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Species and functional diversity effects on productivity and nutrient uptake: implications for designing sustainable agricultural systems in the Midwest

Melissa Renee Cheatham
Iowa State University

Species and functional diversity effects on productivity and nutrient uptake: Implications for designing sustainable agricultural systems in the Midwest

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Melissa Renee Cheatham

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Program of Study Committee:
Matthew Helmers, Co - Major Professor
Heidi Asbjornsen, Co - Major Professor
Randall Kolka
Jim Kiniry

Iowa State University

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ABSTRACT

Temporal data on aboveground biomass and nutrient uptake by species and functionally diverse native perennial plant species and communities is needed to enhance the performance of in-field buffer conservation practices. Comparisons on the performance of monocultures and polycultures of four native perennial prairie species having different functional traits (e.g., forb, grass, nitrogen-fixer) relative to monocultures of corn soybean, brome, and switchgrass were conducted in terms of aboveground biomass production and N & P uptake at peak performance, at the beginning and end of the growing season, and over the course of the whole year. Data collection occurred in 2006, a year after plots were established. Our findings show that the polyculture treatments did not outperform their component species in monoculture for peak values of aboveground biomass and N and P uptake. This was the opposite of what was expected. However, the polyculture treatment with the highest diversity did exhibit the greatest relative aboveground net primary productivity. The perennial species, particularly the C_3 species, had higher biomass production and nutrient uptake at the beginning and end of the growing season compared to annual crops. The species stiff goldenrod was one species that performed as well as Corn for peak aboveground biomass and nutrient uptake. These results suggest that high diversity plant communities may potentially be the best choice for use in in-field buffer conservation practices when production and nutrient uptake at the beginning and end of the growing season as well as over the course of the year are wanted. High yielding monocultures could be good when considering high performance at a single mid summer point in the growing season, however, having multiple species that can accomplish these same functions would be

beneficial in the long run should some species (like Stiff Goldenrod) fluctuate in productivity from year to year (Camill et al., 2004) .

Key Words:

Aboveground Biomass, Aboveground Net Primary Productivity (ANPP), Functional Diversity, Species Diversity.

CHAPTER 1: GENERAL INTRODUCTION

1.0 Introduction

In Iowa, agricultural plant communities are dominated by corn and soybeans in monoculture. Monocultures, while aimed at maximizing agricultural crop production, can lose and degrade the resource bases that production is dependent on, such as soil, nutrients, and water. Early in the growing season, corn and soybeans are not large enough to contribute to stabilizing the soil or utilizing excess water from rain and nutrient losses occur. At the end of the growing season, crops senesce and are harvested reducing the amount of plant cover on the fields, thus providing limited means by which to utilize excess water and help prevent nutrient losses from the fields. The nutrient and soil losses from agricultural fields make up a large portion of the non-point source losses that contribute to reductions in water quality in major water bodies such as the hypoxic zone in the Gulf of Mexico.

The Natural Resource Conservation Service (NRCS-USDA) has designed various in-field buffer conservation methods to address some of the previously mentioned water quality issues at their source. These in-field buffers introduce strips of vegetation in the agricultural field to reduce nutrient losses. Typically, introduced species (smooth brome) and monocultures of native species (switchgrass) are used in the plant communities that comprise these in-field buffers (NRCS (IA)-USDA, 2000, 2002, and 2003; Tufekcioglu et al., 2003). Some drawbacks to the vegetation proposed by NRCS-USDA for in-field buffers are that the vegetation tends to be low in diversity (when considering switchgrass) or it is not necessarily naturally adapted to the region being considered (like in the case of smooth brome). Using plant communities composed of diverse native species may help improve these in-field buffer conservation methods.

Plant communities with high species diversity as well as high functional diversity were found to have higher peak biomass production than those plant communities with lower diversity (Tilman et al., 1997 and 2001). Hooper and Dukes (2004) also observed increased aboveground net primary productivity (ANPP) by plant communities with higher diversity in the seventh and eighth year when theses communities had become more established. Camill et al. (2004) reported that regardless of age, plant communities of tallgrass prairie established in the Midwest significantly increased their ANPP when nitrogen levels increased. This demonstrates how regionally adapted vegetation is able to capture and utilize nutrients when nitrogen levels become high. In addition, those species within the tallgrass prairie that were introduced species exhibited growth in the first years after establishment but significantly decreased in succeeding years. Based on these findings, it is suggested that using more diverse mixtures of native perennial vegetation would improve upon the effectiveness of in-field buffers to capture nutrients.

