NITROGEN, PHOSPHORUS AND POTASSIUM REMOVAL FROM PERENNIAL ENERGY GRASSES WHEN GROWN ON WET MARGINAL LAND

BY

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THESIS

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ABSTRACT

Reduction of nutrient loss from agricultural lands is a major concern facing the agricultural industry. On-farm efforts will lead to a proactive approach that has the potential to confer key ecosystem services. The field study was conducted from 2012 to 2015 on marginal land located at the beginning of a priority IL watershed with the goal of understanding the effects of harvest timing (peak standing crop, H1, and after a killing frost, H2), species (switchgrass, *Miscanthus x giganteus*, prairie cordgrass, and a native grass mixture), and N-rate (0, 56, and 112 kg N ha^{-1}), on nutrient removal in grass biomass grown on a riparian buffer. Harvest year, harvest timing, species, and N- rate, all significantly affected nutrient concentrations in biomass and removals. Nutrient removal across all species was generally greater at H1 than with H2 and with increasing application of nitrogen. At H1, switchgrass removed the most nitrogen and phosphorus, the most potassium removal occurred in *Miscanthus x giganteus*. From this study, we inferred there is considerable potential for perennial energy crops to remove excess nutrients when grown on a riparian buffer; however, a specific recommendation for species selection and best management practices including N fertilization and harvest timing will be dependent on the desired outcome for either biomass or forage production.

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TABLE OF CONTENTS

INTRODUCTION

Nitrogen (N), Phosphorus (P) and Potassium (K) are critical macronutrients for sustainable crop production in modern agriculture. Efforts to maximize crop yields have led to an increased application of these nutrients, even on marginally productive lands, that is often susceptible to conditions of soil and nutrient runoff or poorly drained soils. A model for nutrient runoff found that approximately seventy percent of N and P found in the Gulf of Mexico comes from agricultural sources, with the primary source for N being corn (*Zea mays*) and soybean (*Glycine max*) fields, and the primary P load coming from pastureland (Alexander et al., 2007). In an effort to address this challenge, in 2008, the Environmental Protection Agency (EPA) amended the Mississippi River/Gulf of Mexico task force with a goal of guiding national voluntary efforts for reducing nutrient runoff and utilizing programs currently in place (2008 Action Plan). In 2010, the Natural Resources Conservation Service's (NRCS) plan focused on optimizing the use of nutrients while preventing and entrapping nutrients before entering the water system. In 2013, the NRCS Conservation Effects Assessment Project reported on a per acre basis that the benefit of targeting small high priority watersheds that can receive financial and technical assistance through the farm bill could lead to a reduction in P by 1.4 times and N by 1.3 times compared to a non-targeted watershed general reduction approach.

At a more local level, the state of Illinois developed the *Illinois Nutrient Loss Reduction Strategy* (IEPA et al., 2015) in an effort to compliment the EPA's call to action. Illinois is striving to meet an overall goal of reducing the amount of nutrient loss to the Mississippi River by forty-five percent through improved nutrient management strategies. Agriculture production and subsequent nutrient loss in Illinois can be partially attributed to the fact that in 2017, 4.53

million hectares of corn, and 4.28 million hectares of soybean were planted (USDA-NAAS, 2018) and 3.92 million hectares of the state had tile drainage systems (David et al., 2010).

In constructing different solutions in an effort to reduce our nutrient loss from agricultural lands, the plan identified and developed cost effective solutions to entice producers to modify or enhance their current practices. The most cost efficient practice identified for edge of field nutrient reduction strategies was utilizing buffer and or filter strips (IEPA et al., 2015).

Vegetative buffer strips installed at the edge of fields are designed to slow and reduce the flow of water, allowing for the plants to absorb nutrients and sediments through the roots (Grismer, 2006; Helmers et al., 2008). In a review conducted by Hickey and Doran, studies compared N loss in plots with vegetative buffers loosing 45% to control plots without buffers that lost 184% (Hickey and Doran, 2004). An important factor in maximizing the efficiency in capturing these sediments is the width; optimal buffer widths for agricultural runoff span from 3-6m in width (Yuan et al., 2009). Ideal species for these systems are low maintenance perennials with deep root systems that protect and utilize nutrients more efficiently compared to row crops (Singer, et al. 2009). Such examples should include ones that utilize C_4 photosynthetic pathways, such as *Miscanthus x giganteus (here after Miscanthus),* a warm-season perennial that has demonstrated higher nutrient use efficiency (Beale and Long, 1997). Switchgrass (*Panicum virgatum* L.) is another C_4 warm season perennial candidate species. The large root system can increase the capacity of the plants to obtain water and nutrients from deeper soils and store nutrients for regrowth after harvest or grazing (McLaughlin & Kszos, 2005); and it's known for adaptability to a wide range of environments and soil types (Casler, 2012). Another candidate species, prairie cordgrass (*Spartina pectinata* L.), is a warm-season perennial grass native to

North America in wet prairie swales, sloughs and low areas along rivers and tributaries (Weaver, 1954; Weaver, 1960).

In an effort to maintain longer, sustainable nutrient uptake, effective management of these vegetative buffer strips is essential, and taller statured plants can better compensate the water, sediment and nutrient flows (Dosskey, 2001). A study evaluating switchgrass found that under intensive management, greater biomass can be produced and that N, P and K application may prove necessary in order to compensate the nutrient removal, otherwise stand longevity may be reduced (Guretzky et al., 2011; Thomason et al., 2005). Studies have indicated N requirements for perennial grasses such as switchgrass, are about half of what is needed for maize row crop production (McLaughlin & Walsh, 1998). A study in Kansas, comparing physiological nutrient rates in annual crops compared to perennial crops when harvested at late season, found equal or higher nutrient concentrations in perennial grasses but overall removal was lower due to higher yields (Propheter & Staggenborg, 2010). An Illinois study, conducted on productive mollisols, that typically have issues of poor drainage, evaluated the nutrient leaching in corn and soybean compared to switchgrass and *Miscanthus* found that total N inorganic losses were significantly higher by a magnitude of 7.5 greater than switchgrass and 9 times than *Miscanthus* (McIssac et al., 2010).

Not only can nutrient management in perennial grasses play a role, but also the timing of biomass harvest. A study spanning multiple environments observed yield and nutrient uptake are specific depending on the agronomic management and growth environment such as harvest timing, location, cultivar, and weather for the specific growing season (Serapiglia et al., 2016). Maximum biomass can be collected when harvest timing occurs after the panicle is fully emerged (Mitchell et al., 2008). When harvest timing is delayed until after a heavy frost, plants are able to translocate a large portion of these nutrients into below-ground root structures for use the following growing season, resulting in lower nutrient concentrations and removal in biomass (Serapiglia et al., 2016; Adler et al., 2006). In a perennial system under fertilization conducted in Oklahoma, the study found that nutrient uptake was most optimal in giant reed (*Arundo donax)* for P, and weeping lovegrass (*Eragrostis curvula*) for N, but the harvest timing was impacting nutrient removal, additionally fertilization did improve the productivity of the crop grown on nutrient deficient soils (Kering et al., 2012).

As NRCS and INLRS outlined, riparian buffer and or filter strips that are composed of perennial energy crops are an attractive option for many reasons. Such examples include the growth of perennial energy crops that occurs on land that is marginally productive. Producers could maximize these land resources by diversifying crop production while helping achieve alternative energy opportunities as well as improve ecosystem services.

Connecting nutrient loss reduction with alternative energy creates a more comprehensive solution of sustainable agricultural system. In 2005, the U.S. Department of Energy set a goal of producing one billion tons of biomass annually to reduce petroleum use by 30% by 2040 (Langholtz et al. 2016). A key challenge affiliated with this goal is available land for dedicated energy production as the amount of land needed to achieve this goal is significant. Due to the growing population and resulting food demands, alternative energy sources should not have any negative impact on the amount of land utilized for food production (Pickett et al., 2008; Godfray et al., 2010). Bioenergy feedstock production needs to expand into areas that can be considered as marginal for row crop production. Marginal land generally is accepted as land unable to sustain current row crop practices or land that generates crop loss due to abiotic stresses (Quinn et al., 2015). Land with high susceptibility to issues of erosion and nutrient leaching can also be considered as marginal for crop production practices (Gelfand et al., 2013).

