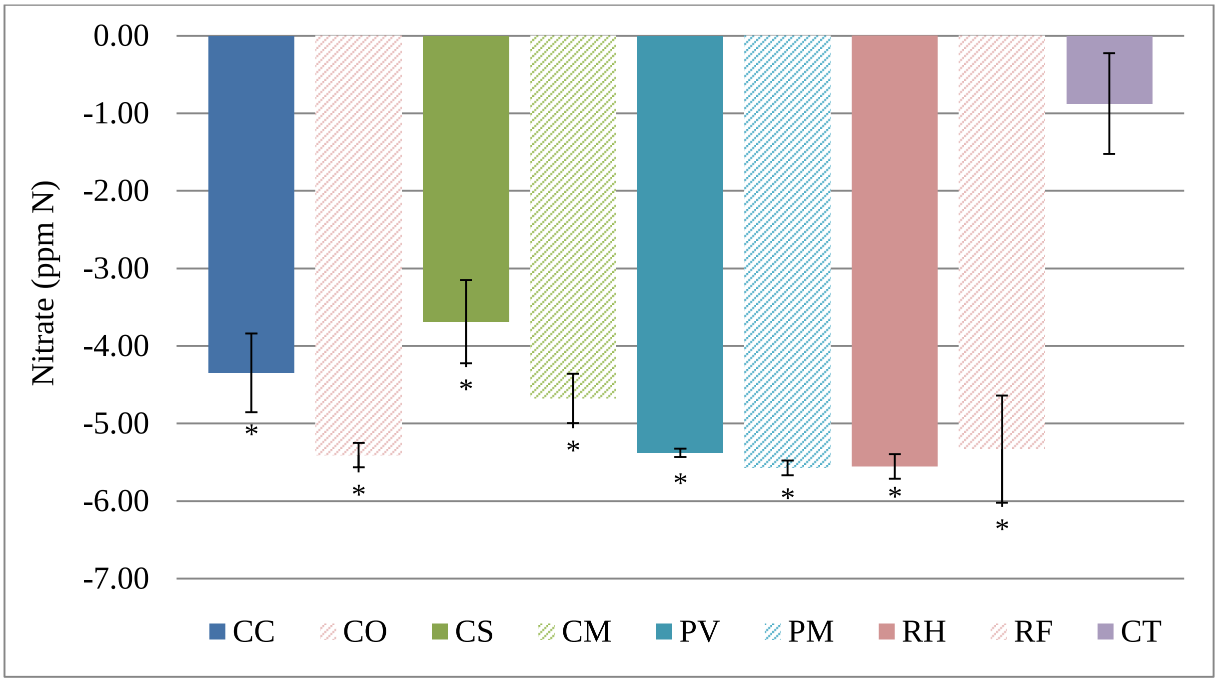
TABLE 2.23 SOIL NITRATE CHANGE BY GENUS

Tukey	Mean	N	Genus
A	-4.182	10	Carex
B	-4.876	10	Calamagrostis
C	-5.44	10	Rudbeckia
C	-5.475	10	Pycnanthemum

Means with the same letter are not significantly different.

The highest soil retention of nitrate was by the Control Column (-0.87 [±0.065] mg/L), followed by *Carex stricta* (-3.69 [±0.74] mg/L), *Calamagrostis canadensis* (-4.35 [±0.51] mg/L), *Carex muskingumensis* (-4.68 [±0.39] mg/L), *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(-5.33 [±0.69] mg/L), *Pycnanthemum virginianum* (-5.38 [±0.15] mg/L), *Calamagrostis x acutiflora* 'Overdam'(-5.41 [±0.16] mg/L), *Rudbeckia hirta* (-5.57 [±0.11] mg/L), *Pycnanthemum muticum* (-5.57 [±0.16] mg/L).

FIGURE 2.32 NITRATE SOIL CONCENTRATION



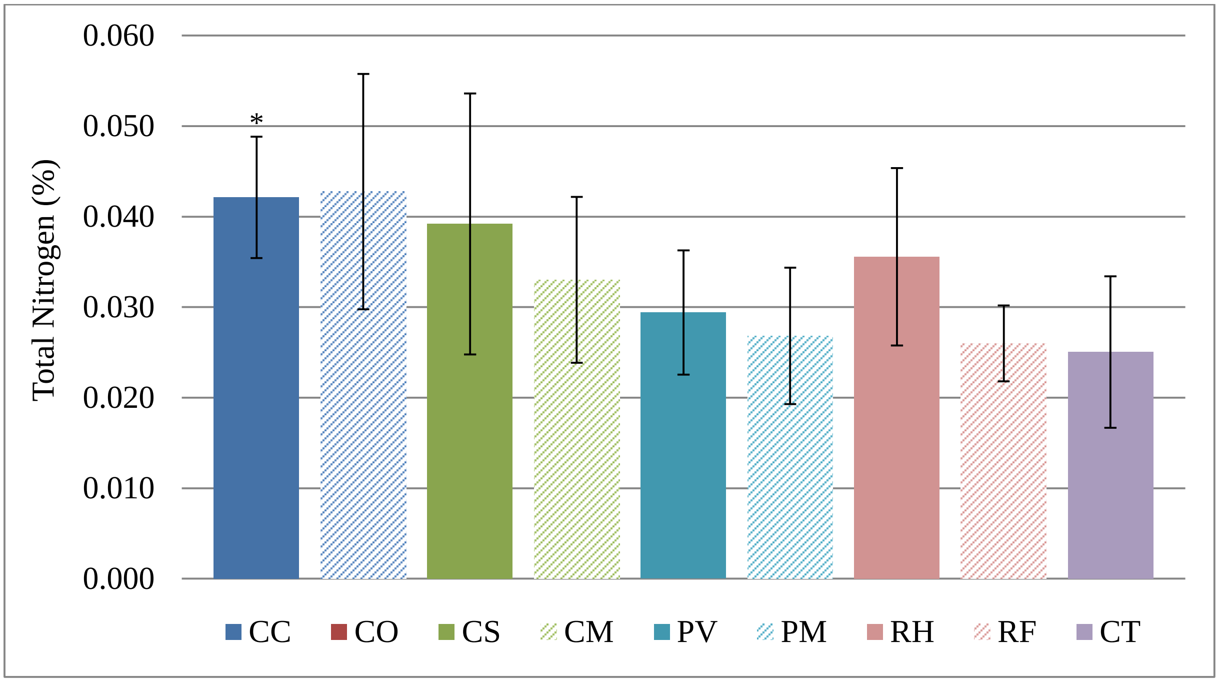
Data represent means ± SD. (*) Indicates significant difference from the control column (p<.05). CC-*Calamagrostis canadensis,* CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm', CT-Control column

Total Nitrogen

There were differences found in the soil total nitrogen concentration between *Calamagrostis canadensis* and the control column. There were no differences between genera or between native and ornamental plant species within each genera.

The highest soil retention of total nitrogen (Figure 2.33) was by *Calamagrostis x acutiflora* 'Overdam' (0.043 [±0.16] %), *Calamagrostis canadensis* (0.042 [±0.006] %), *Carex stricta* 0.039 [±0.011] %), *Rudbeckia hirta* (0.036 [±0.01] %), *Carex muskingumensis* (0.033 [±0.01] %), *Pycnanthemum virginianum* (0.029 [±0.01] %), *Pycnanthemum muticum* (0.027 [±0.01] mg/L), *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(0.026 [±0.004] mg/L),Control Column (0.025 [±0.01] mg/L).

FIGURE 2.33 TOTAL NITROGEN SOIL CONCENTRATION



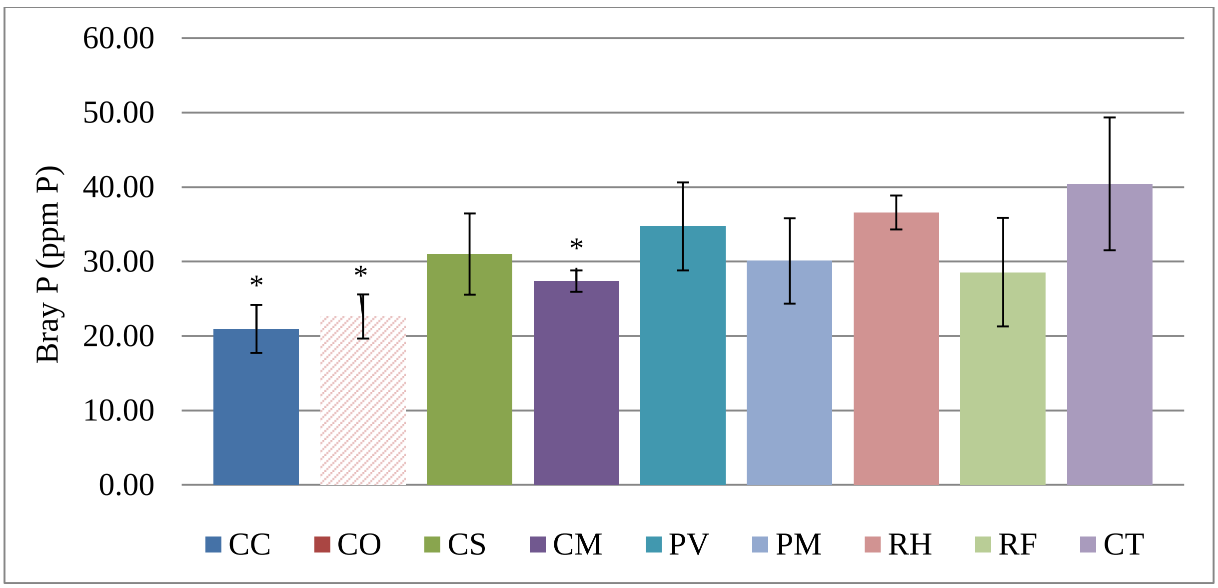
Data represent means ± SD. (*) Indicates significant difference from the control column (p<.05). CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm', CT-Control column

Bray Phosphorus

Differences were found in the soil Bray phosphorus concentration between *Calamagrostis x acutiflora* 'Overdam', *Calamagrostis canadensis*, *Carex muskingumensis*, and the control column. There were no differences between native and ornamental plant species within each genera.

The highest soil retention of Bray phosphorus (Figure 2.34) was by the Control Column (40.42 [±8.91] mg/L), followed by *Rudbeckia hirta* (36.58 [±2.30] mg/L), *Pycnanthemum virginianum* (34.72 [±5.91] mg/L), *Carex stricta* (30.98 [±5.46] mg/L), *Pycnanthemum muticum* (30.58 [±5.73] mg/L), *Rudbeckia fulgida var. sullivantii* 'Goldsturm' 28.55 [±7.28] mg/L), *Carex muskingumensis* (27.38 [±1.44] mg/L), *Calamagrostis x acutiflora* 'Overdam'(22.62 [±2.97] mg/L), *Calamagrostis canadensis* (20.95 [±3.21] mg/L).

FIGURE 2.34 BRAY PHOSPHORUS SOIL CONCENTRATION



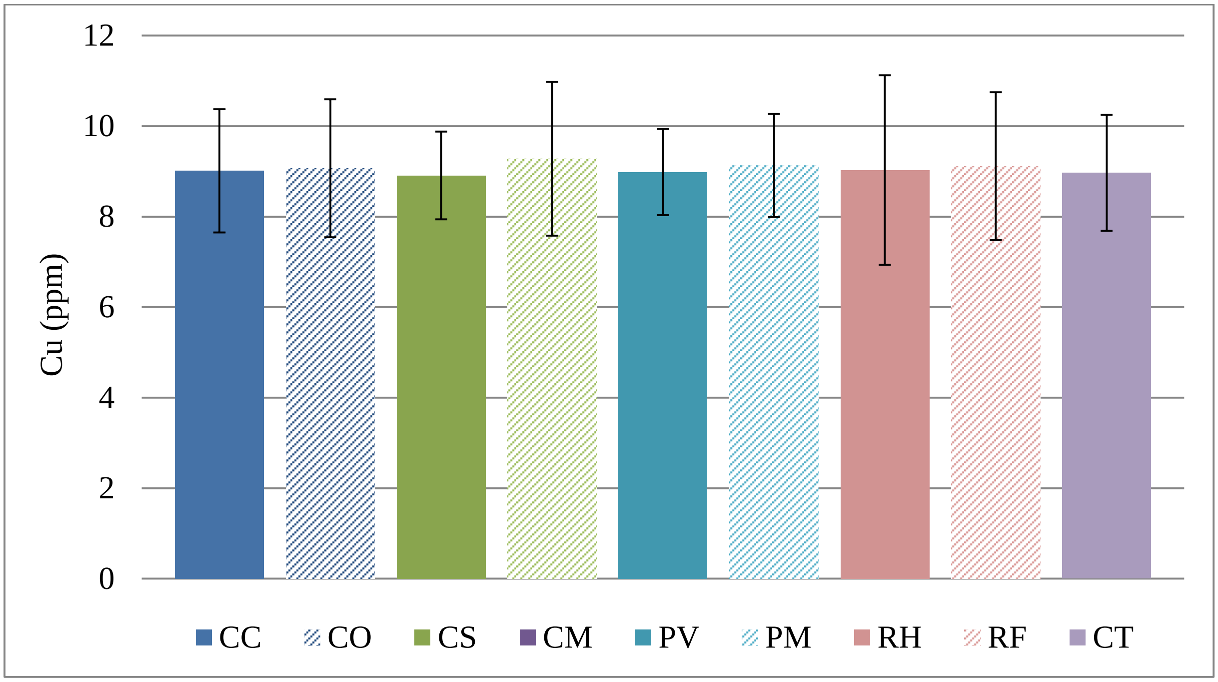
Data represent means ± SD. (*) Indicates significant difference from the control column (p<.05). CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm', CT-Control column

Copper (Cu)

No differences were found for the soil copper concentration between plant species and the control column. There were no differences between genera or native and ornamental plant species within each genera.