For this research project, it is hypothesized that using more diverse vegetation for in-field buffer conservation methods and using vegetation that is naturally adapted to the region in which it will be used (in this case, using prairie vegetation for the Midwest) will improve these in-field conservation methods. Both components would work together to promote a plant community that is more resilient when subjected to fluctuations in weather and climatic conditions, as well as, increasing a plant community’s capacity to capture more nutrients.

2.0 Thesis Organization

This thesis is organized into an Introduction, Field Study, and General Conclusions. The Introduction contains a short introduction to the research study, a description of the thesis' organization, a literature review pertaining to the research topics, and chapter references. The Field Study looks at field research and related data collected. This section includes a short introduction, a materials and methods section, results, discussion, conclusion, and chapter references. The last main part of the thesis is the General Conclusions, which provides an overall summary of this work, implications of this work, and recommendations for future study. Other sections that are included in this thesis are an Appendix section that contains figures, tables, and other related data and information not formally presented in the three main sections, and a list of Acknowledgements.

3.0 Literature Review

For the purpose of this study, this literature review will address the following topics:

- 3.1 In-field buffer conservation methods
- 3.2 Diversity
    - Species diversity
    - Functional diversity
    - Functional diversity in Plant Communities
- 3.3 Community and Ecosystem Functions
    - Properties and processes
    - Static and Dynamic Functions

3.1 In-Field Buffer Conservation Methods

Methods which integrate additional plant communities within a cropping system (in-field buffers) have been designed and used as conservation practices. A few of these methods include contour buffer strips (NRCS Code 332), grassed waterway (NRCS Code 412), and vegetative barriers (NRCS Code 601) (NRCS, 2000, 2002, and 2003; Lowrance et al., 2002). These methods aid in reducing soil loss due to sheet & rill erosion and wind erosion; they reduce concentrated flow erosion and reduce sediment delivery; they increase wildlife habitat; reduce contaminate transport (nutrients, pesticides, sediment, etc.); and increase carbon storage (Lowrance et al., 2002). While helpful in this regard, in-field buffers are usually comprised of vegetation having low diversity (e.g., monocultures of switchgrass used in filter strips) or are introduced species that may not be adapted to the region (e.g., a smooth bromegrass and red clover mixture used in grassed waterways) (NRCS, 2000, 2002, and 2003). Typically, more diverse vegetation has been used in edge-of-field and streamside buffers such as riparian buffers, which utilize 2 or 3 zones of vegetation (tree, shrub, and grass zones). The particular vegetation type of each zone is made more flexible by allowing different combinations to suit landowner preferences (ex. not wanting trees) (Schultz et al., 2004). In one such riparian buffer located in the Bear Creek Watershed in central Iowa, a zone consisting of native prairie vegetation was able to remove “more than 40 percent of total nitrogen and phosphorus and more than 40 percent of the nitrate and phosphate in surface runoff' (Lowrance et al., 2002). This same performance, as seen in the riparian buffers, may be of benefit if native mixtures are used in in-field buffers conservation practices.

3.2 Diversity

Many times when the word diversity is used, it is referring to the collection of species within a given community. The focus can be as narrow as a single trophic level (ex. a community of plants) to as broad as an entire ecosystem (ex. plants, herbivores, predators, decomposers, etc.).

Species Diversity

In particular, species diversity refers to the number of different types of species present in a sample (richness) and/or the number of individuals per a given species that are present in a sample (abundance) (Coffey, 2002; Krebs, 1985). A community or ecosystem can have high species abundance but very low species richness (many of one type of species). Such a community would not be as diverse as a community with high species richness (many different species). At the same time, when a community has high species richness but low species abundance for all but a few species present, the community is said to have low species evenness. If the same community has high species abundance for most or all of the species present, the community is said to have high species evenness. A community with high species evenness is considered to be more diverse than one with low species evenness and greater still than one with low species richness.