Many field studies have evaluated perennial grass buffer strips for removing nutrients, but little work has been completed to evaluate the effects of species and harvesting management on nutrient removal potential under marginal land. However, with so many perennial energy crops available, which ones would be ideal to place in the buffer strip for maximized nutrient reduction? Success and longevity of these systems require species that have an ability for adequate annual nutrient storage with superior biomass yield. Understanding the capacity for these perennial plants to utilize nutrients, and how agronomic management practices may impact the plants would be crucial in considering mitigation of non-point nutrient loss from agriculture while maintaining or improving productivity. This leads to our current study that investigates the development of dedicated energy crop production systems on marginally productive wet land located at the edge of field. The goal of this study was 1) to understand the capacity that perennial energy grasses have for removal of key macro nutrients through plant tissues, 2) to determine the effect of harvest timing and fertilization on the uptake and removal of nutrients, and 3) to determine the best management practice for sustainable bioenergy feedstock production on marginally productive wet soil. This was completed by evaluating biomass potential of model bioenergy feedstock grasses, under a combination of practices to determine the best management for marginal land.

MATERIALS AND METHODS

The study was conducted from 2012 to 2015 at the University of Illinois research farm in Urbana, Illinois (40°07´20.4″N, 88°22´09.0”W) on Drummer silty clay loam (Fine-silty, mixed, superactive, mesic Typic Endoaquolls) with a 0-3 % slope. The field experiment, consisted of two plantings at the same location and was located in the headwaters of the Embarass River, which reaches the Gulf of Mexico via the Wabash, Ohio, and Mississippi Rivers. The Embarass River Watershed is a high priority nutrient loss zone for N and P as prioritized by the *Illinois Nutrient Loss Reduction Strategy* (IEPA et al., 2015). The experimental area was located in a footslope landscape position and categorized as land capability classification (LCC) 5W (USDA NRCS, 1197); exhibiting poor drainage and seasonal flooding in the spring preventing crop production since 2007. Soil samples were collected before planting to evaluate baseline soil chemical properties. The baseline soil sample exhibited 5% soil organic matter, a 6.7 pH, 6.0 mg kg^{-1} of NH_4-N, 1.0 mg kg^{-1} of NO_3-N, 72 mg kg^{-1} of P, and 157 mg kg^{-1} of K.

This experiment was a portion of a larger field experiment. The entire experimental design was a split-split-plot in a randomized complete block with four replications (blocks) in space and two replications (years) in time (planted in 2012 and 2013). Harvest timing (n=3) was treated as a whole plot, Species (n=6) was treated as the sub-plot, and N fertilization rates (n=3) as sub-sub plots. Each planting was independently randomized. The whole plot allocation of harvest timing of above ground biomass tissue included peak standing crop (H1), after killing frost (H2), and an alternate year harvest of timing H1 and timing H2. The species of interest in the field design are ‘Liberty’ and ‘Shawnee’ switchgrass, ‘Savoy’ prairie cordgrass, *Miscanthus x giganteus*, and two native grass mixtures, one containing ‘Goldmine’ big bluestem (*Andropogon gerardii*), ‘Warrior’ indiangrass (*Sorghastrum nutans* [L.] Nash), and ‘Butte’ sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.), and the other polyculture only used in the 2012 planting, was an Illinois adapted mixture of 'IL ecotype' big bluestem and 'Savoy' prairie cordgrass Each species was randomly allocated to each harvest timing. In regard to the N-fertilization rates, these were randomly allocated among each species within each harvest timing. The N-fertilization considered include 0, 56, 112 kg ha^{-1}. For this particular study, we were interested in harvest timings of H1 and H2, species of 'Liberty' (SW), 'Savoy' (PCG), *Miscanthus* x *giganteus* (MG), and 'Goldmine', 'Warrior' and 'Butte' mixture (Mix), and N-fertilization of 0, 56, 112 kg ha^{-1}.

The first planting occurred on May 17, 2012, for all seeded cultivars and mixtures and June 6, 2012, for plug planting of *Miscanthus*. In 2012, the experiment experienced drought conditions, leading to poor stand establishment and loss of the *Miscanthus* transplants. In 2013, replanting of *Miscanthus* occurred on June 4, based upon frequency counts in the summer and fall of 2012 (Vogel and Masters, 2001). The same experiment was repeated adjacent to the first planting that was planted on May 15, 2013. Planting preparations included tilling and packing of soil for control of pre-existing weeds and creating a firm seed bed for planting. Prairie cordgrass, switchgrass, and the native grass mixture were drilled at a rate of 325 pure live seed m^{-2} in 19 cm row spacing with a Great Plain Plot planter (Salina, KS, USA). *Miscanthus* was planted utilizing plugs with 0.6 m row spacing and 0.9 m between plants within a row. Application of N was completed using urea (46-0-0) with a spread application occurring annually in spring of both 2014 and 2015. For pre-emergent weed control, experimental plots containing switchgrass and prairie cordgrass were sprayed with Atrazine (2-chloro-4ethylamine-6-isopropylamino-s-triazine) at 2 kg ai ha^{-1} immediately after planting. Imazapic (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid) was applied to plots containing big bluestem, indiangrass, and sideoats grama at a rate of 70 g ai ha^{-1}. The harvest of aboveground biomass initiated in 2014 for both plantings to ensure establishment with one-year delayed harvesting of the 2012 planting, due to poor establishment in 2012 caused by drought. In harvest year 2014, H1 harvest was on August 28, and H2 harvest was on December 1. In 2015, weather and field conditions were less than desirable, thus delaying H1 harvest to September 15 and H2 harvest on December 18. Biomass harvest was obtained from a 1.2 x 4.0 m area of sub-sub plot at 10 cm stubble height using a plot combine (Wintersteiger Cibus S harvester mounted with a Kemper forage chopper, Ames IA). Fresh weight biomass was recorded and a subsample was collected for dry matter calculation. Subsamples were placed in a forced-air oven at 60 ^{o}C for 5 days. Subsamples were then ground with a cutting mill to pass 2-mm screen for composition analysis. Where 0.2 grams of ground samples were mixed with 1.0 mL of hydrochloric acid and 2.5 mL of nitric acid. Samples were then placed in an incubator for 30 minutes at 102 ^{o}C. After filtering, inductively coupled plasma mass spectrometry were used for determining nutrient concentrations. Nutrient removal (kg ha^{-1}) was determined as a function of plant tissue concentration (g kg^{-1}) multiplied by biomass yield (Mg ha^{-1}).

Data was analyzed with SAS 9.4 (SAS Institute, Cary, NC, USA). Harvest Year, Species, Harvest timing and N-rate were fixed variables, while location and block were considered random. Harvest Year was treated as a repeated measure. UNIVARIATE was utilized to test the distribution of residuals of the model, normality of residuals was tested with Shapiro-Wilk, normality was not met, GLIMMIX procedure was utilized to adjust the distribution to reflect a log normal distribution. GLIMMIX was then conducted for the analyses of variance and comparison of differences of means. Initial analyses of variance significance were tested at a significance level of 0.05. Then the significant effects from the analyses of variance were tested with a Bonferroni adjustment at the level of 0.1.