The highest soil retention of copper (Figure 2.35) was by *Carex muskingumensis* (9.27 [±1.699] mg/L), *Pycnanthemum muticum* (9.12 [±1.13] mg/L), *Rudbeckia fulgida var. sullivantii* 'Goldsturm' (9.11 [±1.63] mg/L), *Calamagrostis x acutiflora* 'Overdam'(9.06 [±1.52] mg/L), *Rudbeckia hirta* (9.03 [±2.09] mg/L), *Calamagrostis canadensis* (9.01 [±1.36] mg/L), *Pycnanthemum virginianum* (8.98 [±.952] mg/L), Control Column (8.96 [±1.28] mg/L), followed by *Carex stricta* (8.91 [±0.96] mg/L).

FIGURE 2.35 COPPER SOIL CONCENTRATION

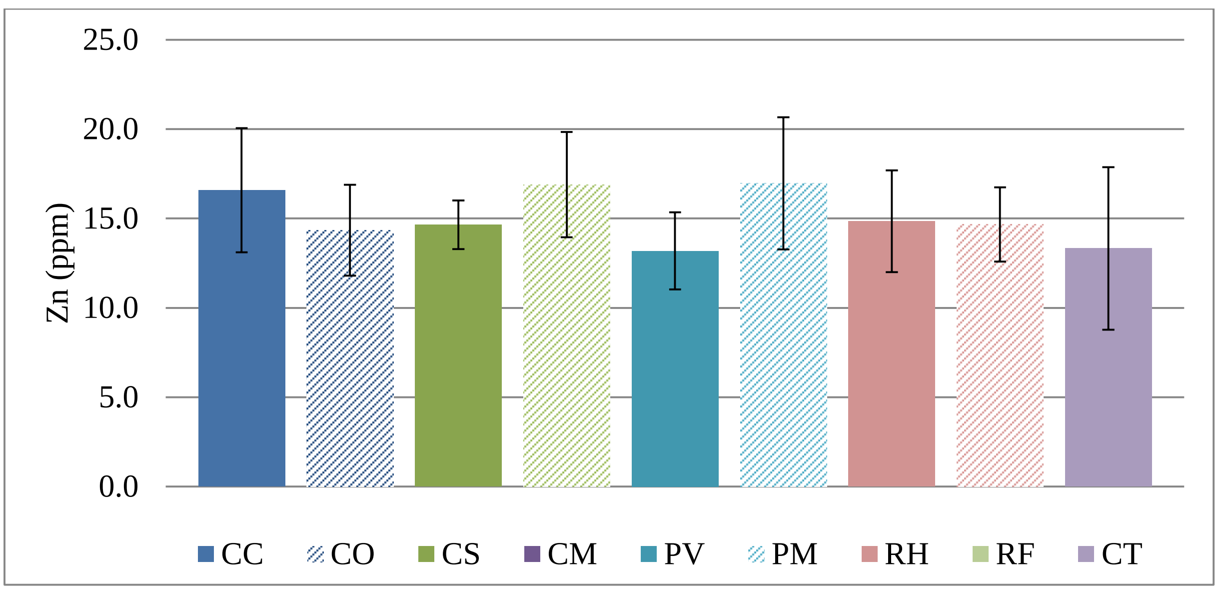


Data represent means ± SD. (*) Indicates significant difference from the control column (p<.05). CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm', CT-Control column

Zinc (Zn)

No differences were found in soil zinc between plant species and the control column. Neither were there differences between genera or native and ornamental plant species within each genera. The highest soil retention of zinc concentration (Figure 2.36) was by *Pycnanthemum muticum* (16.97 [±3.69] mg/L), *Carex muskingumensis* (16.89 [±2.95] mg/L), *Calamagrostis canadensis* (16.59 [±3.47] mg/L), *Rudbeckia hirta* (14.85 [±2.84] mg/L), *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(14.67 [±2.07] mg/L), *Carex stricta* (14.65 [±1.35] mg/L), *Calamagrostis x acutiflora* 'Overdam'(14.34 [±2.53] mg/L), Control Column (13.32 [±4.54] mg/L), followed by, mg/L *Pycnanthemum virginianum* (13.18 [±2.15] mg/L).

FIGURE 2.36 ZINC SOIL CONCENTRATION

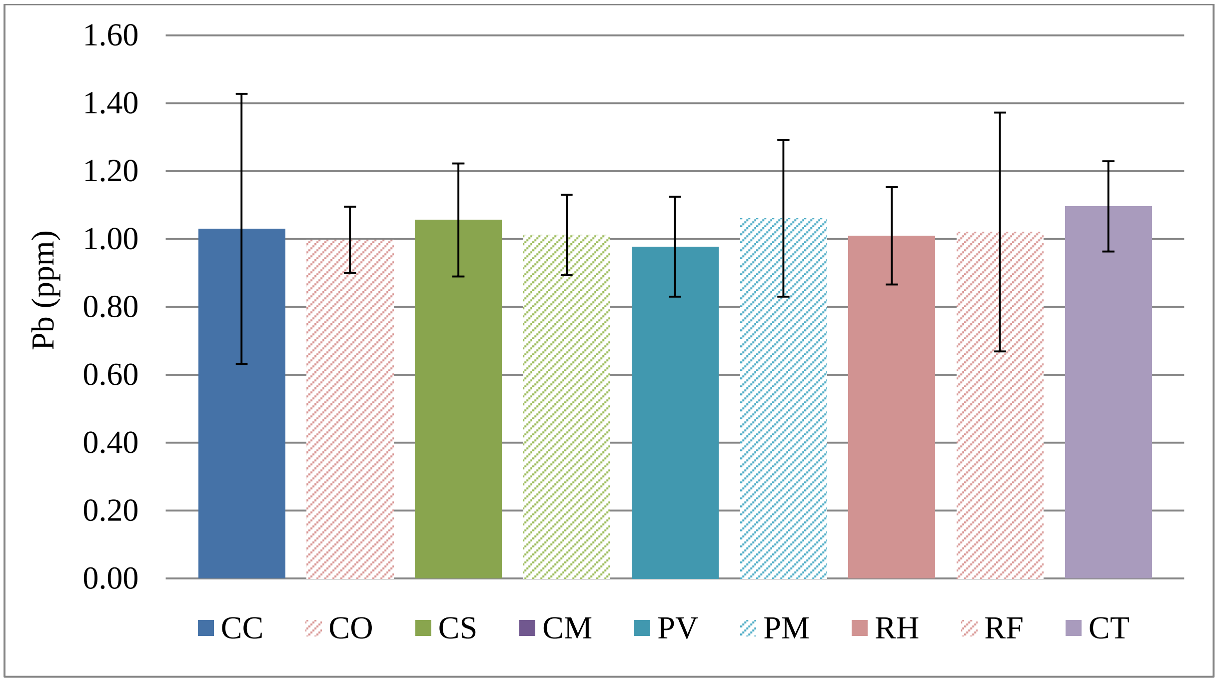


Data represent means ± SD. (*) Indicates significant difference from the control column (p<.05). CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum,* RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm', CT-Control column

Lead (Pb)

No differences were found in soil lead concentration between plant species and the control column. Also, no differences found between genera or native and ornamental plant species within each genera. The highest soil retention of soil lead (Figure 2.37) was by the Control Column (1.09 [±0.133] mg/L), followed by, *Pycnanthemum muticum* (1.06 [±0.23] mg/L), *Carex stricta* (1.05 [±0.166] mg/L), *Calamagrostis canadensis* (1.03 [±0.40] mg/L), *Rudbeckia fulgida var. sullivantii* 'Goldsturm'(1.02 [±0.35] mg/L), *Carex muskingumensis* (1.01 [±0.11] mg/L), *Rudbeckia hirta* (1.01 [±0.14] mg/L), *Calamagrostis x acutiflora* 'Overdam'(1.00 [±0.10] mg/L), *Pycnanthemum virginianum* (0.97 [±0.14] mg/L).

FIGURE 2.37 LEAD SOIL CONCENTRATION



Data represent means ± SD. (*) Indicates significant difference from the control column (p<.05). CC-*Calamagrostis canadensis,* CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta,* CM- *Carex muskingumensis,* PV-*Pycnanthemum virginianum,* PM-*Pycnanthemum muticum,* RH-*Rudbeckia hirta,* RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm', CT-Control column

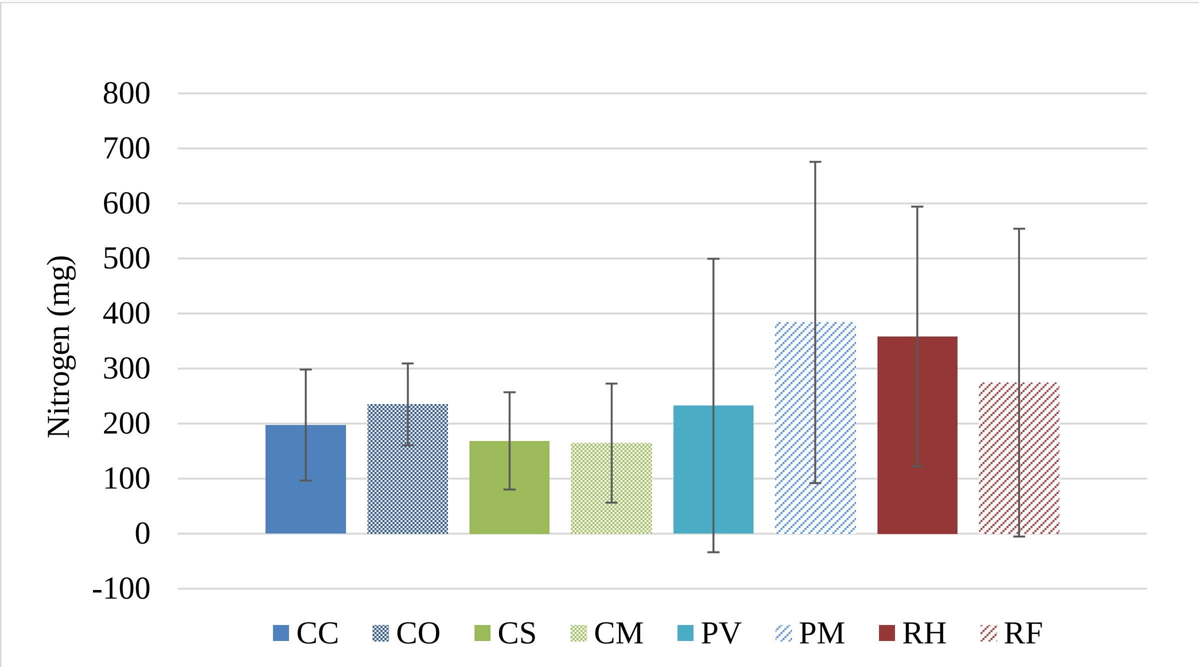
Mass Balances

Mass balance was used to determine the influence of the plant species on the nitrogen and phosphorus content of the system. Total input was calculated by combining initial nitrogen and phosphorus content for the plants and soil with the total stormwater quantities (ammonium, nitrate, and organic nitrogen) (orthophosphate). The quantities from the post-harvest plant tissue, effluent water quantities, and soil were subtracted from the initial input. The unaccounted for nitrogen and phosphorus was the remainder from the equation.

Total Nitrogen (TN) Mass Balance

There were no differences in mass balance of unaccounted nitrogen between genera, or native and ornamental species within genera (Figure 2.38). The highest unaccounted nitrogen was; *Pycnanthemum muticum* (383 [±291.9] mg), followed by, *Rudbeckia hirta* (357 [±236.04] mg), *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’(274 [±279.6] mg), *Calamagrostis x acutiflora* ‘Overdam’ (234 [±74.55] mg), *Pycnanthemum virginianum* (232 [±266.56] mg), *Calamagrostis canadensis* (197 [±101.02] mg), *Carex stricta* at (168 [±88.33] mg), *Carex muskingumensis* (164 [±108.12] mg).

FIGURE 2.38 TOTAL UNACCOUNTED NITROGEN BY EACH PLANT SPECIES



Data represent means ± SD.CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* ‘Overdam’, CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* ‘Goldsturm’

Pie charts represent the distribution of nitrogen in each species between soil, plant, effluent, and unaccounted (Figure 2.39).