Having greater species diversity means that there are more species present that have different traits for dealing with changes in the environment and environmental disturbances. Thus, if some disturbance were to occur, some species would be able to thrive and compensate for those species that are reduced by the disturbance (Tilman and Downing, 1994). Additionally, the various traits that multiple species have, allow them to exploit different aspects of their environment that other species can not access (niches), contributing to greater total community productivity (Lambers et al., 2004; Stocking, 2002).

While species diversity is good in this regard, there is the potential of having high species diversity yet at the same time, having many species that tend to have the same traits and for the most part perform the same functional role(s) in a community (Tilman and Downing, 1994). Such a community would have many species but lack functional diversity.

Functional Diversity

Functional diversity encompasses having many species that all perform different functional roles within a community. The species within a community can be categorized into functional groups based on some common trait or traits (such as morphological traits- form and structure (Tilman et al., 1997; Stein, 1984), physiological traits – functions and organic processes (Leishman et al., 1992; Stein, 1984), and phenological traits – recurring traits that are influenced by climate (Leishman and Westoby, 1992; Tilman et al., 1997; Stein, 1984), etc.) that are inherent to all the species assigned to a given group (Leishman and Westoby, 1992). These grouped species also tend to perform certain functional roles in common in the community (Leishman and Westoby, 1992). Categorizing species into functional groups is important because it provides a method by which to take an ecologically complex system and simplify it for the purposes of predicting (1) system responses to stress (competition and availability of resources (Grime, 1977)), (2) disturbance (partial or total destruction of plant biomass (Grime, 1977)), and (3) changes in community properties and processes (Symstad and Tilman, 2001).

Having greater functional diversity insures that the plant community will have species with multiple traits regarding various functional processes thus making the plant community better able to use resources more completely. In context of plant community use in in-field buffer conservation methods, complete use of resources such a nitrogen and phosphorus means these nutrients are not be loss from the system to become pollutants in water systems.

Functional Diversity in Plant Communities

As with any community, diverse plant communities are composed of many species which can be grouped into different functional groups based on common traits or roles in a given community. Determining which and how many categories are necessary to adequately account for various community properties and processes is still ongoing (Leishman and Westoby, 1992; Symstad and Tilman, 2001). Some past functional groups that have been used for categorizing plant community functional groups are given in Table 3.1. C_3 grasses, C_4 grasses, and legumes were the most frequently used categories. Some suggestions for determining what functional groups should be considered are: (1) make sure that the functional groups are not too broad (Symstad and Tilman, 2001), and (2) when defining functional groups, do not just focus on the functional role/trait of interest, as other traits can play a role in how the functional group impacts community response in a given situation (Symstad and Tilman, 2001).

Table 3.2.1. Functional Groups Used by Other Researchers

Functional Groups	References
C_3 grasses	1, 2, 3, 4
C_4 grasses	1, 2, 3, 4, 5
Perennial forbs	5
Sub-shrubs	5
Annual forbs	5
Legumes	2, 3, 6
Forbs	2
Woody trees	2
Perennial C_4 grass	7
Perennial C_3 grass	7
Non-legume forbs	3
Woody plants	3
Early season annuals	6
Late season annuals	6
Perennial bunchgrasses	6
Annuals/biennials	4
Non-native perennials	4
Native perennial composites	4
Native perennial legumes	4
Non-legume/non-composites native perennial forbs	4
Mid succession forbs/shrubs	8
Late succession forbs/shrubs	8
Mid succession C_3 grasses/cool season grasses	8
Late succession C_3 grasses/cool season grasses	8
Mid succession C_4 grasses/warm season grasses	8
Late succession C_4 grasses/warm season grasses	8
1. Tilman and Downing (1994); 2. Lambers et al. (2004); 3.Tilman et al. (1997); 4. Camill et al. (2004); 5. Leishman et al. (1992); 6. Hooper and Dukes (2004); 7. Kenkel et al. (2000); 8. Levang-Brilz and Biondini (2002)	

3.3 Community and Ecosystem Functions

Properties and Processes

There are two types of community and ecosystem functions: properties and processes (Hooper et al, 2005). Properties refer to the pools of water, energy, and materials and their amounts (like nutrients and biomass) that are in a community. Processes refer to the rates of flow of the properties through the community, like nutrient cycling and productivity (Chapin et al., 1995; Hooper et al, 2005) (see Table 3.3.1). These properties and processes such as plant production or nutrient uptake can be used as measures of the performance of one plant community relative to another.