RESULTS

Biomass

The statistical analysis revealed a significant four-way interaction of harvest year, harvest timing, species, and N-rate for biomass yields (Table 1 and Figure 1). The influence of these factors can be observed in Figure 2 as an average across planting dates. Generally, biomass did show an upward trend with increasing application of N-fertilization across all harvest timings and species with the exception of MG at H1 in 2015. In 2014, comparing between the harvest timings, significant differences among species were generally observed with the exception of MG. In 2015, the opposite was observed as MG exhibits significant differences between harvest timing at H1 compared to H2, and all other species were generally insignificant. Comparing harvested biomass at H2, 2015 had significantly more biomass accumulation compared to 2014. In 2014, at H1 and H2 at 112 kg ha^{-1} of N, SW yielded the highest at 14.7 Mg ha^{-1} and 9.93 Mg ha^{-1} respectively. In 2015, at H1, we again observed SW at 112 kg ha^{-1} of N, yielding the highest at 18.0 Mg ha^{-1}, however at H2, MG at 112 kg ha^{-1} of N, yielded the highest at 20.44 Mg ha^{-1}.

Nutrient concentrations in biomass tissue

Biomass tissue N concentration exhibited a significant three-way interaction (Table 1 and Figure 2) of harvest year, harvest timing, and species, in addition to a significant main effect of N-rate. Tissue N concentration for all species decreased when harvest was delayed till H2, but the magnitude of differences among species between harvest years was different. For example, N concentration of MG biomass in 2015 decreased with much greater scale from H1 to H2, with that difference being greater than any other species compared between H1 and H2. In the main effect of N-rate, as application rates increased, concentration of N found in the biomass tissue also increased, but significance differences were only observed between 0 and 112 Mg ha^{-1} rate.

A significant four-way interaction (Table 1 and Figure 3) was observed for biomass tissue P concentration. With increasing N-rate, concentrations of tissue P decreased significantly when biomass was harvested at H2 compared to H1 for both years, with minimal changes in magnitude among species. All species follow similar trends for harvest timing, N-rate applications, and year. However, at harvest timing H1, MG tissue P concentration was higher than other species for both years.

A significant four-way interaction was observed for biomass tissue K concentration (Table 1 and Figure 4). With increasing N-rate applications, concentrations of tissue K did not exhibit a trend even though N rate interacted with other factors. Tissue K concentrations in both 2014, and 2015 decreased when biomass was harvested at H2 compared to H1 with significantly lower concentrations in SW and PCG compared to species of Mix and MG when biomass was harvested at H1.

Biomass tissue concentration of Calcium, Magnesium, and Sulfur exhibited some significant main effects, and 2-way interactions (Table 1). Comparisons of nutrient concentrations in regard to Harvest Year, Species, Harvest Timing and N-rate revealed that S and Mg followed a similar trend of higher concentrations at H1 compared to H2 (Table 2 and 3). Calcium did not show much response in regard to harvest timing. Highly significant variations in concentrations were observed across species.

Nitrogen, Phosphorus, and Potassium Removal

Nitrogen, P, and K removal all exhibited various significant two- and three-way interactions for each respective nutrient removal (Table 1). Removal was calculated as a component of concentration taken by biomass harvested. Biomass was observed driving trends observed in nutrient removal. Nitrogen removal exhibited a significant four-way interaction of harvest year, harvest timing, species, N-rate (Table 1 and Figure 5). With increasing N application, removal trended upward for almost all species at all harvest timings with the only exception being MG at H1 in 2015. Significant differences for all species, at all N-rates are observed when comparing H1 to H2 in 2014. In the following year, only SW was significantly different at an N application rate of 112 kg ha^{-1}. Total N removal potentials were similar for H1 in both 2014 and 2015. H2 exhibits a higher magnitude of removal potential in 2015.

For P removal, harvest year, harvest timing, N-rate and harvest year, species, and N-rate, were all significant three-way interactions and a significant two-way of harvest timing, species was observed (Table 1 and Figure 6). Overall, across the two years more P was being removed when harvested at H1 compared to H2. Within a species, the magnitude has an increasing removal trend with increasing application of N, with the exception of MG harvested at H1 in 2015. Removal potentials were similar in 2014 compared to 2015.

Potassium removal also exhibited significant two- and three-way interactions of harvest year, harvest timing, N-rate and harvest year, species, N-rate, in addition to harvest timing, species (Table 1 and Figure 7). Here we observed a highly significant difference between K removals with regard to harvest timing. H1 harvest for both 2014 and 2015 tended to trend towards increasing removal with increasing application rates of N. This trend was not observed in H2 as all values were statically similar. Comparing 2014 to 2015, the magnitude of removal was lower for H1 in 2015. The magnitude of difference in H2 was not statically significant.

DISCUSSION

Biomass

Effectively understanding the relationship between biomass produced, the amount of nutrients the perennial grass will utilize and what the crop needs to be sustainable is the forefront of this work. Generally, in perennial systems, harvesting at H1 is recommended for maximum biomass collection (Adler et al., 2006). Considerations for the longevity of the crop need to be included when deciding between H1 and H2, as harvest at H2 will allow the plant the ability to naturally store nutrients to be involved in the nutrient cycling process (Williams 1964; Mulkey et al., 2008). Harvested biomass trended to exhibit a positive relationship with increasing application of N, especially in SW, similar results were observed in a study comparing MG to SW (Heaton et al., 2004). This observation leads us to believe that under particular management strategies, the biomass potentials could be prolonged with annual application of N, to respond in a similar manner as plants that are allowed to complete a full natural life cycle would. (Mitchell, R. et al., 2008; Lee et al., 2014; Anderson et al., 2013). In this study we only evaluated two years of harvest data, but based on finding in the literature a common trend of knowledge appears to find that repeated harvesting of perennial grasses at H1 can limit the biomass yield potential. In our study, we observed a negative unexpected response for *Miscanthus* biomass yields that are not consistent with past findings for growth in Urbana, Illinois (Arundale et al., 2014). Based upon these observations, it could be concluded that environment, and possibly establishment of the stand, could have been of lower quality at the time of harvest. *Miscanthus* was not native to the United States, but had shown a higher biomass productivity compared to SW (Heaton et al. 2008). However, in our study we observed that SW has a higher productivity at H1, and H2 with the exception of 2015, H2, which would have allowed for extra time to become a more mature stand. Interestingly, studies conducted on N-application to MG, found that N had no response, but in our case, we observed a positive response to yield with increasing application of N (Miguez et al., 2008; Christian et al., 2008). Boe and Lee (2007) found that prairie cordgrass had higher biomass yields compared to SW under ideal conditions. Prairie cordgrass has the ability to withstand saline conditions along with wet marshy soils, but in a study conducted in South Dakota on PCG, under marginal conditions, yields were reduced approximately one third compared to favorable land with no other considerations for additional agronomic considerations (Boe et al., 2009). In our study, results exhibited that PCG, while statistically significant different from SW, it appeared to be relatively comparable, given the rather variable conditions found at this field location it could be considered that PCG has considerable potential.