FIGURE 2.39 DISTRIBUTION OF NITROGEN FOR EACH SPECIES

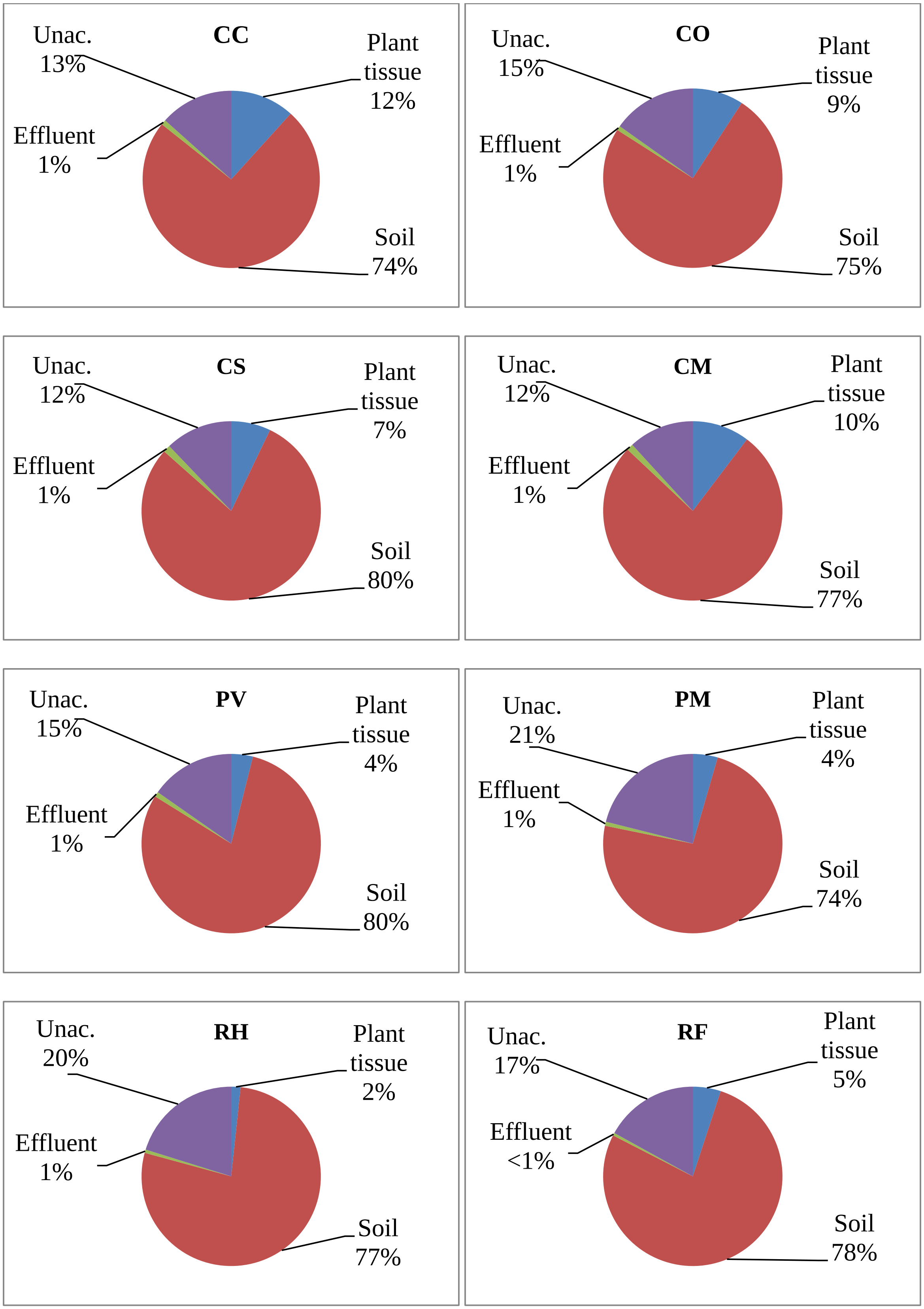
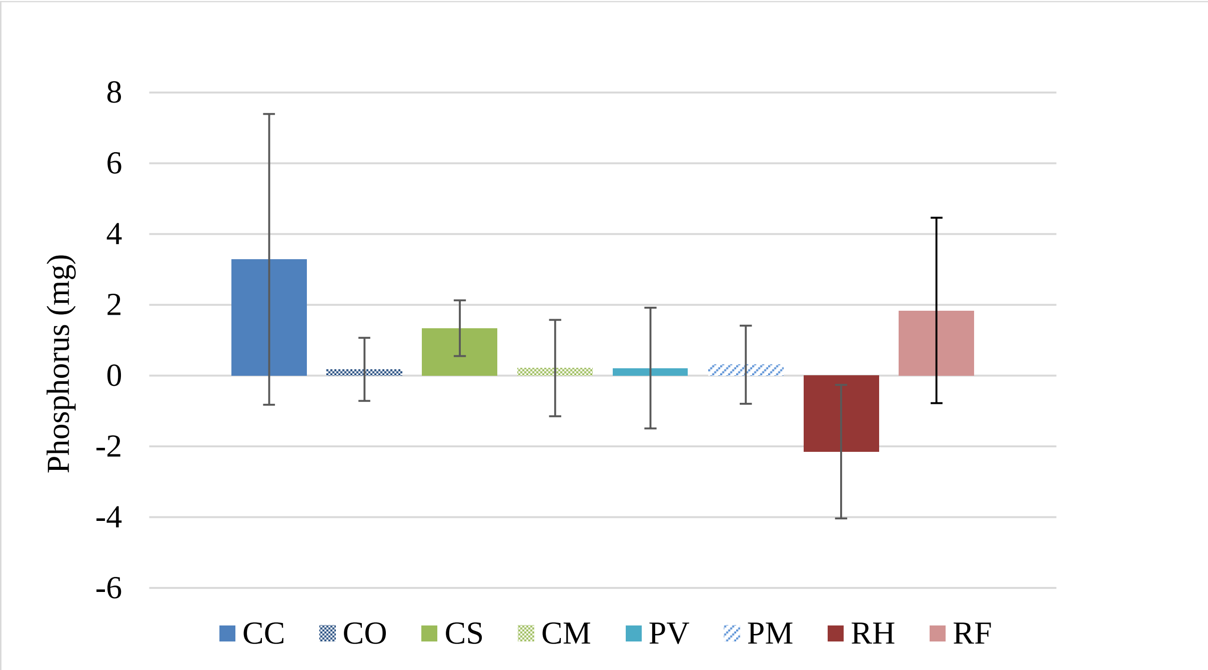


FIGURE 2.39 (cont'd)
CC-*Calamagrostis canadensis,* CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta,* CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm'

Total Phosphorus (TP) Mass Balance

There were no differences in mass balance of unaccounted phosphorus between genera, native and ornamental species within genera (Figure 2.40). The highest unaccounted phosphorus was; *Calamagrostis canadensis* (3.28 [±4.10] mg), *Rudbeckia fulgida var. sullivantii* 'Goldsturm' (1.84 [±2.62] mg), *Carex stricta* at (1.33 [±0.78] mg), *Pycnanthemum muticum* (0.307 [±1.10] mg), *Carex muskingumensis* (0.21 [±1.36] mg), *Pycnanthemum virginianum* (0.21 [±1.70] mg), *Calamagrostis x acutiflora* 'Overdam' (0.17 [±0.89] mg), *Rudbeckia hirta* (-2.14 [±1.88] mg).

FIGURE 2.40 UNACCOUTNED FOR TOTAL PHOSPHORUS BY EACH PLANT SPECIES



*Data represent means ± SD.*CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm'

Pie charts represent the distribution of phosphorus in each species between soil, plant, effluent and unaccounted (Figure 2.41).

Figure 2.41 DISTRIBUTION OF PHOSPHORUS FOR EACH SPECIES

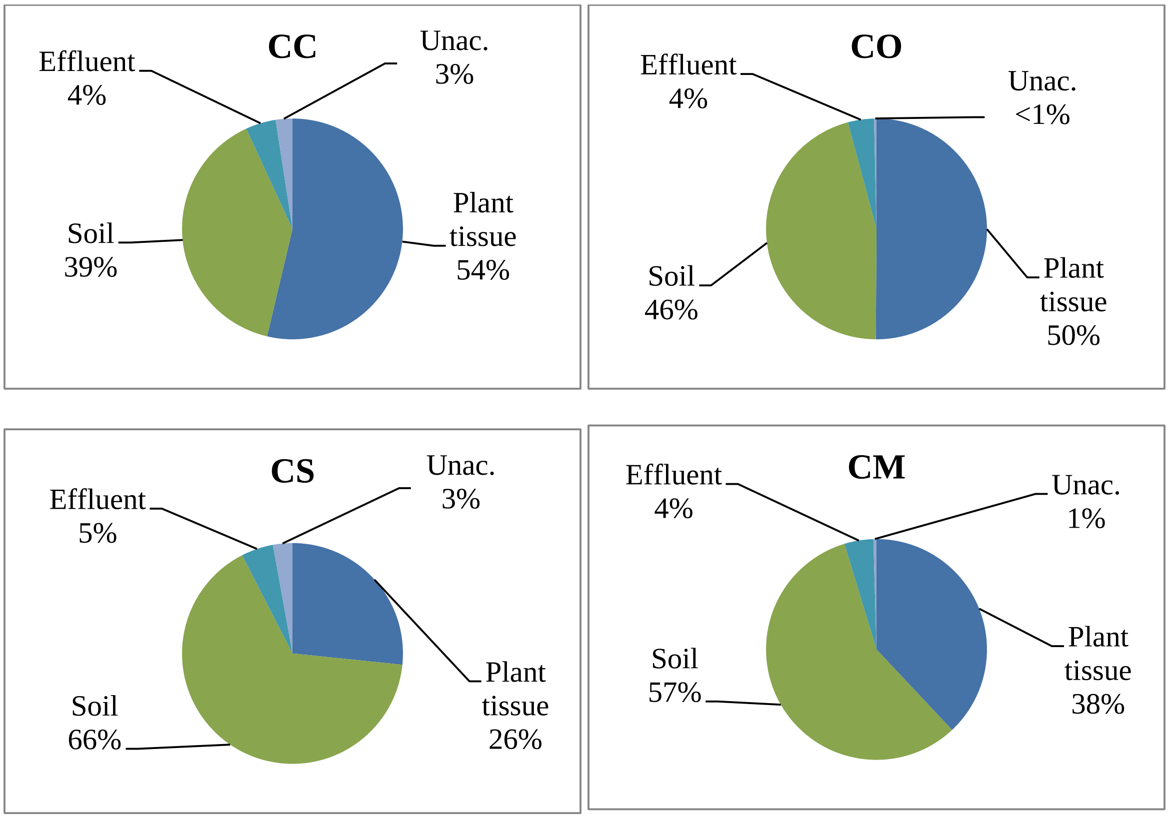
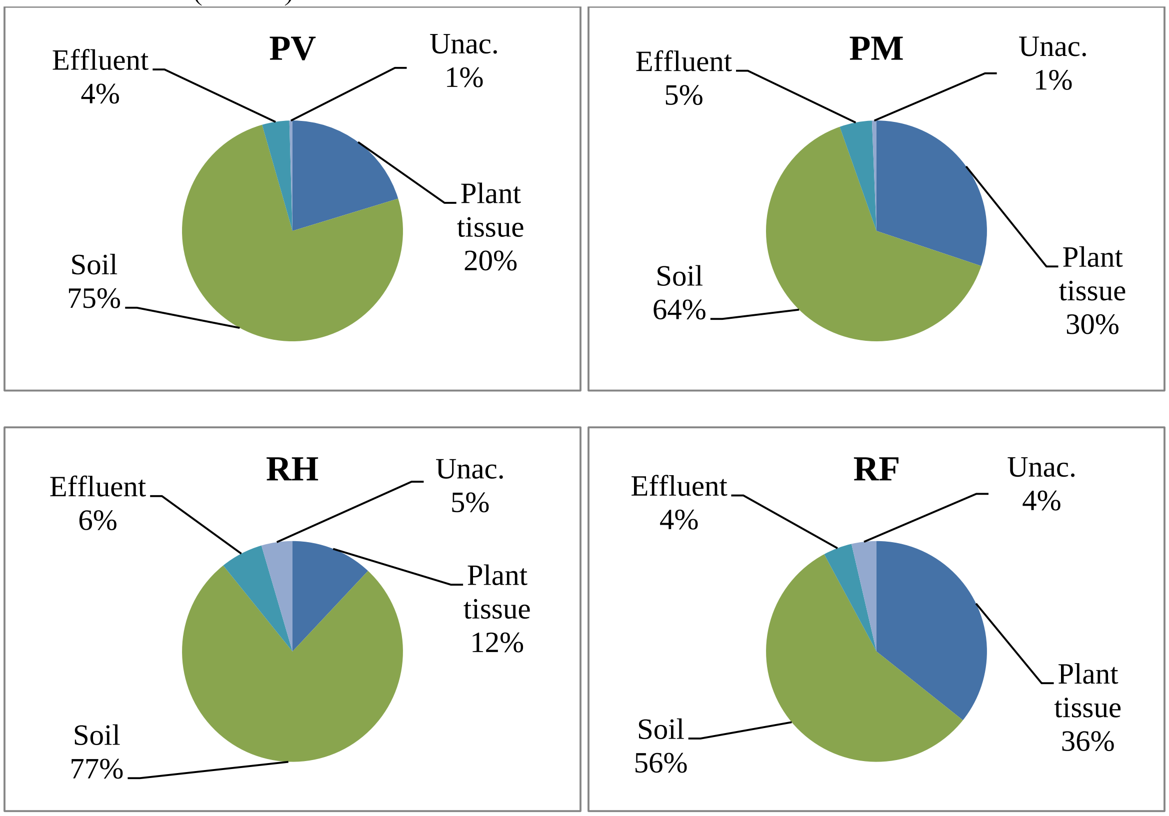


FIGURE 2.41 (cont'd)



CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* 'Overdam', CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* 'Goldsturm'

DISCUSSION

Water Use

Water use by plants was not strongly linked to increases in plant mass. Water use by each species was similar, and only Carex *muskingumensis* and *Calamagrostis x acutiflora* 'Overdam' exhibited a different from the control column. Water treatments simulated a 5.08 cm [2"] rainfall event, which is a 2 year 24 hour storm accounting for >90% of precipitation events in Michigan. This equates to 925 mL per column per treatment event. These treatments volumes were coupled with a weekly maintenance watering (300 mL). These low volumes for treatment led to low effluent volumes of water for each run. An experiment that tested for larger storm events (>5.08 cm) or events with greater frequency may display a greater difference between species and especially between the vegetated and control column water use. An increase in the water volume used may have exhibited changes in pollutant effluent concentrations, masses, as well as plant uptake and soil retention. Low effluent volumes may also be attributed to the cooling system implemented in the greenhouse to maintain a day and night constant temperature of 24°C for the duration of the study. The cooling system implements 2, 20" heavy duty greenhouse fans which are also used to reduce moisture levels and therefore increases evaporation.

Effluent

Ammonium (NH_4^+)

The removal of ammonium from the synthetic stormwater was very high for all species and control column (Table 2.24).

TABLE 2.24 REMOVAL RATE OF AMMONIUM

Species	**Removal Rate**
Calamagrostis canadensis	93.56%
Calamagrostis 'Overdam'	93.71%
Carex stricta	93.89%
Carex muskingumensis	94.14%
Pycnanthemum virginianum	94.16%
Pycnanthemum muticum	94.30%
Rudbeckia hirta	94.38%
Rudbeckia fulgida var. sullivantii 'Goldsturm'	94.77%
Control	94.83%

High removal rates regardless of plant species are similar to findings by Zhang et al. (2011) where vegetative columns exhibited a removal rate of 95% ammonium. The low concentrations of ammonium in the effluent water can typically be attributed to several factors. The positive charge of the ammonium ion (NH_4^+) is attracted to and held by negatively charged ions of clay soil particles which then bind the ammonium in the soil as the water infiltrates. The binding of the ammonium to soil and then uptake into the plant tissue would account for the decrease in soil ammonium for several species over the course of experiment and the increase in plant tissue nitrogen content in all species except *Rudbeckia hirta*.