Table 3.3.1. Examples of Ecosystem Processes and Properties

Properties/Processes	Measurements
Species interactions	Competition, predation, mutualism
Trophic level biomass or process rate	Plant biomass (standing crop)
	Plant productivity (biomass produced in a certain time interval)
	Consumer biomass
	Consumption (predation, herbivory)
	Decomposer biomass
	Decomposer activity
	Decomposition rate
Nutrient uptake/retention	Nutrient uptake efficiency of plants
	Maintenance of initial concentrations of minerals and organic nutrients in the plant-soil system
Soil properties	Water Content
	Organic matter content
	Cation exchange capacity
	pH-
Community respiration	Respiration
	CO_2- production
Schläpfer and Schmid (1999); Chapin et al. (1995)	

Diversity / Productivity Relationships

The relationship between diversity and productivity is of importance because understanding this relationship (for example, what levels of diversity will yield greater productivity in plant communities) will allow us to better compose plant communities for use in-field buffer conservation practices

Relationships of diversity - community/ecosystem productivity are influenced by evenness and sampling effect. Evenness, as mentioned before, is the richness of a community relative to that community's abundance. When plants are grown together in experiments, the properties and processes (in this case, productivity) are considered to be a certain percentage for each species grown in monoculture. For example, if two plants are grown together in polyculture, each species is thought to produce 50% of what they would in monoculture (assuming high evenness or equal abundance) because 50% of the number of each plant species is present in polyculture from that in monoculture. If the plants in polyculture produce more than 50% of what they produce in monoculture they are considered to have overyielded and if the plants produce less than 50% of what they produce in monoculture they are considered to have underyielded (Hooper et al., 2005; Lambers et al., 2004).

Sampling effect is a term used to describe how the design of a diversity/productivity experiment impacts the results of that experiment and specifically refers to the increased probability of a pattern occurring between productivity and diversity when species that are dominant (those that tend to be the most abundant in a given community (Fridley, 2001)), complementary (those that have different resource requirements and therefore when growing together utilize environmental resources more completely (Fridley, 2001; Loreau, 2000)), or facilitators (a species' beneficial effects on resources that increases the productivity of another species (Fridley, 2001)) are randomly chosen from a species pool (Fridley, 2001; Hooper and Dukes, 2004) for inclusion in a treatment. This increased probability of a pattern occurring becomes greater when the number of species chosen from a species pool for a treatment is increased (Fridley, 2001). Functional diversity can impact the productivity/diversity relationship in that complementarity and facilitation becomes stronger with greater differences in functional traits being present (Hooper et al., 2005). This stronger occurrence of complementarity and facilitation can, in turn, potentially lead to the occurrence of patterns in the productivity/diversity relationship (Fridley, 2001; Hooper and Dukes, 2004).

Sampling effect has been debated by researchers regarding community assemblage (Hooper et al., 2005) and random extinction in diversity/productivity experiments. This has to do with the potential for patterns of extinction to occur due to random chance (not true patterns) (Fridley, 2001; Hooper and Dukes, 2004). In the case of extinction experiments, species are randomly chosen from out of a species pool, to determine which will continue to grow while all others are said to have experienced extinction. Some would say that random extinction is not relevant because extinction would not occur randomly but that various conditions that do or do not occur would determine which species would experience extinction (Fridley, 2001; Hooper and Dukes, 2004; Hooper et al., 2005). Others would disagree and say that random extinction is legitimate, thus resulting in the debate as to how results should be interpreted (Fridley, 2001; Hooper and Dukes, 2004; Hooper et al., 2005). It is the opinion of this author that randomly excluding species from a treatment on the bases of extinction is only legitimate if some common occurrence(s) could result in those species becoming lost from the plant community. This would then add the component of comparing conditions that would cause such extinctions (the various treatments that would be included in the experiment).