Nutrient Concentrations

Nutrient concentrations found within plants are often an important indicator of plant health, but will play a crucial role in the future of ecosystem management. The results found in this study have clearly demonstrated that agronomic management was an essential part of the conversation around sustainable perennial production for alleviating excess nutrient runoff. The most striking result in response to agronomic factors was harvest timing, observed across all species. The various perennial grass morphologies could be playing a role in observed concentrations noted in our study, as seasonal temperatures started falling into the killing frost range in mid-October for 2014 and 2015. The grass species included in our study would have begun the nutrient cycling/translocation process at this time of year and our result was consistent with documentation found across literature (Serapiglia et al., 2016; Adler et al., 2006; Cahill et al., 2014; Gamble et al., 2014; Kering et al., 2012; Heaton et al., 2009; Anderson et al., 2013). In 2015, at H2, we observed a large contrast in N concentration in MG compared to other species for this timing, which coincides with the highest amount of biomass produced by MG. This dilution effect was widely observed across various studies evaluating *Miscanthus* nutrient efficiency and removal (Lewandowski & Schmidt 2006; Cadoux et al., 2012). This could also be a result of an almost a two-month window between the killing frost and when H2 above ground biomass harvest occurred, allowing considerable amounts of leaf tissue in MG to drop upon the ground to decompose and eventually become soil available nutrients (Borkowska & Molas, 2013). The concentrations of P and K in MG in our study was similar to the meta-analysis outputs for the literature review conducted from twenty-seven *Miscanthus* trials, evaluating nutrient uptake from global studies (Lewandowski & Schmidt 2006). For all species P and K nutrient concentration, we observed lower concentrations in the second year at H2. This result could be a factor of a few different consequences. One could be the lack of annual reapplication of these nutrients that could be leading to a more P and K limited soil environment depending on annual leachate absorbed from the annual crop production (Parrish & Fike, 2005). The second being that the mineral concentrations in harvested biomass declined with a progressively later harvest date, and in 2015, our harvest was delayed about half a month compared to 2014 (Gamble et al., 2015). The large decrease in concentration observed in H2, may be a consequence of actual time of harvest, as a considerable amount of K could be degraded in the leaf tissue over time with periods of increased moisture and exposure to environment. Application of N showed impacts on nutrient concentrations in species, as N can impact the plants demand for other nutrients (Fageria, 2006). Phosphorus concentrations decreased with increased application of N for all species, across all harvest timings. This result conflicted with a study, conducted in Iowa that showed N application impacts N, but had minimal impact on other plant macronutrients in the shoot (Lemus et al., 2008). However, this result agreed with results observed for K, Mg, Ca, and S in that study.

Nutrient Removal

In effort to evaluate the effectiveness of this study in aiding with reducing state and nation to nutrient losses, nutrient removal is of primary concern. The most notable trend that we observed in removal potential was the relationship with N application that was being driven by above ground harvested biomass. Similar overall averaged N removal averages were observed in other studies as in our study for SW and MG (Palmer et al., 2014; Jach-Smith and Jackson, 2015). Kering et al., (2012) observed similar nutrient removal for N, P and K, for SW, using a similar lowland cultivar, EG1101. Limited literature on PCG and a species mixture removal potential was available, based upon our results it was comparable to other perennial grasses and could be excellent alternatives, especially when grown under other area of marginal stress, such as saline conditions for PCG. A species mixture may be more appropriate when used in a buffer strip in IL to mimic the conditions of a natural prairie habitat.

Interestingly enough, nutrient removal with consideration for harvest timing aligned more closely with the trend observed in nutrient concentrations, with lower removal potential at late season harvest. Nutrient removal occurring at H1, demonstrated switchgrass being the best overall species for removal across all nutrients, but performance of all species observed in this study, were relatively close to each other, especially with results observed at H2.

CONCLUSION

Overall from this study beneficial knowledge was obtained that allowed us to understand the relationship between harvest timing, species, and application of N in relation to bioenergy feedstock production, when grown on marginal land. Our findings concluded that significant differences occurred for nutrient removal potential between harvest timings across all species and N-rates. Individual species yield performance suggested that all species of interest have potential for promising biomass production under marginal lands. Consideration for what particular nutrient is of primary interest will prove valuable when making specific considerations for ideal candidate species. Applications of N had impacts on the biomass potential and may play a role in the longevity of the crops functionality and impacts the nutrients being removed. Further studies investigating the nutrient holding capacity of below ground plant tissue and nutrient movement in consideration for water movement could provide additional value to a comprehensive solution for nutrient management to alleviate nutrient loads. This study complements the volunteer policies outlined within the *Illinois Nutrient Loss Reduction Strategy* and could provide multiple opportunities for added value for producers (IEPA et al., 2015). From this study, we inferred there is considerable potential for perennial energy crops to remove excess nutrients when grown on a riparian buffer; however, a specific recommendation for species selection and best management practices including N fertilization and harvest timing will be dependent on the desired outcome for both bioenergy feedstock composition and sustainability of feedstock production.

TABLES AND FIGURES

Table 1. ANOVA for biomass tissue nutrient concentration and removal of warm-season grasses grown on a buffer strip showing main effects and interactions.

Source of variation	Num df	Nutrient concentration, $p > F$					
		N	P	K	S	Mg	Ca
Year	1	**0.02**	**<.0001**	**<.0001**	0.1800	0.1678	0.7261
Harvest Timing	1	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	0.5349
Year, Harvest Timing	1	**<.0001**	**0.0004**	**0.0002**	0.2564	**0.0006**	0.7943
Species	3	**0.0086**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
Year, Species	3	**<.0001**	**0.0071**	**<.0001**	**<.0001**	**<.0001**	**0.0001**
Harvest Timing, Species	3	**<.0001**	**0.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
Year, Harvest Timing, Species	3	**<.0001**	**0.0055**	**0.0015**	**<.0001**	**<.0001**	**0.0008**
N rate	2	**0.0437**	**<.0001**	0.7093	0.6365	**0.0216**	0.1243
Year, N-rate	2	0.8345	0.2371	**0.0097**	0.9306	0.1898	0.5837
Harvest Timing, N-rate	2	0.2254	0.1942	0.2196	0.9570	0.5787	0.9725
Year, Harvest Timing, N-rate	2	0.5002	0.6228	0.806	0.3791	**0.0194**	0.0835
Species, N-rate	6	0.1578	**0.0001**	0.1984	0.7131	0.1700	0.6697
Year, Species, N-rate	6	0.7026	0.4098	0.0622	0.8841	0.6601	0.6656
Harvest Timing, N-rate, Species	6	0.8164	**0.0311**	**0.0034**	0.3367	0.7346	0.9756
Year, Harvest Timing, Species, N-rate	6	0.7911	**0.0048**	**0.0065**	0.4012	0.3708	0.7167

Source of variation	Num df	Biomass yield and nutrient Removal, $p > F$						
		Yield	N	P	K	S	Mg	Ca
Year	1	**<.0001**	**<.0001**	**0.003**	**0.0006**	0.7111	0.4006	0.1590
Harvest Timing	1	0.0809	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**0.0243**
Year, Harvest Timing	1	**<.0001**	**<.0001**	**<.0001**	0.4633	**0.0005**	**<.0001**	**<.0001**
Species	3	**0.0058**	**0.0253**	**0.0025**	**0.0628**	**0.0001**	**<.0001**	**<.0001**
Year, Species	3	**0.0003**	**0.0002**	0.495	0.7668	**0.0002**	**0.0182**	0.0751
Harvest Timing, Species	3	**<.0001**	0.0895	**<.0001**	**0.006**	0.4721	0.0613	**0.0531**
Year, Harvest Timing, Species	3	**0.001**	**0.0032**	0.799	0.3799	0.0956	0.7429	0.6576
N-rate	2	**<.0001**	**<.0001**	**0.0001**	**0.0001**	**<.0001**	**<.0001**	**<.0001**
Year, N-rate	2	**0.017**	0.1975	**0.0222**	**0.0041**	0.1125	0.1794	0.3349
Harvest Timing, N-rate	2	0.2541	**0.0105**	0.5237	0.1402	0.0604	0.3808	0.1889
Year, Harvest Timing, N-rate	2	**0.0453**	0.1733	**0.0294**	**0.0438**	**0.0329**	**0.0032**	**0.0350**
Species, N-rate	6	0.2416	0.4967	0.1876	0.1894	0.4556	0.1957	**0.0436**
Year, Species, N-rate	6	**0.0224**	0.2786	**0.0068**	**0.0006**	0.4306	0.0852	**0.0106**
Harvest Timing, N-rate, Species	6	0.3319	0.6081	0.576	0.8192	0.7846	0.1349	0.2182
Year, Harvest Timing, Species, N-rate	6	**<.0001**	**0.0258**	0.2771	0.0654	**0.0230**	**0.0002**	**0.0001**

Figure 1. Biomass yield of 'Goldmine' big bluestem, 'Warrior' indiangrass, and 'Butte' sideoats grama mixture (Mix), 'Liberty' switchgrass (SW), 'Savoy' prairie cordgrass (PCG), *Miscanthus* x *giganteus* (MG) affected by harvest timing, at peak standing crop (H1) and after killing frost (H2) and N fertilization during 2014 and 2015. Error bars denote standard error.