Nitrate (NO_3^-)

The removal of nitrate varied for each species when compared to the control column. (Table 2.25), *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ exhibited the greatest removal rate (82.26%) with other species ranging between 42.83%-72.39%, removing more than the control column (33.74%).

TABLE 2.25 REMOVAL RATE OF NITRATE

Species	**Removal Rate**
Calamagrostis canadensis	67.92%
Calamagrostis 'Overdam'	70.38%
Carex stricta	42.83%
Carex muskingumensis	49.90%
Pycnanthemum virginianum	72.39%
Pycnanthemum muticum	71.88%
Rudbeckia hirta	57.37%
Rudbeckia fulgida var. sullivantii ‘Goldsturm’	82.26%
Control	33.74%

All removal rates were on average highest during the first (49-86%) and second (49-87%) treatment dates. Results varied for each sequential treatment until the spike nitrate treatment on 3/24 where all removal rates dropped. *Rudbeckia hirta* leached more nitrate (-9.25%) than the synthetic stormwater dose on 3/24 possibly due to mobilization of soil nitrate content or the conversion of other forms of nitrogen into nitrate. The second spike treatment dose (4/1), improved removal rates over 3/24 for all species, excluding *Carex muskingumensis*.

When comparing the native to ornamental species within genera, *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ was more effective than *Rudbeckia hirta* in removing nitrate from stormwater. All other genera displayed similar removal rates between native and ornamental plants. The effluent mass of nitrate did not correlate with plant mass, or water use, which differs from a study by Read (2010) where a correlation between the removal of nitrogen and plant root length, and vegetative mass was found. The length of the study may have been a factor in the lack of correlation of root mass with nitrate removal between this study and results found by Read (2010). The length of the testing period was 2 months for this study. A longer testing time may have increased overall root mass which could have led to improved capability of nitrate uptake. *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ was the most effective species at removal of nitrate while exhibiting one of the lowest masses (shoot: 9.7 g, root: 72.0 g). *Carex muskingumensis* mass was the highest (shoot: 23.8 g, root: 130.7 g), yet displayed one of the lowest removal rates. Stuber (2012) found *Carex comosa* removal rate of nitrate to be 96.7% where here the rates reported in this study were lower, *Carex muskingumensis* 49% and *Carex stricta* 42% respectively. *Carex comosa* species, (Stuber, 2012), received a larger volume of water due to the experiment saturating the columns with 2.5 cm prior to the application of the stormwater (500-800 mL). The saturating of the column prior to testing could change the removal efficiency by slowing the leaching of stormwater through the column and allowing for greater exposure time for treatment.

Orthophosphate

The removal of orthophosphate varied for each species when compared to the control column. (Table 2.26), *Pycnanthemum virginianum* exhibited the greatest removal rate (75.65%) with other species ranging between 58.94%-68.79%, removing more than the control column (24.96%).

TABLE 2.26 REMOVAL RATE OF PHOSPHATE

Species	**Removal Rate**
Calamagrostis canadensis	68.78%
Calamagrostis 'Overdam'	63.67%
Carex stricta	61.74%
Carex muskingumensis	58.94%
Pycnanthemum virginianum	75.65%
Pycnanthemum muticum	68.79%
Rudbeckia hirta	59.70%
Rudbeckia fulgida var. sullivantii ‘Goldsturm’	73.25%
Control	24.96%

Removal rates were very high (88.18 %) during the first treatment on 2/13 and then dropped for all species for the next two treatments. All columns expect the control show increasing removal rates after 3/10. This correlates with water use, as the effluent orthophosphate mass was lower with higher water usage. However there was no correlation between total plant mass and water use during the study. Therefore, there was no correlation that could be made between plant mass and orthophosphate removal efficiency. This is indicated by the two highest removal rates being displayed by two species with low mass *Pycnanthemum virginianum* (shoot: 4.39 g, root: 40.29 g) and *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ (shoot: 9.7 g, root: 72.0 g), both of which were lower than either *Carex* or *Calamagrostis* species. Studies have shown great variation in orthophosphate removal rates . A column study by Davis (2001) found a 70%

removal rate of phosphorus while Hsieh, et al., (2007) results exhibited only had 41-48% removal. Orthophosphate is impacted by the properties of soil media such as calcium for neutral to slightly basic soils and iron and aluminum in acidic soils. The positive removal of orthophosphate by all columns may be attributed to the higher calcium (2210 ppm ±396) content in the bioretention soil used for the study.

Total Nitrogen (TN)

The removal of total nitrogen varied for each species when compared to the control column. (Table 2.27), *Rudbeckia fulgida var. sullivantii* 'Goldsturm' exhibited the greatest removal rate (83.5%) with other species ranging between 61.54%-77.30%, removing more than the control column (30.41%).

TABLE 2.27 REMOVAL RATE OF TOTAL NITROGEN

Species	**Removal Rate**
Calamagrostis canadensis	71.41%
Calamagrostis 'Overdam'	74.20%
Carex stricta	61.54%
Carex muskingumensis	64.79%
Pycnanthemum virginianum	71.47%
Pycnanthemum muticum	71.91%
Rudbeckia hirta	77.30%
Rudbeckia fulgida var. sullivantii 'Goldsturm'	83.50%
Control	30.41%

For all columns the effluent total nitrogen increased for the first 4 treatments (3/10) and then dropped gradually until the spike treatment on 3/24 where the highest effluent masses were exhibited. However, the second spiked treatment (4/1) showed improved removal efficiency over 3/24 for all species except *Carex muskingumensis*. On the final treatment date (4/1), *Rudbeckia* *fulgida var. sullivantii* 'Goldsturm' removed 92.12% of the total nitrogen which was 8.62% more efficient than its average for the entire study. These results are similar to what was observed in the nitrate removal. Nitrate content is correlated to total nitrogen since nitrate constitutes 24% of the synthetic stormwater total nitrogen content for the first six treatments and 50% of the last two treatments (3/24 & 4/1) due to the spike. The greater retention of total nitrogen by plants was also seen by Lucas & Greenway (2009) where, in that study a vegetated column removed 76% as compared to 18% by a soil only column.

Total Phosphorus (TP)

Removal of total phosphorus differed for *Calamagrostis x acutiflora* 'Overdam' and *Pycnanthemum virginianum* as compared to the control column (Table 2.28). *Pycnanthemum virginianum* exhibited the greatest removal rate (80.5%) with other species ranging from 68.51%-79.93%, and the control column (68.46%).

TABLE 2.28 REMOVAL RATE OF TOTAL PHOSPHORUS

Species	**Removal Rate**
Calamagrostis canadensis	74.99%
Calamagrostis 'Overdam'	79.93%
Carex stricta	76.52%
Carex muskingumensis	78.49%
Pycnanthemum virginianum	80.50%
Pycnanthemum muticum	76.47%
Rudbeckia hirta	68.51%
Rudbeckia fulgida var. sullivantii 'Goldsturm'	77.35%
Control	68.46%

Rudbeckia was the only genus to show difference between species. The ornamental *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ had higher removal efficiency than the native *Rudbeckia hirta*.

Removal rates fluctuated with treatment date and species, with the widest range displayed on 3/10. On the 6^{th} treatment date (3/17) total phosphorus effluent was the lowest for all species. This correlated with the highest water use date of the experiment. Water use correlated with effluent total phosphorus mass, being lower with high water usage by all plant species. There was no correlation found between total plant mass and total phosphorus removal from effluent water during the study. The lack of differences between vegetative columns and the control column were similar to results found by Read (2008) where removal rates were 41% for vegetated columns as compared to 31% for soil only columns. High removal rates from effluent in columns is similar to orthophosphate, possibly due to high calcium content in the bioretention soil binding total phosphorus to soil particles.

Change in Plant Mass

Differences in plant mass were found between genera; *Calamagrostis* (monocot) had a higher mass increase than either dicot (*Pycnanthemum* & *Rudbeckia*).

Overall, the ornamental *Carex muskingumensis* and *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ had higher mass increase than their native counterparts. The difference between the *Rudbeckia* species was the greatest with the ornamental *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ having 197.35% greater mass change than the native *Rudbeckia hirta*. With the exception of *Rudbeckia hirta*, all plant species increased masses, similar to the results by Read

(2008). In which it was found that stormwater did not increase plant stress on growth and development.

Shoot mass increase was correlated with water use. Neither root, nor, total mass correlated with water use. Root and total mass were closely associated because most of the total mass increase was through roots (86%). The increase in root mass may have created greater channels in the soil allowing for more rapid movement of water through the column. While it is typically noted that increase in root mass improves treatment capabilities in bioretention systems there may be a tradeoff between infiltration and contact time between pollutants and plant roots.

Uptake

Nitrogen

Total nitrogen removal from stormwater attributed to plant tissue was (2.44% ±2.30%) with the highest by *Carex muskingumensis* (Table 2.29). Dietz and Clausen (2006) reported removal by plant tissue of only 0.3%, however in their study mulch removed an additional 33% prior to contact with plant roots.

TABLE 2.29 NITROGEN REMOVAL BY PLANT TISSUE

Species	**Nitrogen %**	
Calamagrostis canadensis	4.45%	±2.05%
Calamagrostis 'Overdam'	2.62%	±1.18%
Carex stricta	4.34%	±3.31%
Carex muskingumensis	4.58%	±1.48%
Pycnanthemum virginianum	0.88%	±0.45%
Pycnanthemum muticum	1.67%	±1.21%
Rudbeckia hirta	-0.06%	±0.70%
Rudbeckia fulgida var. sullivantii 'Goldsturm'	1.09%	±1.17%

Calamagrostis and *Carex* both exhibited higher uptake of nitrogen into plant tissue than either *Pycnanthemum* or *Rudbeckia*. This was correlated with total plant mass increase. The total plant mass for the *Calamagrostis* (130.08 g) and *Carex* (110.931 g) are greater than *Pycnanthemum* (61.695 g), and *Rudbeckia* (49.047 g). *Rudbeckia hirta* exhibited a loss of nitrogen in plant tissue due to plant dieback. While *Carex* and *Calamagrostis* had higher uptake, both genera did not correlate with greater removal efficiency from the effluent water. Also these two genera had a lower unaccounted for nitrogen in the mass balance (*Calamagrostis* [14%], *Carex* [12%]) than *Pycnanthemum* (18%) and *Rudbeckia* (18%). Unaccounted for nitrogen can be lost from the system through denitrification, which can be a preferable outcome as it removes the nitrogen from the system.

Phosphorus

Phosphorus removal from stormwater attributed to plant tissue assimilation was 1.66% ±1.25%. The highest uptake was exhibited by *Calamagrostis canadensis* (Table 2.30). Lower phosphorus assimilation was found in this study than the 3% reported by Dietz and Clausen (2006). The lower uptake by this study could be attributed to the binding of phosphorus onto soil particle surfaces due to the high calcium, thus making phosphorus less available for plant uptake.

TABLE 2.30 PHOSPHORUS REMOVAL BY PLANT TISSUE

Species	**Phosphorus %**	
Calamagrostis canadensis	3.14%	±1.15%
Calamagrostis 'Overdam'	2.63%	±0.96%
Carex stricta	1.46%	±0.56%
Carex muskingumensis	1.85%	±0.52%
Pycnanthemum virginianum	0.76%	±0.27%
Pycnanthemum muticum	1.45%	±0.96%
Rudbeckia hirta	-0.01%	±0.73%
Rudbeckia fulgida var. sullivantii ‘Goldsturm’	1.97%	±1.64%

Calamagrostis exhibited the only difference in uptake of phosphorus into the plant tissue over the other genera. This correlates with total plant mass increase as *Calamagrostis* (130.08 g) exhibited a greater mass than; *Carex* (110.931 g), *Pycnanthemum* (61.695 g), and *Rudbeckia* (49.047 g). As with nitrogen uptake *Rudbeckia hirta* exhibited a loss of phosphorus in plant tissue due to plant dieback. The uptake of phosphorus correlated with removal of total phosphorus from stormwater but not with orthophosphate. The high removal efficiency from the system was not correlated to plant tissue uptake. This could be due to the high calcium content in the soil as explained in the orthophosphate effluent discussion.

Copper

Pycnanthemum virginianum exhibited the greatest uptake of copper by any species (Table 2.31). In all other genera except *Rudbeckia* the native species exhibited increase uptake of copper over the ornamental species. The highest uptake of copper was by *Calamagrostis canadensis* and *Pycnanthemum virginianum*. However, species still accounted for much less of the copper uptake than the soil. Copper removal from stormwater attributed to plant tissue was (1.45% ±0.75%) while Dietz and Clausen (2006) reported only 0.1%.Typical copper content of plant tissue is between 8-20 (ppm), the copper concentration in the plant tissue after harvest were at a higher level. Several plant samples (*Calamagrostis canadensis [2]*, *Pycnanthemum virginianum [1], Rudbeckia hirta [1])* exhibited levels of copper >50ppm at the end of the study.

TABLE 2.31 REMOVAL RATE OF COPPER

Species	**Cu Removal Rate**
Calamagrostis canadensis	2.22%
Calamagrostis 'Overdam'	0.72%
Carex stricta	1.34%
Carex muskingumensis	0.55%
Pycnanthemum virginianum	2.53%
Pycnanthemum muticum	1.06%
Rudbeckia hirta	1.09%
Rudbeckia fulgida var. sullivantii 'Goldsturm'	1.22%

Zinc

Pycnanthemum virginianum exhibited the greatest uptake of zinc by any species (Table 2.32). No differences could be determined in the uptake of zinc between the genera. The uptake of zinc was similar between native and ornamental species with the exception of *Pycnanthemum virginianum* which exhibited a greater uptake over the ornamental *Pycnanthemum muticum.* Similar to copper uptake into the plant tissue, *Calamagrostis canadensis* and *Pycnanthemum virginianum* both exhibited the highest zinc uptake. The uptake of zinc in the soil column is significantly higher than that found in plant species. Since zinc is not a very mobile element it adheres to solid soil particles as the water moves through the columns. Zinc removal from stormwater attributed to solely plant tissue was (1.64% ±0.89%) while Dietz and Clausen (2006) reported removal by plant tissue of only 0.2%. This difference may be attributed to the number of samples found below the detection limit by Dietz and Clausen (2006). In addition a very low concentration of stormwater was used in the study (149 μg/L).