Tilman et al. (1997) concluded that functional diversity has a greater impact on ecosystem processes than species diversity but that both are correlated and have significant effects on ecosystem properties and processes. Based on the sampling effects, there should be a strengthened pattern of functional diversity-productivity because of a greater chance of choosing complementary and facilitator species due to the nature of increasing functional diversity.

Indicators for Assessing System Performance

Community and ecosystem functions that have been measured in past research on diversity are total aboveground biomass, live aboveground biomass, dead (standing and/or litter) aboveground biomass, total belowground plant biomass, live belowground biomass, dead belowground biomass; total net primary productivity (TNPP), aboveground net primary productivity (ANPP), belowground net primary productivity (BNPP); plant nitrogen; plant phosphorus; light penetration; soil NO_3^- and NH_4^+; nutrients in stream and runoff water (total N and P, nitrate, phosphate); soil infiltration rates; total soil organic carbon; root nutrient influx rates (N and P); soil microbial biomass; stream bank erosion; and presence/absence of wildlife (small mammals, birds, etc.). A few of the results obtained when using these functions as indicators of community or ecosystem performance are given below.

*Total, Above, and Belowground Plant Biomass***.** Lambers et al. (2004) measured aboveground biomass to determine biomass as a yield. An index of looking at overyielding and underyielding was used to make comparisons between treatments. Overyielding, in this case, was the degree to which a treatment produced more than expected based on monoculture production while underyielding was the degree to which a treatment produced less than expected based on monoculture production. It was observed that underyielding species were exclusively forbs while overyielding species were C_3 grasses, C_4 grasses, and legumes. Additionally, the presence of legumes usually positively affected the yields of most species. In comparing plant communities, Schultz et al. (2004) notes that riparian areas put into buffers have 8 times more below ground biomass than adjacent crop field. In contrast, Kenkel et al. (2000), found no difference in aboveground biomass between high diversity plots and low diversity plots.

*Plant Productivity***.** Plant productivity refers to how plants perform regarding biomass production over a given time frame. This can be useful in determining how a plant community performs over the length of an entire growing season as opposed to looking at individual points throughout the growing season. In Tilman et al. (1997), both functional diversity and functional composition had significant effects on plant productivity. In particular, having a C_4 grass present in mixed plots increased productivity 40% (consistent with lower tissue N concentrations in C_4 grasses), while having a legume present in mixed plots increased productivity 59% (consistent with ability to fix N). In general many species experienced lower productivity in monocultures and low diversity plots than in high diversity plots. This was also experienced in the study by Tilman et al. (1996). In contrast, Hooper and Dukes (2004) observed that the relationships between productivity and diversity depended on the year since plots were established. In the 3rd year since establishment, the perennial bunchgrasses group was the most productive, the early season annuals group was the least productive, with no mixture exceeding the productivity of the perennial bunchgrass group in monoculture (Hooper and Dukes, 2004). On the 8th year, it was observed that productivity increased as species richness increased with several groups in mixtures out producing the highest producing single functional group (the late-season annuals) (Hooper and Dukes, 2004). The lowest producer was a single functional group, early-season annuals (Hooper and Dukes, 2004). Finally, on the 9th year, the highest producing treatment was once again the single functional group bunchgrasses which exceeded all the mixtures (Hooper and Dukes, 2004). In general, Hooper and Dukes (2004) experienced similar observations as Tilman et al. (1997) and Tilman et al. (1996) such that the groups that had the most positive increase in productivity in mixtures were the functional groups that did not have the highest productivity in monoculture. Additionally, N-fixers improved the productivity of other functional groups as reflected in high measures of overyield similar to what Tilman et al. (1997) experienced. This is expanded on in the study by Tilman and Downing (1994) in which resistance and resilience (bounce back) of species experiencing drought were observed. Those plots with high species richness experienced higher resistance and resilience than low diversity plots. Lastly, Levang-Brilz and Biondini (2002) measured total plant biomass, aboveground biomass, and below ground biomass to determine relative growth rates. It was observed that mid successional grasses had higher relative growth rates than late successional grasses. The status of mid successional and late successional plants have to do with how quickly different species of plants come into an area after disturbance and become established. The late successional species would take the longest to start growing and become established in area after disturbance.