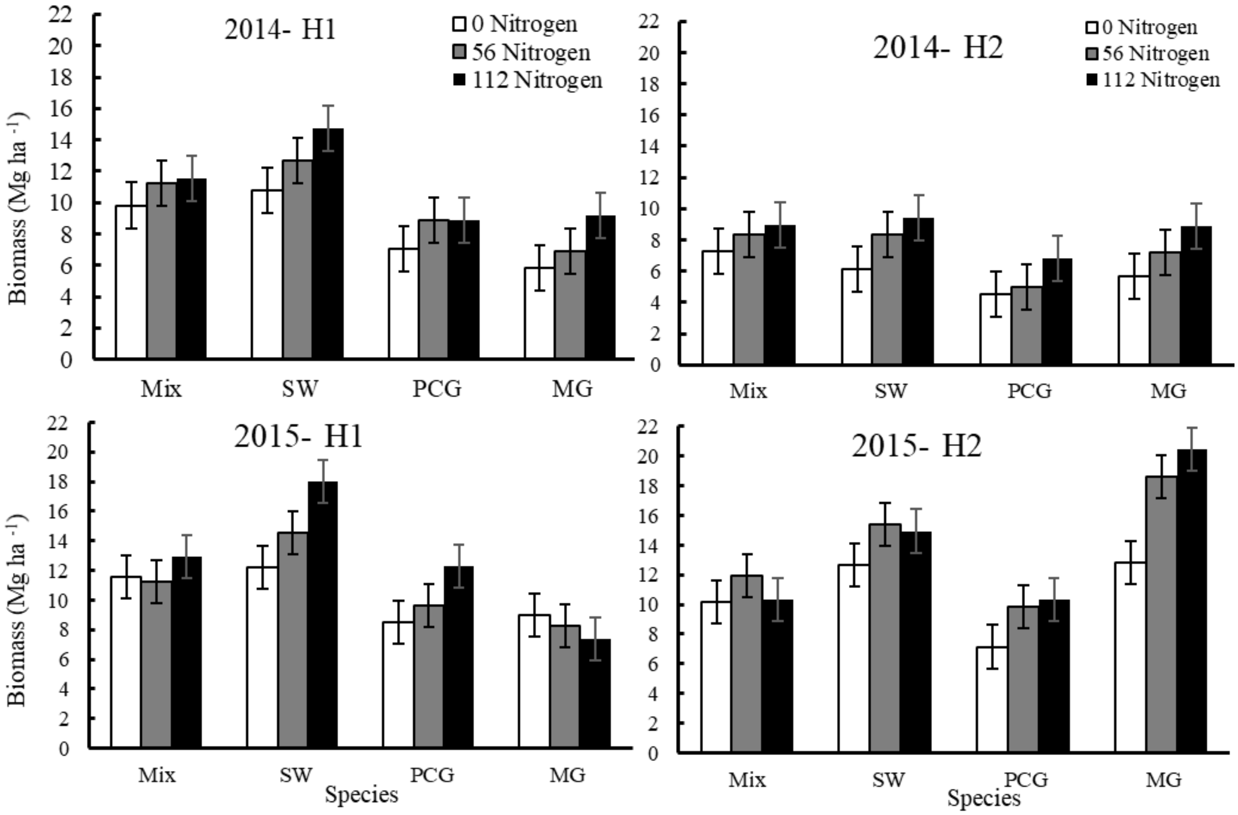

Figure 2. Nitrogen concentration in biomass tissue of 'Goldmine' big bluestem, 'Warrior' indiangrass, and 'Butte' sideoats grama mixture (Mix), 'Liberty' switchgrass (SW), 'Savoy' prairie cordgrass (PCG), and *Miscanthus* x *giganteus* (MG) affected by harvest timing, at peak standing crop (H1) and after killing frost (H2), and N fertilization during 2014 and 2015. Error bars denote standard error.

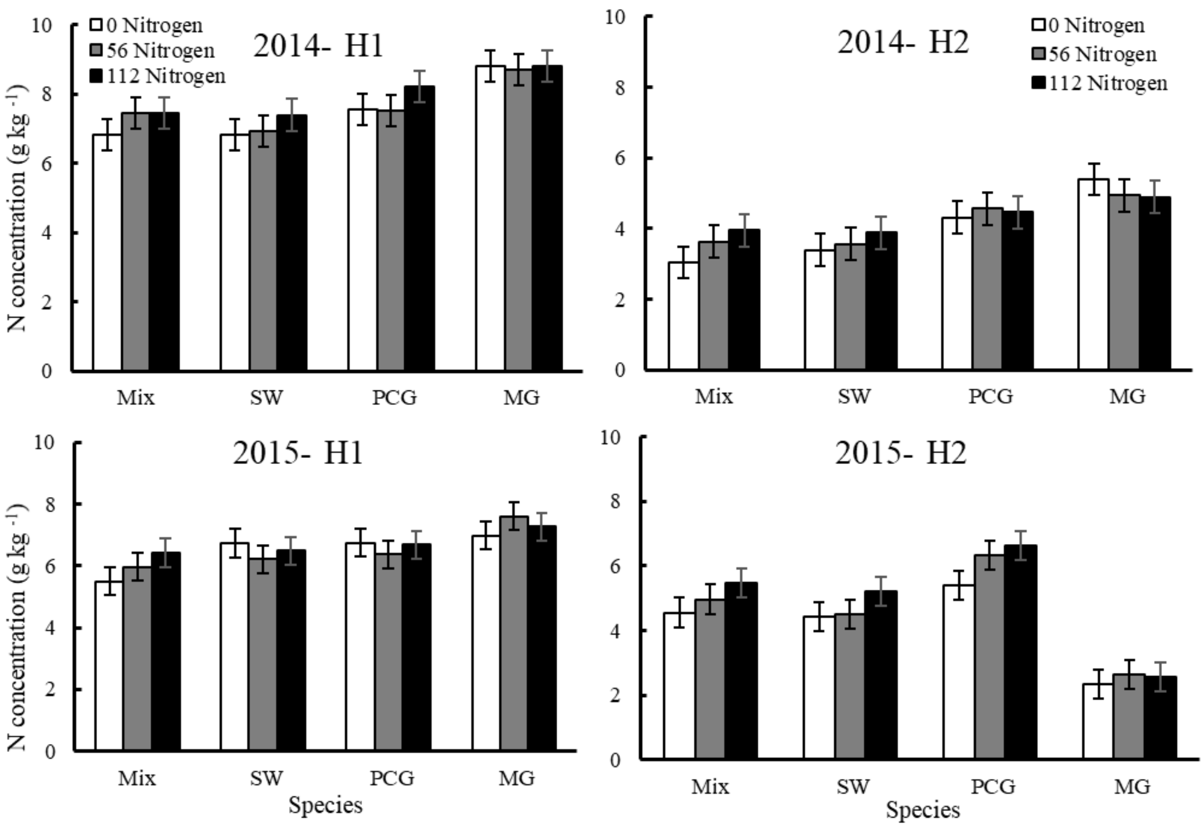

Figure 3. Phosphorus concentration in biomass tissue of ‘Goldmine’ big bluestem, ‘Warrior’ indiangrass, and ‘Butte’ sideoats grama mixture (Mix), ‘Liberty’ switchgrass (SW), ‘Savoy’ prairie cordgrass (PCG), and *Miscanthus* x *giganteus* (MG) affected by harvest timing, at peak standing crop (H1) and after killing frost (H2), and N fertilization during 2014 and 2015. Error bars denote standard error.