TABLE 2.32 REMOVAL RATE OF ZINC

Species	**Zn Removal Rate**
Calamagrostis canadensis	2.50%
Calamagrostis 'Overdam'	1.70%
Carex stricta	1.23%
Carex muskingumensis	0.65%
Pycnanthemum virginianum	3.14%
Pycnanthemum muticum	0.46%
Rudbeckia hirta	1.84%
Rudbeckia fulgida var. sullivantii 'Goldsturm'	1.64%

Lead

Lead uptake by plant tissue occurs at the roots by Ca_2^+ channels and apoplastic pathways and is controlled by the soil physiochemistry such as; pH, cation-exchange capacity, and soil particle sizing. *Pycnanthemum virginianum* exhibited the greatest uptake of lead by any species (Table 2.33). No differences could be determined in the uptake of lead between the genera, or between the native species and their ornamental counterparts. Overall the plant species accounted for a small amount of lead uptake into the plant tissue (0.75% ±0.24%) as compared to the soil. These results are similar to study findings by Dietz and Clausen (2006), which did not detect lead in plant tissue. For their study the removal rate may have been unusually low due to half of the samples being below the reporting limit and therefore removed from the data set.

TABLE 2.33 REMOVAL RATE OF LEAD

Species	Pb Removal Rate
Calamagrostis canadensis	0.69%
Calamagrostis 'Overdam'	0.75%
Carex stricta	0.41%
Carex muskingumensis	0.52%
Pycnanthemum virginianum	1.20%
Pycnanthemum muticum	0.91%
Rudbeckia hirta	0.89%
Rudbeckia fulgida var. sullivantii 'Goldsturm'	0.69%

Soil

Ammonium

Calamagrostis x acutiflora 'Overdam', *Carex muskingumensis*, *Pycnanthemum muticum*, *Rudbeckia hirta*, and *Rudbeckia fulgida var. sullivantii* 'Goldsturm' all differed from the control column in soil ammonium content. These five species all removed more ammonium than was present in the soil at the start of the experiment. *Calamagrostis canadensis*, *Carex stricta*, and *Pycnanthemum virginianum* all added ammonium to the soil.

These results do not correlate with the effluent mass of ammonium since all of the species exhibited high removal rates. These results also do not correlate with the nitrogen content in the plant tissue since *Calamagrostis canadensis* had the highest uptake of nitrogen while *Rudbeckia hirta* actually ended with less nitrogen in the tissue. This typically occurs in well-drained soils, such as that found in bioretention systems, where ammonium can quickly transform into nitrate (nitrification). The soil ammonium content may also be lost through ammonia volatilization converting to NH_3 gas and would be part of the unaccounted for nitrogen from the mass balance. The species with the highest unaccounted for nitrogen was

Pycnanthemum muticum, Rudbeckia hirta, and *Rudbeckia fulgida var. sullivantii* 'Goldsturm' which all removed ammonium from the soil but had low uptake into plant tissue.

Nitrate

All species had lower soil nitrate content than the control column. *Pycnanthemum* and *Rudbeckia* removing the most nitrate from soil. The ornamental species of *Calamagrostis*, *Carex* and *Pycnanthemum* removed more nitrate from the soil than the native species. The native *Rudbeckia hirta* removed more than the ornamental *Rudbeckia fulgida var. sullivantii* 'Goldsturm'.

When soil does not have sufficient oxygen, microorganisms use the oxygen from NO_3^- and rapidly convert NO_3^- to nitrogen oxide and nitrogen gases (N_2). These gases escape to the atmosphere and are not available to plants. This transformation can occur within two or three days in poorly aerated soil and can result in large loses from nitrate-type fertilizers.

All species and the control column had lower nitrate content than the initial concentration before the start of the experiment. Nitrate is either being converted in low oxygen conditions, or leaching from the columns.

Total Nitrogen

Only *Calamagrostis canadensis* exhibited a difference in soil total nitrogen from the control column. The lack of differences between the genera and species is due to the wide range in soil total nitrogen % for each column. All of the columns exhibited an increase in soil total nitrogen, and reduced nitrate content. Several species had a reduction in soil ammonium. This suggests that ammonium and nitrate forms of nitrogen converted into organic nitrogen and were immobilized in the soil by microorganisms.

Bray Phosphorus

On average, vegetation reduced the bray phosphorus soil content by 28.29% from the control column. This reduction in soil phosphorus may be due to uptake and assimilation in to plant tissue. *Calamagrostis* and *Carex* Both genera exhibited high root masses increases which would improve uptake of available phosphorus. This would suggest that since the plant species displayed lower effluent orthophosphate mass and a decrease in soil Bray phosphorus concentration that vegetation would improve the removal of phosphorus from a bioretention system regardless of being a native or ornamental plant species.

Copper, Zinc, & Lead

There were no differences between the control and any species for copper, zinc, and lead (Table 2.34).

TABLE 2.34 SOIL REMOVAL RATES OF COPPER ZINC & LEAD

Species	**Cu Removal**	**Zn Removal**	**Pb Removal**
Calamagrostis canadensis	93.69%	94.24%	92.74%
Calamagrostis 'Overdam'	94.26%	81.47%	89.84%
Carex stricta	92.64%	83.23%	95.16%
Carex muskingumensis	96.42%	95.99%	91.14%
Pycnanthemum virginianum	93.37%	74.90%	88.02%
Pycnanthemum muticum	94.90%	96.41%	95.53%
Rudbeckia hirta	93.88%	84.36%	90.93%
Rudbeckia fulgida var. sullivantii 'Goldsturm'	94.74%	83.35%	91.94%
Control	93.14%	75.68%	98.74%

These findings are similar to other studies where the soil media removed 88-97% (Sun & Davis 2005) and 93-98% (Muthanna et al. 2007) of metals respectively. Soil continues to be shown as the most effective remover of heavy metals from stormwater regardless of vegetation type.

Nitrogen Mass Balance

The range in unaccounted nitrogen in the mass balance contributed the lack of differences found between the species. This suggests that each columns interaction between plants, soil, organisms, and nutrients are highly variable.

Pycnanthemum muticum and *Rudbeckia hirta* had the highest unaccounted for nitrogen but two of the lowest changes in plant mass and effluent mass. This would indicate that nitrogen was leaving the system through another pathway such as denitrification due to the columns becoming saturated during the treatments or through ammonification.

Phosphorus Mass Balance

Percent of unaccounted phosphorus was low contributing to no differences being found between native and ornamental species. The percent of unaccounted phosphorus is low since it does not have the same mobility as nitrogen to leave the system.

CONCLUSION

The evaluation of native and ornamental plant species for pollution removal from stormwater under greenhouse conditions produced a range of results for effluent water quality as well as soil and plant tissue retention of pollutants.

The ornamental *Rudbeckia fulgida var. sullivantii* 'Goldsturm' consistently exhibited better performance than the native *Rudbeckia hirta* in nutrient removal of; nitrate, orthophosphate, total nitrogen, and total phosphorus. Overall, native or ornamental *Calamagrostis*, *Carex*, and *Pycnanthemum* did not provide any distinct advantage nutrient removal from stormwater. Results varied depending on the pollutant in question but very few differences were found. Species did display an improved efficiency over the soil control column for the removal of nutrients from stormwater.

No differences were found between ornamental and native species for metal uptake of the four genera investigated. Similar to the results found in other studies the uptake by plants (.75-1.64%) is much lower than the removal by the soil (75.68%-98.74%) for the metals; copper, zinc, and lead.

Several variables observed during the study did not have an impact on plant performance. Unlike the study by Read (2010) plant root mass did not affect the pollutant removal rates for the different species. Water use did have an impact of orthophosphate and total phosphorus removal of effluent pollutant content.

Overall, the study indicates that for these species the selection of native or ornamental plants will not improve performance of pollutant removal for bioretention applications.

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LITERATURE CITED

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CHAPTER 3: FIELD EVALUATION OF NATIVE AND ORNAMENTAL PLANT SPECIES WITHIN A BIORETENTION SITE

INTRODUCTION

Bioretention systems are being installed throughout the Great Lakes region as low impact development (LID) practices that reduce the effect of stormwater runoff on natural waterway ecosystems, which is found to be negatively impacted by stormwater pollutants. Research shows that vegetation can improve the efficiency of pollutant removal and increase the effectiveness of bioretention systems (Denman et al., 2006) (Henderson et al., 2007) (Pham et al., 2008) (Read et al.,2008). Vegetation has been observed to slow runoff flow and trap sediment & pollutants, while improving soil infiltration capacity through root structure in column studies (Read et al. 2008) (Read et al., 2009) (BES, 2007). The role of vegetation function is critical to the optimization of bioretention systems for stormwater management.

Bioretention basins pose a challenge to vegetation establishment and survival by exhibiting a range of environmental factors. Plants must have the ability to survive conditions of drought stress during the summer and potential for saturated and freezing soil in the winter. Summer drought may be coupled with elevated urban air temperatures leading to higher water use by plants. Plants must also compete with weed species that are carried to the basin with stormwater runoff. These challenges underline the need for careful plant selection for use in bioretention systems.

Previous studies have tested plants in column studies to observe pollutant removal capabilities of particular species in a controlled environment. However, there has been limited research that links pollutant removal with success under field conditions. The objective of this study was to determine a difference in performance between native and ornamental plant species of the same genus for growth and establishment in bioretention conditions.

MATERIALS & METHODS

This study compares performance of native and ornamental plant species for use in bioretention systems. Eight plant species; *Calamagrostis canadensis* (Michx.) (P. Beauv.), *Calamagrostis x acutiflora* (Schrad.) (Rchb.) 'Overdam', *Carex stricta* (Lam.), *Carex muskingumensis* (Schwein.), *Pycnanthemum virginianum* (L.), *Pycnanthemum muticum* (Michx.), *Rudbeckia hirta (L.)*, and *Rudbeckia fulgida* var. *sullivantii* 'Goldsturm' (Aiton), were evaluated for performance under field conditions. The field study was conducted in a bioretention system on the Michigan State University campus to determine the ability of the selected plant species to establish and produce horizontal coverage under field conditions.

Native Plant Selection

Four native plant species were selected: two herbaceous perennials (*Rudbeckia* & *Pycnanthemum*), one grass (*Calamagrostis*), and sedge (*Carex*). The plant species selected using criteria listed:

1. Perennial, non-woody stemmed plants.
2. Species proven to exist in the USDA Planting Hardiness Zone 5.
3. Defined as a species for bioretention by the Southeastern Michigan Council of Governments (SEMCOG) *Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers* (SEMCOG) 2008) plant list, Appendix C.
4. Evaluated in a phytoremediation study previous to the start of this research project as shown in Table 3.1.

TABLE 3.1 PHYTOREMEDIATION STUDIES OF PLANT SPECIES

Native Plant Species	Phytoremediation Study
Calamagrostis canadensis (Bluejoint Grass)	Fate of Naphthalene in Laboratory-Scale Bioretention Cells: Implications for Sustainable Stormwater Management (Lefevre et al. 2012)
Carex stricta (Tussock Sedge)	Greenhouse and Field Assessment of Phytoremediation for Petroleum Contaminants in a Riparian Zone (Euliss et al. 2008)
Pycnanthemum virginianum (Virginia Mountain Mint)	An Ecologically Engineered System for Remediation of Arsenic-Contaminated Water: Plant Species for Northwest (*Rofkar, 2010)*
Rudbeckia hirta (Black-eyed Susan)	Analysis of Arsenic Uptake by Plant Species Selected for Growth in Northwest Ohio by Inductively Coupled Plasma – Optical Emission Spectroscopy (Rofkar et al. 2007)

Ornamental Plant Selection

For each of the native plant species selected an ornamental plant species counterpart was selected for comparison. These ornamental plant species were selected using the following criteria;

1. A non-native species from the native plant genera was selected.
2. Perennial non-woody stemmed plants.
3. Species proven to establish in the USDA Planting Hardiness Zone 5.

4. Display a distinct ornamental quality differing from the native plants as described in Table 3.2.

TABLE 3.2 ORNAMENTAL QUALITY OF PLANT SPECIES

Ornamental Plant Species	**Ornamental Quality**
Calamagrostis x acutiflora 'Overdam' (Feather Reed Grass)	"'Overdam' is a hybrid (*C. arundinacea* x *C. epigejos*) feather reed grass cultivar which is valued for its variegated foliage, early bloom, vertical lines and ability to grow in wet soils." **Missouri Botanical Garden**, http://www.missouribotanicalgarden.org/gardens-gardening/your-garden/plant-finder/plant-details/kc/n750/calamagrostis-x-acutiflora-overdam.aspx
Carex muskingumensis (Palm Sedge)	"Dense, clump-forming sedge which is grown for its foliage effect. Produces rigid, erect stems to 20" tall with 8" long, pointed, grass-like, light green leaves radiating from the stem tops." **Missouri Botanical Garden**, http://www.missouribotanicalgarden.org/gardens-gardening/your-garden/plant-finder/plant-details/kc/r390/carex-muskingumensis.aspx
Pycnanthemum muticum (Clustered Mountainmint)	"Silvery bracts highlight dense clusters of small pinkish flowers from summer to early fall. The flowers are an extraordinarily good source of nectar for smaller types of butterflies. The leaves smell strongly of spearmint when they are crushed." **American Beauties Native Plants** http://www.abnativeplants.com/index.cfm?fuseaction=plants.plantdetail&plant_id=72
Rudbeckia fulgida 'Goldsturm' (Goldsturm Blackeyed Susan)	"This coneflower cultivar is an upright, rhizomatous, clump-forming perennial which typically grows 2-3' tall. Features large, daisy-like flowers (3-4" across) with deep yellow rays and dark brownish-black center disks. Flowers appear singly on stiff, branching stems in a prolific, long-lasting, mid-summer-to-fall bloom." **Missouri Botanical Garden,** http://www.missouribotanicalgarden.org/gardens-gardening/your-garden/plant-finder/plant-details/kc/i780/rudbeckia-fulgida-var.-sullivantii-goldsturm.aspx

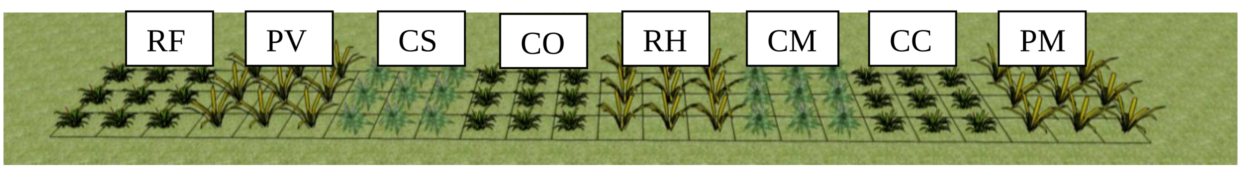
Site Preparation and Plant Installation

The bioretention basin field site was graded July of 2012, prior to the installation of plant material, allowing for uniform water movement through the system (Figure 3.1).