*Plant Nitrogen***.** In the study conducted by Tilman et al. (1997), both functional diversity and functional composition had significant effects on plant total N and %N such that all 5 functional groups used in the study (C_3 grasses, C_4 grasses, woody plants, legumes, non-legume forbs) contributed to %N but legumes in particular contributed to plant total N. In contrast, Levang-Brilz and Biondini (2002), observed no differences in plant N when soil N levels were low, but when soil N levels were high, the C_3 grasses and mid successional grasses have lower N productivity than C_4 grasses and late successional grasses.

*Plant Phosphorus***.** C_3 grasses and mid successional grasses had lower P productivity (higher P concentration) than C_4 grasses and late successional grasses when soil N levels were high, while no difference was observed when soil N levels were low (Levang-Brilz and Biondini, 2002).

Light Penetration. In their research, Tilman et al. (1996) and Tilman et al. (1997) used light interception to estimate biomass for their plots. Tilman et al. (1997) determined that both functional diversity and functional composition had significant effects on light penetration and thus plant biomass.

*Others***.** In the article by Schultz et al. (2004), it is noted that native grass filters 7-m wide reduced the total nitrogen, total phosphorus, nitrate, and phosphate in surface runoff by more than 60% and reduced the sediment loss from crop fields by more than 95%. Multispecies riparian buffer systems also had up to 5 times greater infiltration after the first six growing seasons than corn, soybean, and pasture systems (Schultz et al., 2004 and Bharati et al., 2002), and tended to generate 65% more total organic carbon in the top 50 cm of soil than crop fields (Schultz et al., 2004). Riparian buffers had a 2.5 fold increase in soil microbial biomass and a 4 fold increase in denitrification than crop fields and decreased stream bank erosion by 80% compared to cropped or heavily grazed stream banks (Schultz et al., 2004). Additionally, streams with buffers had increased substrate leading to increased fish diversity. Also, small rodents like mice and voles preferred the riparian and prairie vegetation over introduced cool season grasses, and riparian buffers supported 5 times more bird species than riparian areas that were heavily grazed or in row-crop (Schultz et al., 2004). These findings suggest other benefits of using native vegetation in riparian buffers such as increase wildlife habitat, soil organic carbon generation, and reduces in nutrient concentrations in runoff water and these benefits may also have their place in in-field buffer methods.

4.0 Hypothesis and Objectives

Based on the findings in the literature, it is proposed as part of this research that using more diverse and locally-adapted native perennial plant communities in in-field buffer conservation practices will increase their capacity to capture nutrients for utilization in biomass production, with the potential of enhanced resistance and resilience to environmental fluctuations such as climate change. Baseline information on the performance of functionally diverse native perennial plant communities is needed to improve the design of in-field conservation methods. Specifically, it is hypothesized that perennial plant communities having higher species diversity will be more productive and will take up more nutrients over the length of the growing season relative to plant communities with lower species diversity. Although productivity and nutrient uptake of annual crop species may exceed that of perennial monocultures and polycultures during the peak growing season, their performance will be substantially lower during the critical early and late season time periods.

The objective of this study is to compare the performance of monocultures and polycultures of four native perennial prairie species having different functional traits (e.g., forb, grass, nitrogen-fixer) relative to monocultures of corn, soybean, brome, and switchgrass in terms of aboveground biomass production, nutrient uptake, light interception, plant area index (PAI), and temporal patterns at the beginning, ending, and over the whole growing season.

An additional objective related to this study is to investigate the potential of using light interception as a nondestructive means for determining biomass. Such a technique if feasible would help to reduce the amount of time needed to obtain biomass data, as well as, reducing the amount of disturbed area in treatment plots for other measurements to be conducted in future research projects.