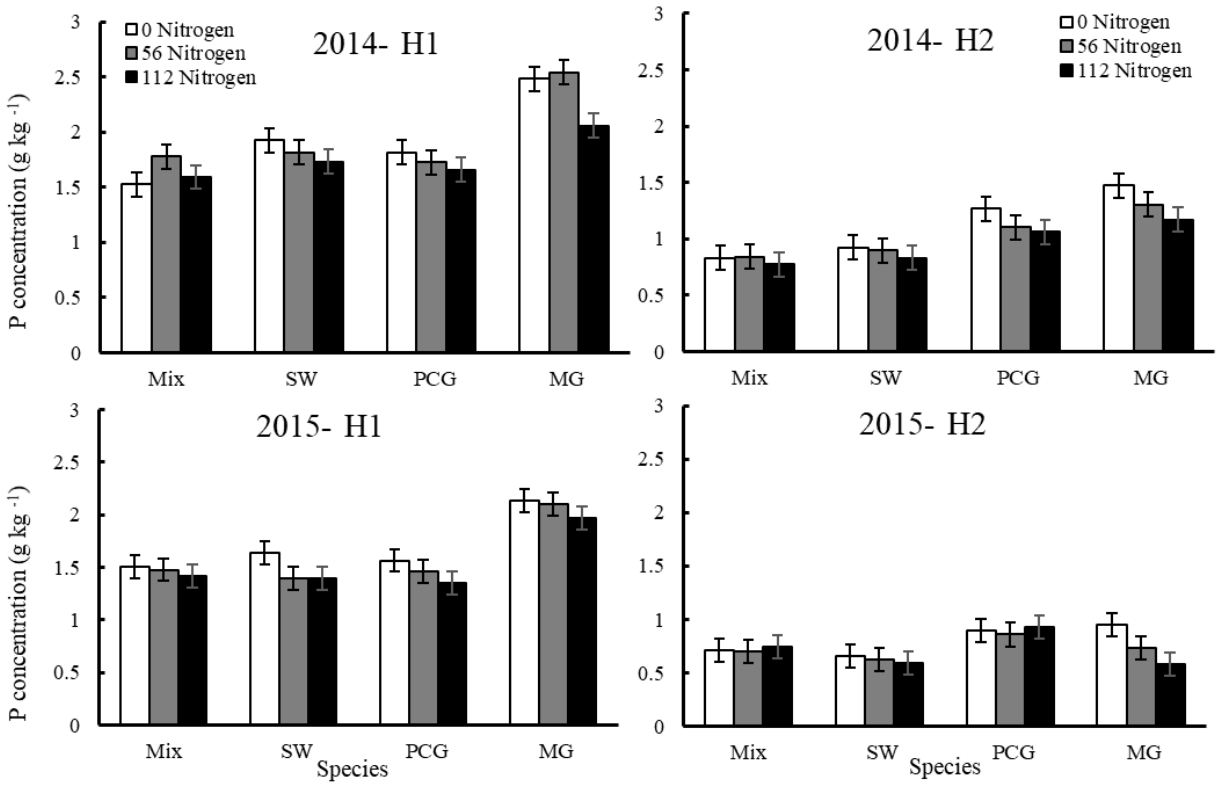

Figure 4. Potassium concentration in biomass tissue of ‘Goldmine’ big bluestem, ‘Warrior’ indiangrass, and ‘Butte’ sideoats grama mixture (Mix), ‘Liberty’ switchgrass (SW), ‘Savoy’ prairie cordgrass (PCG), and *Miscanthus* x *giganteus* (MG) affected by harvest timing, at peak standing crop (H1) and after killing frost (H2), and N fertilization during 2014 and 2015. Error bars denote standard error.

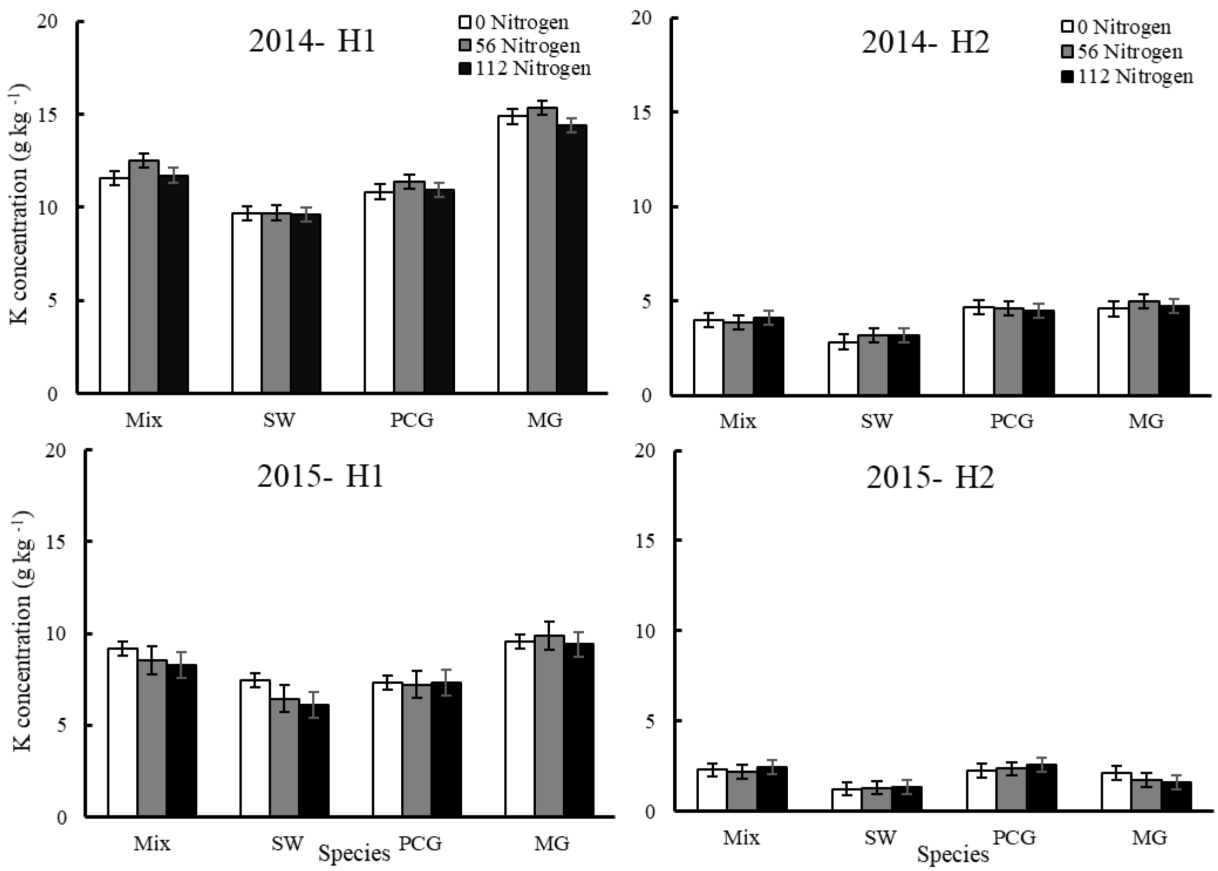

Figure 5. Nitrogen removal by ‘Goldmine’ big bluestem, ‘Warrior’ indiangrass, and ‘Butte’ sideoats grama mixture (Mix), ‘Liberty’ switchgrass (SW), ‘Savoy’ prairie cordgrass (PCG), and *Miscanthus* x *giganteus* (MG) in response to harvest timing, at peak standing crop (H1) and after killing frost (H2), and N fertilization during 2014 and 2015. Error bars denote standard error.