FIGURE 3.1 FLOW PATTERN AFTER SITE GRADING

The field study was a Completely Randomized Block Design with all 8 plant species replicated in 5 blocks (Figure 3.2).

FIGURE 3.2 EXAMPLE OF RANDOMIZED BLOCK DESIGN



Blocks were placed in the basin to create a range of moisture conditions for the plant species. Based upon water flow regime through the bioretention basin five flow patterns were determined. Blocks differ in estimated water received based on observations of soil surface soil moisture during measurement dates in 2012 and 2013. There were seven testing dates in 2012 and ten testing dates in 2013; soil moisture was noted for each block during each testing date.

Block 1: Nearest to water inlet (3.65 m). Surface soil moisture observed during all seven measurements in 2012 and all ten in 2013

Block 2: Next closest to the water inlet (9.14 m). Surface soil moisture observed during all seven measurements in 2012 and nine in 2013.

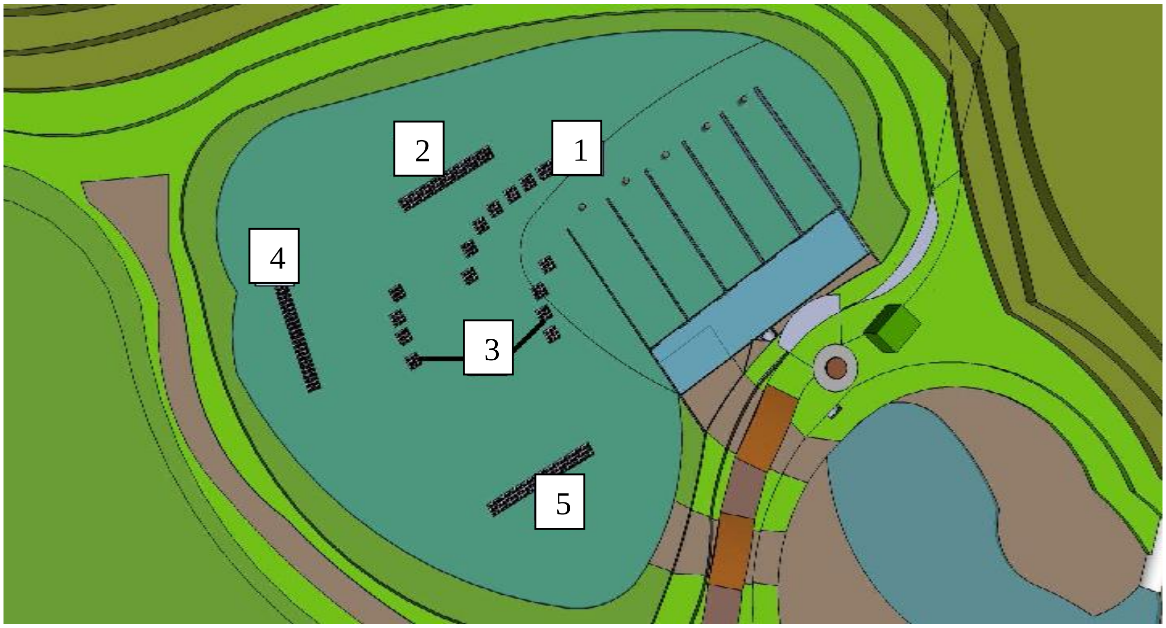
Block 3: Closest block to the center of the basin (11.58 m). Surface soil moisture observed during four measurements in 2012 and six in 2013.

Block 4: On the western edge of the basin (22.86 m). Surface soil moisture observed during one measurement in 2012 and one in 2013.

Block 5: Farthest block from the inlet (27.43 m). Surface soil moisture observed during one measurement in 2012 and one in 2013.

Locations were selected and mapped for 5 blocks (Figure 3.3). These blocks were positioned to allow as even of a flow and water volume for each of the plants within a single block.

FIGURE 3.3 BLOCK LOCATION WITHIN THE BASIN



Each block contains 9 plants from each of the 8 species, for 72 plants per block, and a total of 360 plants for the entire field study. Each block was hand weeded prior to planting. Plants were installed on July 23, 2012 using standard planting methods. Each plant species was placed 30 cm on centers (o.c.) within a 1 m by 1m square area with 30 cm spacing between species (Figure 3.4) (Figure 3.5).

FIGURE 3.4 EXAMPLE OF SPACING BETWEEN AND WITHIN THE BLOCK

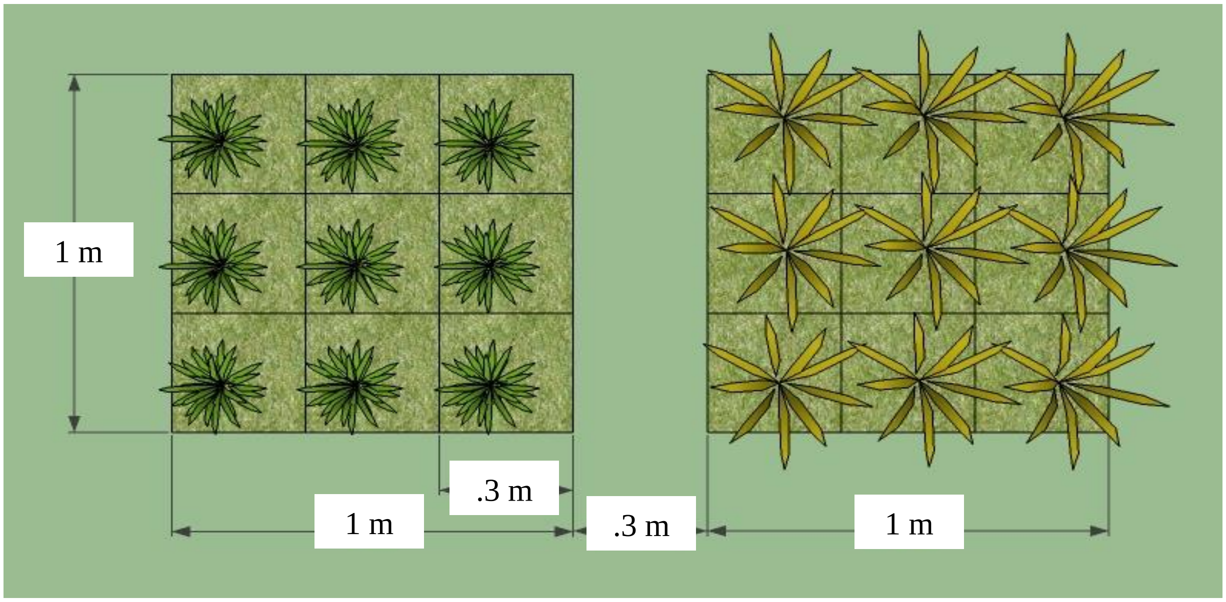


FIGURE 3.5 INSTALLATION OF BLOCK 5

Bioretention Soil Characteristics

The bioretention soil media was installed in 2010 and was composed of 85% clean sand, 12% top soil, and 3% compost. The permeability test conducted after construction was 12.7 cm/hr. The drainage layer is at ~1m depth uniformly across the basin, consisting of 6A peastone with an underdrain that leads to the outlet pipe.

Bulk density of the soil was taken on 7-20-12 (Table 3.3). This was determined using the USDA 2008 method of testing. 5 random samples were taken from each block at 3 depths using a 3” bulk density ring obtained from the *Hancock Turfgrass* Research Center, East Lansing, MI.

TABLE 3.3 BULK DENSITY TEST

Test:	Bulk Density			
Site	Bioretention Basin			
Date:	7/20/2012			
Sample	0-15 cm	15-30 cm	30-15 cm	units
Density	1.534 ±0.067	1.546 ±0.078	1.584 ±0.086	g/cm3

Soil samples were taken at 8 random points within each section of a block and at 3 different depths of; 0-4”, 4-8” and 8-12”. The 8 samples at each depth will be mixed giving 3 different samples from each block for a total of 15 soil samples that were evaluated (Table 3.4). These samples were evaluated in the Soil and Plant Nutrient Laboratory in A81 Plant Soil Science Building, East Lansing, MI. The samples were tested for; pH, Bray-P, K, Ca, Mg, Nitrate, Total Nitrogen, Ammonium, and organic matter %, from each of the proposed blocks of plants to establish the base conditions of the field sites soil.

TABLE 3.4 SOIL NUTRIENT DATA

Bray Phosphorus	ppm	32.20	± 24.9
Potassium	ppm	32.00	± 9.57
Calcium	ppm	2122.00	± 396.1
Magnesium	ppm	141.00	± 23.7
Organic Matter	%	1.87	± 0.271
Total N	%	0.02	± 0.011
Nitrate-N	ppm N as	5.80	± 6.63
Ammonium-N	ppm N as	2.01	± 1.28
pH		8.13	± 0.157

Watering & weeding

Following installation, the plants were watered as needed for the first 4 weeks to promote establishment (Figure 3.6). The water was taken from the pretreatment settling pond within the bioretention system (Figure 3.7). Within each planting block a .5 m perimeter was weeded by hand for the duration of the study (Figure 3.8).

FIGURE 3.6 WATERING OF ONE SPECIES

FIGURE 3.7 SETTLING POND

FIGURE 3.8 WEEDING AROUND EACH PLANT CELL

Plant establishment and horizontal coverage

Plants were evaluated for 2 growing seasons, August to November 2012 and May to October 2013 to determine percentage plant cover using a quadrant method with digital photographs (Cox, 1990) for plant coverage evaluations. Starting 8-20-2013, a digital image was taken at the predetermined height of 1.67 meters and in the center of each plant species within all 5 blocks for a total 40 images. This was repeated every two weeks until 11-24-13 and resumed again 5-3-13 until 9-4-13. These images were then uploaded to Photoshop CS 6.0 image software (Adobe Inc.) where the digital image area outside the delineated 1m x 1m stakes were cropped from each image to retain only the cell (Figure 3.9). The pixels were then determined using the Histogram function (Figure 3.10). After the total pixels were determined for the cell area the Color Range function was used to select the pixels of just the vegetation and removed the background pixels from the image. Any weed plants also growing in the cell were removed using the Eraser function as needed. Once only the plant species remained on the image, the pixel count was recorded (Figure 3.11). The pixel count for the plant was then divided by the total pixels for the cell to determine plant horizontal coverage at that time.

FIGURE 3.9 IMAGE OF PLANT CELL

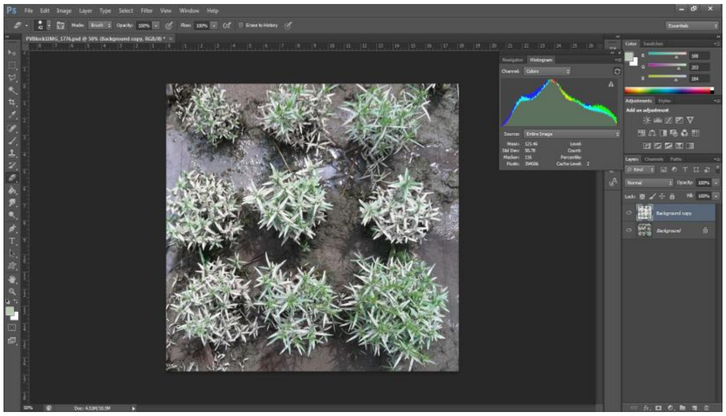


FIGURE 3.10 PLANT BACKGROUND REMOVED WITH COLOR RANGE FUNCTION

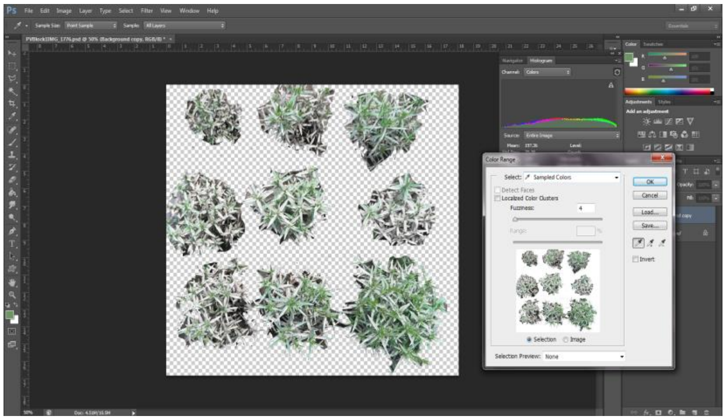
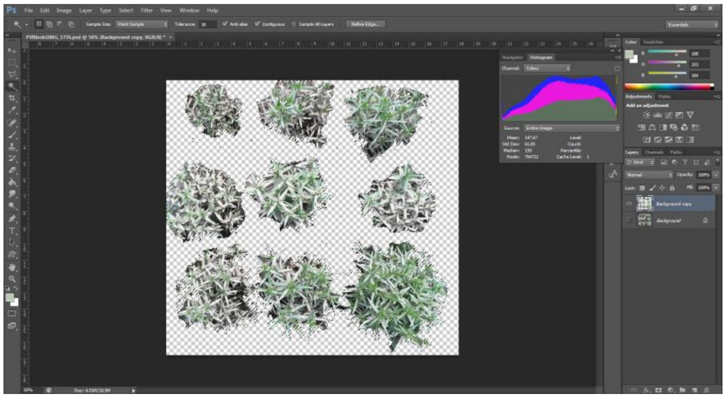


FIGURE 3.11 PIXELS DETERMINED FOR HORIZONTAL COVER



Root Length Evaluation

After the last plant growth evaluation was completed on 9-4-13, plants were removed to evaluate the change in biomass and root lengths were measured. To achieve an accurate root length measurement on the edge of each block, ~.3 meters from the plants a trench was dug down to the sub-drainage crushed rock layer 1 meter below the surface. Once a trench was dug, soil was scraped away towards the plant root systems using metal rakes and a shovel. Once the plant roots were identified the soil was removed below the longest identifiable root for each of the three plants on the edge of the block for each species. With the soil removed the longest roots for three plants hung down freely and were measured (Figure 3.12).

FIGURE 3.12 EXCAVATION FOR ROOT LENGTH & SAMPLES FOR PLANT MASS

Plant Mass

After the longest roots were measured the first row of plants were removed. The second row of three plants were extracted while retaining as many roots and above ground vegetation as possible. Three plants of each species from each block were then gently washed with tap water to remove soil from roots and crowns. After washing the plants were then divided between roots and shoots and put into paper bags (Figure 3.13). Roots and shoots from each species was taken to the Michigan State University Horticulture Farm and put in drying ovens at 60° C for 72 hours. These samples were then weighed against the initial plugs mass to attain mass increase of shoots, roots, and total mass (Table 3.5).

TABLE 3.5 INITIAL PLANT MASS

SPECIES	SHOOT (g)	ROOT (g)
Calamagrostis canadensis,	2.72	1.74
Calamagrostis x acutiflora 'Overdam'	2.48	2.72
Carex stricta	2.31	5.44
Carex muskingumensis	1.71	1.34
Pycnanthemum virginianum,	3.28	5.99
Pycnanthemum muticum	2.21	2.39
Rudbeckia hirta	1.13	2.33
Rudbeckia fulgida 'Goldsturm'	3.62	2.18

FIGURE 3.13 REMOVAL OF SOIL FROM SAMPLES AND PARTITIONING OF SHOOTS FROM ROOTS

Bioretention Basin Water Quality

Water samples were taken at the influent and effluent points of the bioretention basin during the growing season for the Michigan State University Stormwater Quality Monitoring Project. Sampling began March 2012 to November 2012 and started again May 2013 to November 2013. Water tested was captured prior to entering the bioretention basin (influent), and after leaving the basin (effluent). The samples taken are being tested for; chemical oxygen demand (COD), pH, and totals solids (TS).

Statistical Analysis

Statistical analysis was performed using SAS 9.3 (2011). Statistical evaluation of data was conducted for horizontal cover for each species by block by date for 2012 and 2013. A random mixed model for coverage data was developed using repeated terms to describe the r-matrix in the model. A means comparison was conducted using least squared means for fixed effects which estimated the marginal means. Due to the failure of *Rudbeckia hirta* in all blocks the zero values were dropped for coverage to help model fitting. Plant shoot, root, total mass, as well as root length were all evaluated using a repeated mixed model with a means comparison using least squared means for fixed effects.

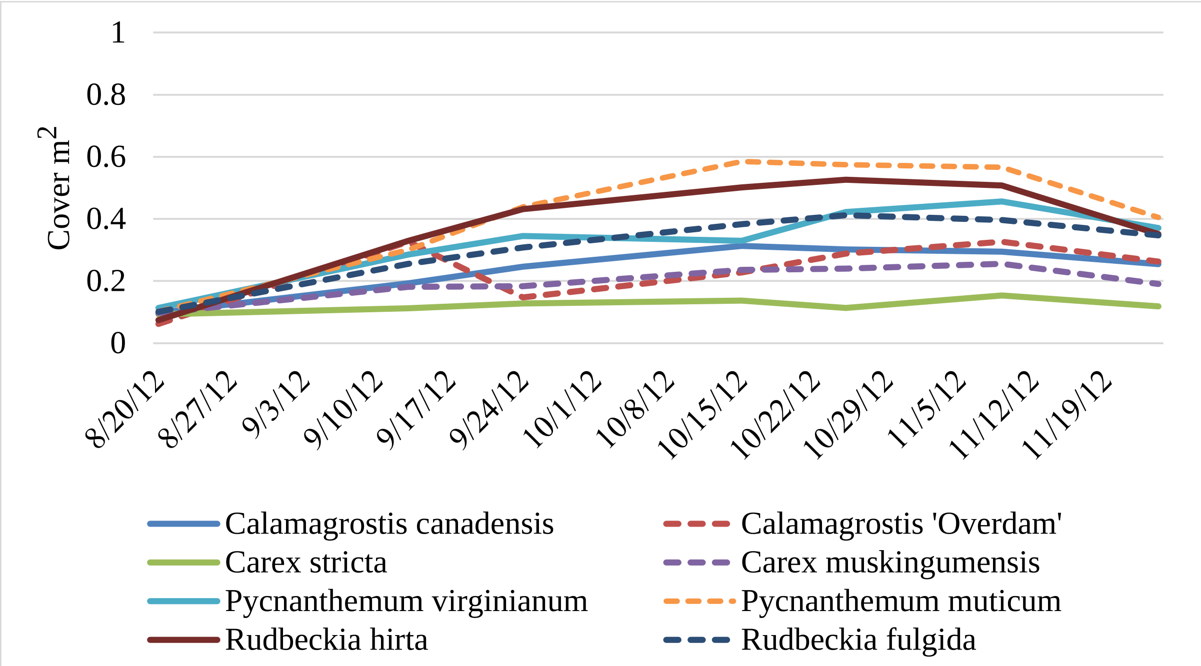
RESULTS

Horizontal Coverage

The plant species coverage was calculated seven times in 2012 starting on 8-20 and ending 11-24 (Figure 3.14). The coverage was evaluated two ways; comparing the native and ornamental species for each of the four genera in each of the five blocks by date, and overall change across all the blocks by date.

2012 Coverage

FIGURE 3.14 PLANT MASS COVER 8-20-12 TO 11-24-12

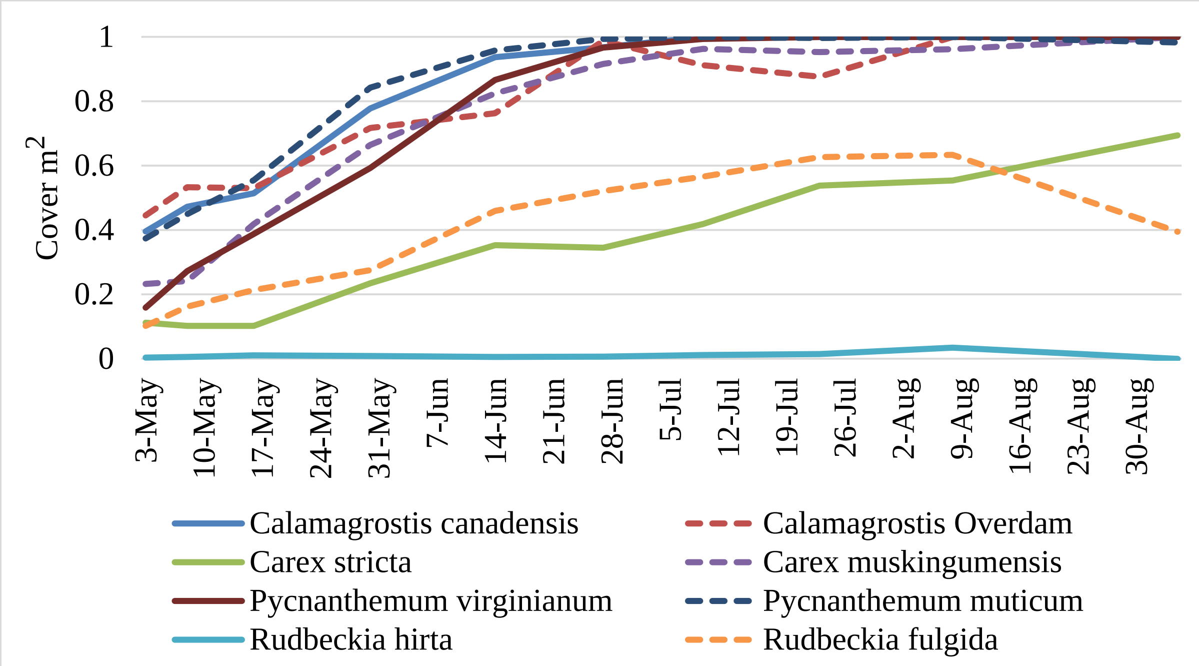


From August to November of 2012 no difference was exhibited between native and ornamental species for *Calamagrostis*, *Pycnanthemum*, and *Rudbeckia* for overall coverage of by date. On 11-9-12 the ornamental *Carex muskingumensis*, exhibited an increase in cover over the native *Carex stricta* (P-value 0.0351).

2013 Coverage

In 2013 ten measurements were taken starting 5-3 and ending on 9-4. During the 2013, *Rudbeckia hirta* field plants failed to emerge in the spring except in block 3. Seeds from 2012 *Rudbeckia hirta* germinated in blocks 2 but failed to thrive and were not present after 5-30. All other species emerged by 5-3 and grew in all five blocks (Figure 3.15).

FIGURE 3.15 PLANT MASS COVER 5-3-13 TO 9-4-13



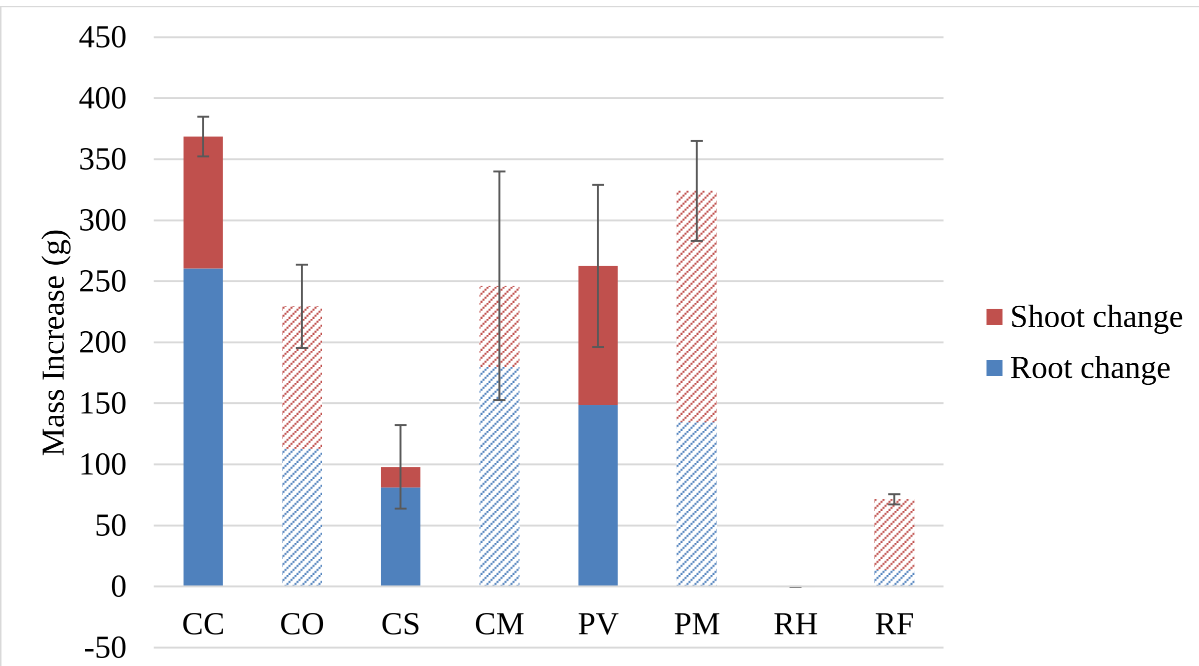
The ornamental *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ had an increase in horizontal coverage over the native *Rudbeckia hirta*. The ornamental *Carex muskingumensis* had an increase in coverage over the native *Carex stricta*. The genera, *Calamagrostis* and *Pycnanthemum*, both exhibited >90% coverage by 6-27, but did not exhibit a difference between the native and ornamental species for 2013.

The first difference shown by date was exhibited on 5-16; the ornamental *Carex muskingumensis* exhibited increased coverage over the native *Carex stricta*, which continued until 8-8 when both were not significantly different. *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ exhibited greater coverage over the native *Rudbeckia hirta*. Neither *Calamagrostis* nor *Pycnanthemum* had a difference in coverage between native and ornamental species for any of the dates, with all species reaching >90% m^2 coverage by July 2013.

Total Mass

Total plant mass of *Calamagrostis*, *Carex*, and *Rudbeckia* all displayed a difference between the native and ornamental plant species (Figure 3.16). *Pycnanthemum* did not exhibit a difference in total mass. The native *Calamagrostis canadensis* (369 g ±16) had a greater mass than the ornamental *Calamagrostis x acutiflora* 'Overdam' (229 g ±34) (p-value .0012). The ornamental *Carex muskingumensis* (246 g ±93) had a greater mass than the native *Carex stricta* (97 g ±34) (p-value .0038) and *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ (71 g ±4.2) over the native *Rudbeckia hirta* (0g).

FIGURE 3.16 SHOOT, ROOT, AND TOTAL MASS INCREASE



Data represent means ± SD. CC-*Calamagrostis canadensis,* CO-*Calamagrostis x acutiflora* ‘Overdam’, CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, *PM-Pycnanthemum muticum*, *RH-Rudbeckia hirta*, *RF-Rudbeckia fulgida var. sullivantii* ‘Goldsturm’

Root Mass

Calamagrostis, Carex, and Rudbeckia exhibited a difference between a native and ornamental plant species for root mass. The native *Calamagrostis canadensis* (260 g ±55) was found to have a greater root mass than *Calamagrostis x acutiflora* ‘Overdam’ (114 g ±64) (p-value <.0001). Also the ornamental *Carex muskingumensis* (180 g ±86) exhibited greater root mass than the native Carex stricta (82 g ±39) (p-value 0.045) and *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ (23 g ±13) over the native *Rudbeckia hirta* (0g).