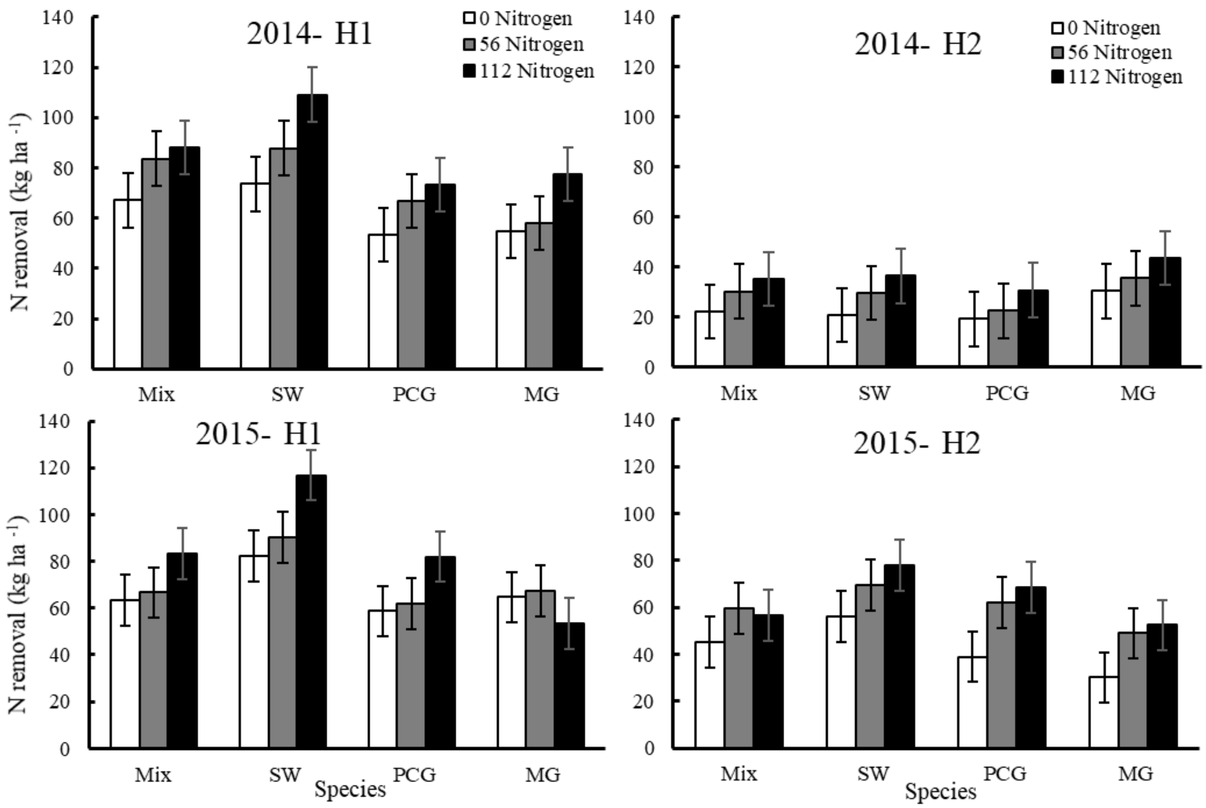

Figure 6. Phosphorus removal by ‘Goldmine’ big bluestem, ‘Warrior’ indiangrass, and ‘Butte’ sideoats grama mixture (Mix), ‘Liberty’ switchgrass (SW), ‘Savoy’ prairie cordgrass (PCG), and *Miscanthus* x *giganteus* (MG) in response to harvest timing, at peak standing crop (H1) and after killing frost (H2), and N fertilization during 2014 and 2015. Error bars denote standard error.

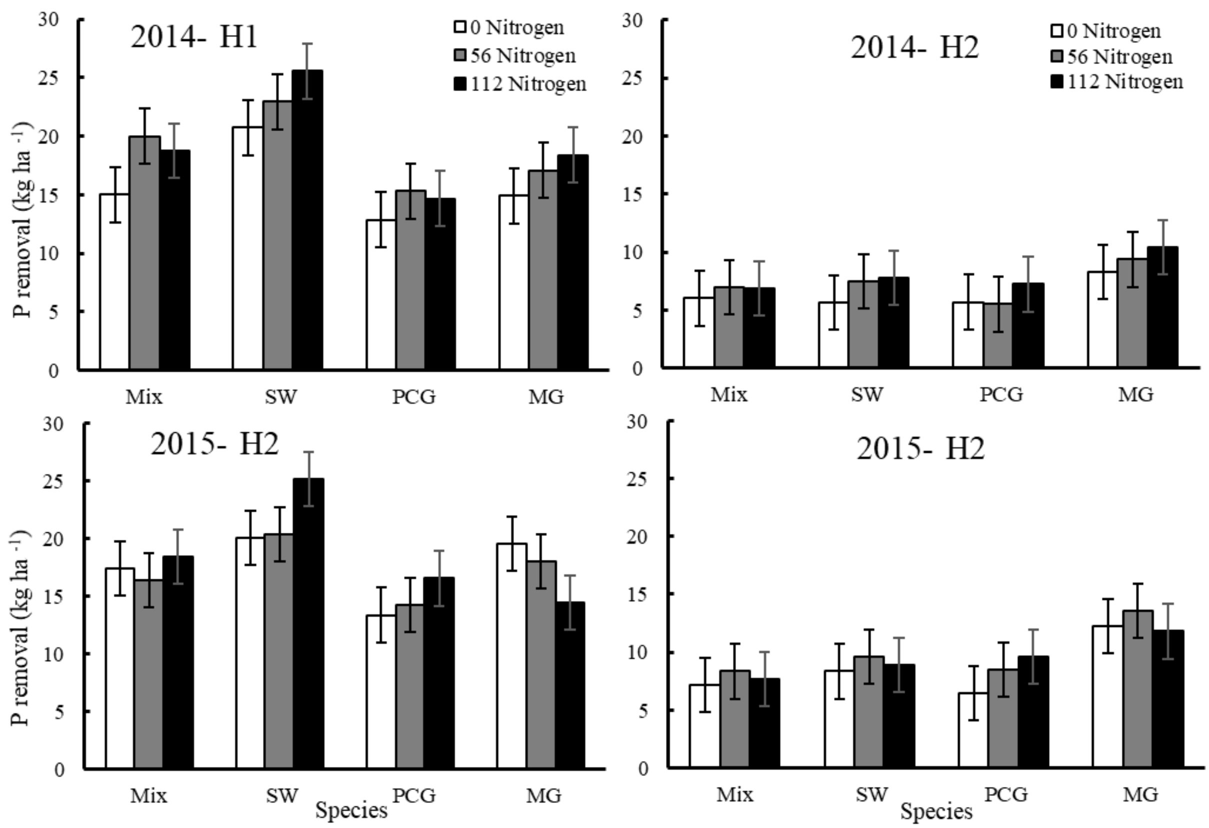

Figure 7. Potassium removal by 'Goldmine' big bluestem, 'Warrior' indiangrass, and 'Butte' sideoats grama mixture (Mix), 'Liberty' switchgrass (SW), 'Savoy' prairie cordgrass (PCG), and *Miscanthus* x *giganteus* (MG) in response to harvest timing, at peak standing crop (H1) and after killing frost (H2), and N fertilization during 2014 and 2015. Error bars denote standard error.

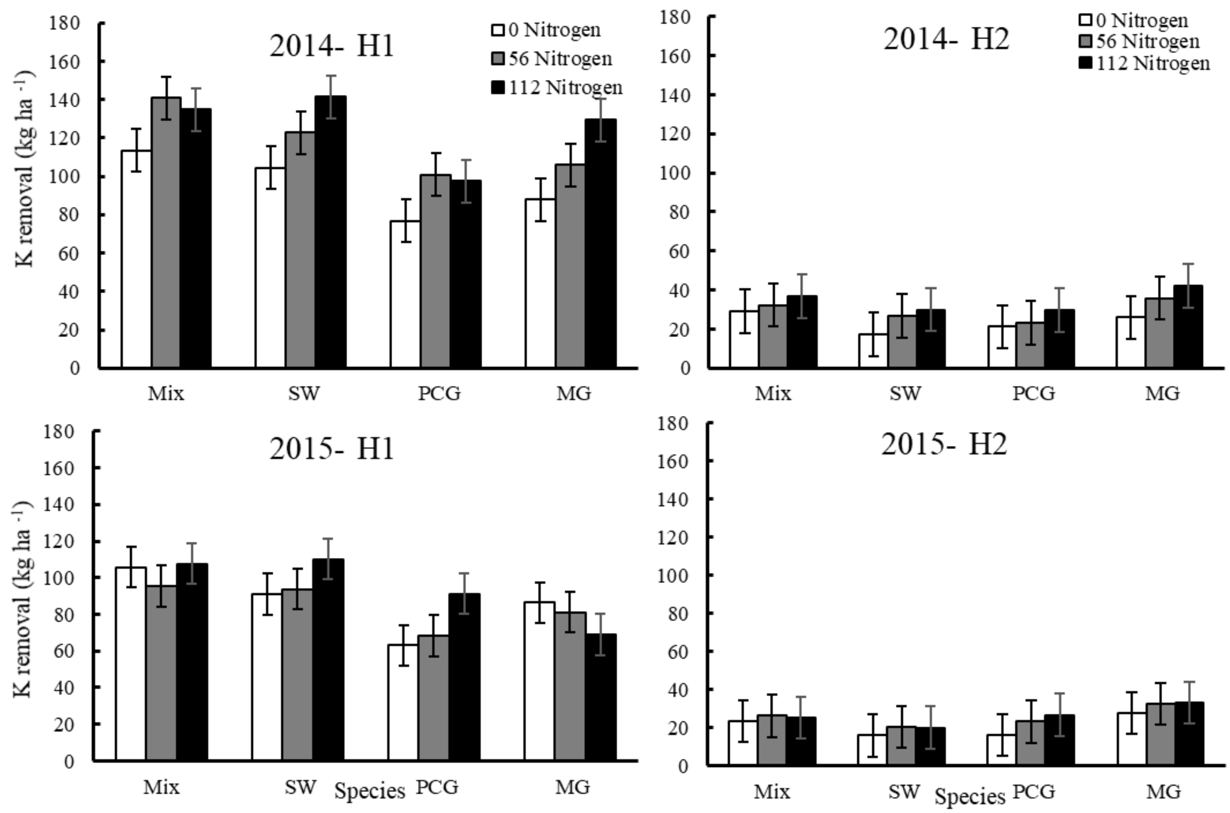

Table 2. Calcium concentration in biomass tissue of 'Goldmine' big bluestem, 'Warrior' indiangrass, and 'Butte' sideoats grama mixture (Mix), 'Liberty' switchgrass (SW), 'Savoy' prairie cordgrass (PCG), and *Miscanthus* x *giganteus* (MG) affected by harvest timing, at peak standing crop (H1) and after killing frost (H2), and N fertilization during 2014 and 2015.

Calcium (g kg^{-1})

	N rate (kg ha^{-1})	2014 H1	2014 H2	2014 Mean	2015 H1	2015 H2	2015 Mean
Mix	0	4.16	4.21	4.19	4.81	5.66	5.23
	56	4.65	4.34	4.49	4.90	5.70	5.30
	112	4.19	4.18	4.18	4.81	5.61	5.21
	Mean	4.33	4.24	4.29	4.84	5.66	5.25
SW	0	3.69	4.18	3.93	4.54	4.48	4.51
	56	3.84	4.38	4.11	4.66	4.94	4.80
	112	3.89	4.39	4.14	4.98	5.05	5.01
	Mean	3.80	4.31	4.06	4.73	4.82	4.77
PCG	0	3.55	3.59	3.57	3.51	3.54	3.53
	56	3.80	3.58	3.69	3.33	4.40	3.87
	112	3.77	3.45	3.61	3.72	4.50	4.11
	Mean	3.71	3.54	3.62	3.52	4.15	3.83
MG	0	4.62	4.49	4.55	4.67	3.25	3.96
	56	4.88	4.21	4.55	4.78	3.51	4.15
	112	5.23	4.23	4.73	4.61	3.49	4.05
	Mean	4.91	4.31	4.61	4.69	3.42	4.05

Table 3. Magnesium concentration in biomass tissue of 'Goldmine' big bluestem, 'Warrior' indiangrass, and 'Butte' sideoats grama mixture (Mix), 'Liberty' switchgrass (SW), 'Savoy' prairie cordgrass (PCG), and *Miscanthus* x *giganteus* (MG) affected by harvest timing, at peak standing crop (H1) and after killing frost (H2), and N fertilization during 2014 and 2015.

Magnesium (g kg^{-1})

		2014			2015		
	N rate (kg ha^{-1})	H1	H2	Mean	H1	H2	Mean
Mix	0	1.64	1.20	1.42	1.54	1.40	1.47
	56	2.21	1.36	1.79	1.74	1.49	1.62
	112	1.87	1.33	1.60	1.66	1.49	1.58
	Mean	1.91	1.30	1.60	1.65	1.46	1.55
		2014			2015		
		H1	H2	Mean	H1	H2	Mean
SW	0	2.34	1.66	2.00	2.14	1.53	1.83
	56	2.44	1.68	2.06	2.08	1.59	1.83
	112	2.53	1.75	2.14	2.31	1.60	1.96
	Mean	2.43	1.70	2.06	2.18	1.57	1.87
		2014			2015		
		H1	H2	Mean	H1	H2	Mean
PCG	0	1.56	1.40	1.48	1.30	1.16	1.23
	56	1.71	1.37	1.54	1.20	1.30	1.25
	112	1.77	1.25	1.51	1.32	1.36	1.34
	Mean	1.68	1.34	1.51	1.27	1.27	1.27
		2014			2015		
		H1	H2	Mean	H1	H2	Mean
MG	0	2.15	1.41	1.78	1.49	0.78	1.13
	56	2.60	1.38	1.99	1.55	0.86	1.21
	112	2.49	1.38	1.93	1.69	0.89	1.29
	Mean	2.41	1.39	1.90	1.57	0.84	1.21

Table 4. Sulfur concentration in biomass tissue of 'Goldmine' big bluestem, 'Warrior' indiangrass, and 'Butte' sideoats grama mixture (Mix), 'Liberty' switchgrass (SW), 'Savoy' prairie cordgrass (PCG), and *Miscanthus* x *giganteus* (MG) affected by harvest timing, at peak standing crop (H1) and after killing frost (H2), and N fertilization during 2014 and 2015.

Sulfur (g kg^{-1})

		2014			2015		
	N rate (kg ha^{-1})	H1	H2	Mean	H1	H2	Mean
Mix	0	0.59	0.48	0.53	0.51	0.44	0.48
	56	0.73	0.46	0.59	0.53	0.48	0.50
	112	0.63	0.49	0.56	0.51	0.48	0.49
	Mean	0.65	0.48	0.56	0.52	0.46	0.49
		2014			2015		
		H1	H2	Mean	H1	H2	Mean
SW	0	0.84	0.51	0.68	0.66	0.48	0.57
	56	0.74	0.53	0.63	0.60	0.51	0.56
	112	0.73	0.63	0.68	0.65	0.50	0.58
	Mean	0.77	0.55	0.66	0.64	0.50	0.57
		2014			2015		
		H1	H2	Mean	H1	H2	Mean
PCG	0	1.11	0.80	0.96	0.99	0.71	0.85
	56	1.03	0.78	0.90	0.88	0.70	0.79
	112	1.10	0.73	0.92	0.93	0.78	0.85
	Mean	1.08	0.77	0.93	0.93	0.73	0.83
		2014			2015		
		H1	H2	Mean	H1	H2	Mean
MG	0	0.92	0.69	0.80	0.66	0.28	0.47
	56	1.08	0.59	0.83	0.58	0.24	0.41
	112	1.03	0.60	0.81	0.73	0.23	0.48
	Mean	1.01	0.63	0.82	0.66	0.25	0.45

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