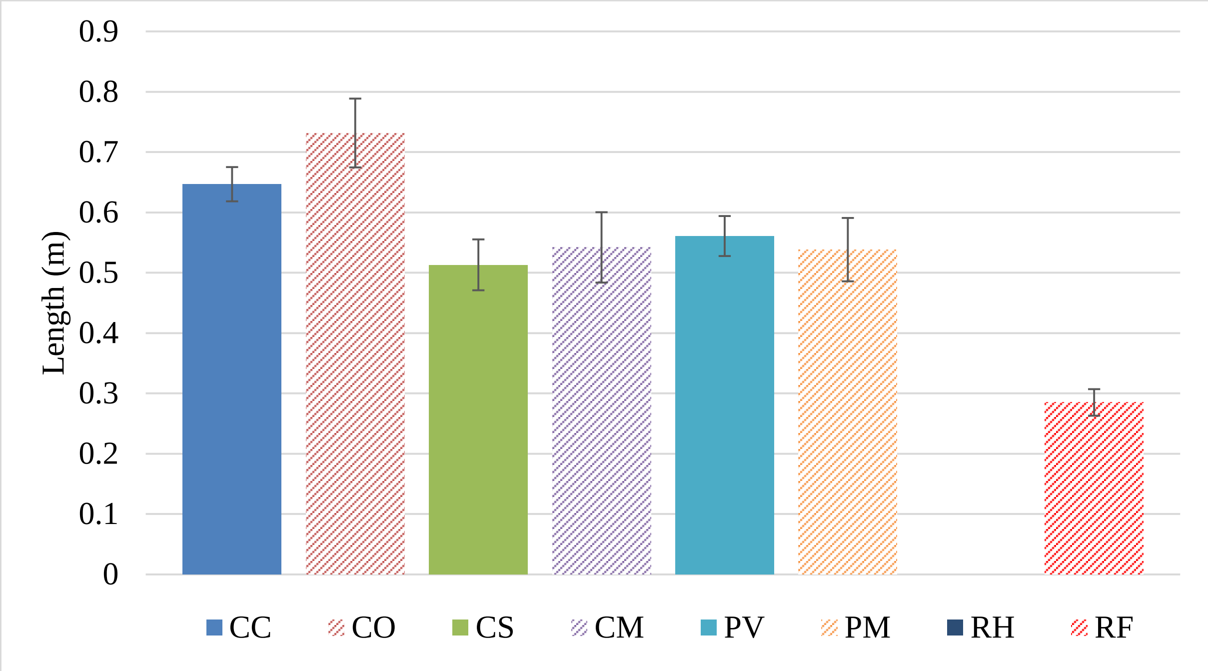
Shoot Mass

Shoot mass differences were found in *Carex, Pycnanthemum* and *Rudbeckia*. In all three cases the ornamental species had greater shoot mass increase over the native plants; *Carex muskingumens*is (66 g ±28) over Carex stricta (17 g ±8) (p-value 0.0024), Pycnanthemum muticum (189 g ±40) over Pycnanthemum virginianum (113 g ±32) (p-value 0.0234), and *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ (97 g ±31) over Rudbeckia hirta (0g).

Root Length

The *Calamagrostis*, *Carex*, and *Pycnanthemum* exhibited similar root lengths when averaged across the blocks (Figure 3.17). The root length of *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ was greater since no native *Rudbeckia hirta* existed at the end of the study.

FIGURE 3.17 ROOT LENGTH



Data represent means ± SD. CC-*Calamagrostis canadensis*, CO-*Calamagrostis x acutiflora* ‘Overdam’, CS-*Carex stricta*, CM- *Carex muskingumensis*, PV-*Pycnanthemum virginianum*, PM-*Pycnanthemum muticum*, RH-*Rudbeckia hirta*, RF-*Rudbeckia fulgida var. sullivantii* ‘Goldsturm’

DISCUSSION

Horizontal Coverage 2012

Throughout 2012 the plant growth and establishment was comparable between species. *Rudbeckia hirta* (38.8%) and *Pycnanthemum muticum* (42.4%) both exhibited the highest average cover. *Calamagrostis canadensis* (24.2%), *Calamagrostis x acutiflora* 'Overdam' (23.4%), *Pycnanthemum virginianum* (33.1%) and *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ (31.4%) while slower to establish by the end of the season exhibited similar overall coverage. *Carex muskingumensis* (19.7%) and *Carex stricta* (12.1%) lagged behind the other species suggesting that *Carex* species may be slow to establish in bioretention environments. This could lead to increases weeding and maintenance needs for the site.

Calamagrostis canadensis exhibited the highest growth in block 2 at 47.7% on 10-25. Blocks 1, 4, & 5 were exhibited similar cover (put in block %). Block 3 exhibited the lowest cover (19.3%) for 2012. *Calamagrostis x acutiflora* 'Overdam' had low cover still by 9-24 (14.7%), but all plants survived to reemerge in 2013. Block 4 exhibited the lowest growth (13.5%) with all other blocks exhibiting similar coverage (23.0-28.0%).

Carex stricta exhibited the lowest cover (6.2-20.1%) throughout 2012 of all the species. Block 1 exhibited the highest coverage of 29.5% on 11-9. The lowest coverage for 2012 were blocks 4&5 (6.2% & 9.2%). *Carex muskingumensis* had low overall coverage across all blocks (11.5-27.0%). The highest cover was exhibited in block 2 at 41.5% on 11-9.

Pycnanthemum virginianum exhibited the highest horizontal growth in blocks 4 & 5, exhibiting 61.2-42.2% on 10-25. For 2012 *Pycnanthemum virginianum* exhibited the highest growth in blocks 4&5 and the lowest growth in block 1 (22.9%). *Pycnanthemum muticum*, while exhibiting the overall highest growth for all five blocks (42%). The lowest cover exhibited for *Pycnanthemum muticum* was in blocks 1 & 5.

Rudbeckia hirta growth was rapid until 9-24. In the blocks 4 & 5, *Rudbeckia hirta* exhibited rapid growth and establishment with horizontal cover of 90.2-92.6% by 10-25. *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ exhibited very consistent cover results from blocks 1-3 (20.8-28.3%), while having much higher cover in blocks 4 & 5 (35.9-48.2%). On 10-15 *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ covered 67.8% of block 5 while only covering 22-29% of blocks 1-3.

Horizontal Coverage 2013

On 4-20-13 there was no evidence of emergence of any plant species from dormancy. On the first observation date, 5-3-13, all plant species excluding *Rudbeckia hirta* had emerged and established new vegetative cover. *Calamagrostis canadensis, Calamagrostis x acutiflora* 'Overdam', *Pycnanthemum muticum, Pycnanthemum virginianum,* and *Carex muskingumensis* increased in cover rapidly. *Carex stricta* and *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ did not increase cover as quickly. By the 6-27*, Calamagrostis canadensis, Calamagrostis x acutiflora* 'Overdam', *Pycnanthemum muticum, Pycnanthemum virginianum,* and *Carex muskingumensis* had established >90% cover in five blocks that continued until the end of the study. *Carex stricta* and *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ never established >70% cover throughout the 2013 growing season.

Calamagrostis canadensis emerged from dormancy quickly and established horizontal cover in all five blocks. By 5-30, the species had 77.7% coverage. Five blocks exhibited 100% cover by 7-9. Differences between block locations did not impact horizontal cover and *Calamagrostis canadensis* exhibited the potential to provide coverage early in the growing season for bioretention basin applications. *Calamagrostis x acutiflora* 'Overdam' emergence into spring growth was similar to *Calamagrostis canadensis. Calamagrostis x acutiflora* 'Overdam' had established 95.0-100% cover by 6-27. From 7-9 to 7-23, blocks 4 & 5 exhibited a decrease in cover indicating a potential sensitivity to drought since July was the month with the lowest precipitation (6.75 cm).

Carex stricta was slow to create cover, averaging >50% coverage only after 7-23. On the final testing date 9-4, blocks 4 & 5 (60.1-52.8%) exhibited lower cover than blocks 1-3 (72.8-83.5%) which is similar to the differences by block locations cover exhibited during 2012. *Carex* *muskingumensis* had a rapid change in cover from 5-8 to 6-14 to 58% across all block locations. Two plants in Block 3 did not emerge in the spring which reduced the cover of that block, not reaching 100% cover until 9-4. All blocks exhibited 64-100% cover by 6-14 and maintained high cover until the end of the study regardless of block location.

Pycnanthemum virginianum exhibited rapid growth and coverage, by 6-14 the average cover across all five block locations was 86%, and 96% by 6-27. Cover was not influenced by block locations. *Pycnanthemum muticum* exhibited similar cover to *Pycnanthemum virginianum* with the exception of block 1. In block 1, two plant samples failed to reemerge in the spring, and cover was delayed as compared to the other blocks as evident on 5-30, when block 1 cover was 39% and blocks 2-5 were 92-100% cover. By 6-27 the cover of block 1 was the same as the other four locations and continued with full coverage until the end of the study.

Rudbeckia hirta failed to emerge in the spring from any of the block locations and cover was 0% for the 2013 season. *Rudbeckia fulgida var. sullivantii* 'Goldsturm' had six of nine plant samples in block 1 fail to reemerge in the spring. Block 4 exhibited high early growth, 21.3% by 5-8 but by 5-30 eight of the nine samples had failed. Blocks 2, 3 & 5 all exhibited full growth by 7-23. Flooding of the site occurred twice in August 2013, in both cases plants were submerged up to ~60 cm for up to 24 hours. During the second flooding period *Rudbeckia fulgida var. sullivantii* 'Goldsturm' exhibited 100% mortality of samples in block 5. This indicates that this species is unable to tolerate saturated soil conditions during the growing season.

Total Mass & Root Length

Calamagrostis canadensis exhibited the highest mass increase (368 ±16 g) of all the plant species, with most of the increase exhibited in the roots (260 ±7.2 g). *Calamagrostis x acutiflora*

'Overdam' was significantly lower in total plant mass but exhibited a much more even distribution between roots (113 ±30 g) and shoots (116 ±4.9 g). Overall there were no differences in horizontal cover performance; therefore the mass was not significant indicator of performance between the native and ornamental *Calamagrostis.*

The native *Pycnanthemum virginianum* (262 ±66 g) and ornamental *Pycnanthemum muticum* (323 ±40 g) species did not exhibit a difference in total plant mass nor between root ([148 ±45 g], [134 ±37 g]) and shoot mass ([113 ±36 g], [189 ±14 g]). These plants also exhibited similar cover across all blocks as well which indicates the potential for similar performance of native and ornamental *Pycnanthemum* species in bioretention basins.

There were differences exhibited in masses between the native and ornamental *Carex* species. The Ornamental *Carex muskingumensis* had 222% more root and 412% more shoot masses than the native *Carex stricta*. This higher mass was evident in the higher horizontal coverage for *Carex muskingumensis* for block locations for 2013. There were no differences in root length between the species.

Rudbeckia hirta did not reemerge during the 2013 season, there were no comparisons made between the native and ornamental *Rudbeckia* species. *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ total mass (71 ±4.2 g) was significantly less than all species except *Carex stricta* (97 ±34 g). Root length of *Rudbeckia fulgida var. sullivantii* ‘Goldsturm’ (0.28 ± 0.02 m) was shorter than all other species measured. The low root mass and short length indicates a non-extensive and shallow root system which could have led to the failures of block 4 & 5.

CONCLUSION

Overall this study indicates several species have potential for bioretention applications. There is the potential for limiting the need of maintenance of bioretention basins by establishing extensive horizontal cover. Bioretention vegetation needs early spring emergence and rapid growth. Plants that are slow to break dormancy and establish cover will be outcompeted by weed species especially early season weeds that emerge early, grow rapids and reproduce quickly. Annual plant species will always be a challenge in these systems because of their potential for rapid growth in uncovered ground.

The challenge for bioretention systems is that weed seeds enter from a much larger area than in other landscape areas. All weed seeds that land on the basin itself or in the drainage area, can travel into the basin and have the potential to become established.

Calamagrostis canadensis and *Calamagrostis x acutiflora* 'Overdam' exhibited similar results for horizontal cover. Both species survived to reemerge in the spring and achieved 100% cover in all five blocks by the end of the study. Overall, plant mass did not influence performance of these species. *Calamagrostis x acutiflora* 'Overdam' did exhibit some loss of cover during July of 2013 potentially due to drought stress. Neither species showed adverse effects to the two periods of flooding in August. Cover by the native and ornamental *Calamagrostis* species indicate that both have the potential to be successfully implemented in bioretention basins.

The native and ornamental *Carex* exhibited different levels of success. The native *Carex stricta* exhibited limited cover due to the growth habit of the species. *Carex stricta* displays a low density of leaves and an upright form which reduces the area covered by each plant. While the species survived and did provide cover in all five blocks, the lack of vegetative density of the plants would allow for pressure from weed species. *Carex muskingumensis* exhibits a fan leaf growth pattern that maximizes the horizontal cover. All blocks exhibited total coverage regardless of block location. Under field conditions in this study the ornamental *Carex muskingumensis* outperformed the native *Carex stricta*.

The native *Pycnanthemum virginianum* and ornamental *Pycnanthemum muticum* established in all 5 block locations and created horizontal cover of ≥1m. The dense vegetation exhibited during the 2013 season had the potential to prohibit weed species from establishing. The rhizomatous growth habit of these species potentially leading to fewer plants needed to cover an area. Both species were also observed to have bees and other insects during their flowering season adding to biodiversity. The native and ornamental species exhibited similar performance in regards to bioretention applications.

The initial cover by *Rudbeckia hirta* in 2012 suggested that the species is a good native plant for bioretention applications. It provided horizontal cover to outcompete weed species. However, the species failed to reemerge in the spring, questioning consistent presence within bioretention system. The ornamental, *Rudbeckia fulgida var. sullivantii* 'Goldsturm', exhibited mixed results based upon block location. Three of the five blocks exhibited high coverage for most of 2013. Two blocks failed early, and block 5 was unable to survive a period of flooding, indicating poor tolerance. Overall, both the native and ornamental *Rudbeckia* species exhibited poor performance in the bioretention basin.

This study suggests that the selection of native or ornamental plant species will not improve performance growth and establishment of vegetation for use in bioretention systems.

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