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CHAPTER 2. FIELD STUDY

ABSTRACT

Temporal data on aboveground biomass and nutrient uptake by species and functionally diverse native perennial plant species and communities is needed to enhance the performance of in-field buffer conservation practices. Comparisons on the performance of monocultures and polycultures of four native perennial prairie species having different functional traits (e.g., forb, grass, nitrogen-fixer) relative to monocultures of corn soybean, brome, and switchgrass were conducted in terms of aboveground biomass production and N & P uptake at peak performance, at the beginning and end of the growing season, and over the course of the whole year. Data collection occurred in 2006, a year after plots were established. Our findings show that the polyculture treatments did not outperform their component species in monoculture for peak values of aboveground biomass and N and P uptake. This was the opposite of what was expected. However, the polyculture treatment with the highest diversity did exhibit the greatest relative aboveground net primary productivity. The perennial species, particularly the C_3 species, had higher biomass production and nutrient uptake at the beginning and end of the growing season compared to annual crops. The species stiff goldenrod was one species that performed as well as Corn for peak aboveground biomass and nutrient uptake. These results suggest that high diversity plant communities may potentially be the best choice for use in in-field buffer conservation practices when production and nutrient uptake at the beginning and end of the growing season as well as over the course of the year are wanted. High yielding monocultures could

be good when considering high performance at a single mid summer point in the growing season, however, having multiple species that can accomplish these same functions would be beneficial in the long run should some species (like Stiff Goldenrod) fluctuate in productivity from year to year (Camill et al., 2004) .

Key Words:

Aboveground Biomass, Aboveground Net Primary Productivity (ANPP), Functional Diversity, Species Diversity,

1.0 Introduction

In-field buffer conservation methods are one way of reducing non-point source pollution from agricultural fields. Buffers such as contour buffer strips (NRCS Code 332), grassed waterways (NRCS Code 412), and vegetative barriers (NRCS Code 601) (NRCS(IA)-USDA, 2000, 2002, and 2003; Lowrance et al., 2002) provide permanent vegetatative cover for taking up soil nutrients that would otherwise be lost to leaching or tile drainage and reducing soil losses from soil erosion. Typically, introduced species (smooth brome) and monocultures of native species (switchgrass) predominate in these in-field buffers (NRCS (IA)-USDA, 2000, 2002, and 2003; Tufekcioglu et al., 2003); however, using plant communities composed of diverse native species may help improve these in-field conservation methods.

Tufekcioglu et al. (2003) reported how perennial vegetation has the advantage of earlier spring growth and therefore captures nitrogen during time periods when the annual crops, corn and soybeans, have low or no growth. This time frame relates to when nitrogen losses from agricultural fields are high. The annual crops did however produce more live biomass and captured more nitrogen in live biomass during mid summer. In contrast, when comparing native perennial grassland communities having different levels of species diversity, plant communities with high species diversity as well as high functional diversity were found to have higher peak biomass production than those plant communities with lower diversity (Tilman et al., 1997, 2001). Hooper and Dukes (2004) also observed increased aboveground net primary productivity (ANPP) by more diverse grassland plant communities with higher diversity, but only after 7-8 years after becoming established. Camill et al. (2004) reported that regardless of age, ANPP in tallgrass prairie plant communities significantly increases when nitrogen levels increase.

These and other studies report diversity performance at some point(s) in time (example, peak values) or over the course of the growing season (example, net primary productivity (NPP)), but few mention how these plant communities perform at multiple points in the year as well as over an entire growing season. This gap in information, if made available, would be valuable in determining how diverse plant communities of native perennial vegetation can be used to improve upon existing in-field buffer conservation methods. It would allow one to know in what situations plant communities of differing compositions would be of greatest benefit depending on what condition(s) are being addressed.

We propose that integrating diverse mixtures of native perennial vegetation within annual cropping systems could improve capacity of these integrated agroecosystems to capture and retain nutrients. As a first approximation towards testing this hypothesis, we conducted a field experiment to compare effects of contrasting levels of species and functional diversity on agroecosystem performance with regard to biomass production, nutrient uptake, and annual net productivity. Our results serve as baseline information for designing in-field conservation buffers and other agricultural practices targeting amelioration of nutrient and carbon cycling processes

2.0 Hypotheses and Objectives

It is proposed as part of this research that using more diverse and locally-adapted native perennial plant communities in in-field buffer conservation practices will increase their capacity to capture nutrients for utilization in biomass production with the potential of enhanced resistance and resilience to environmental fluctuations such as climate change. Baseline information on the performance of species diverse and functionally diverse native perennial plant communities is needed to improve the design of in-field conservation methods. Specifically, it is hypothesized that perennial plant communities having higher species diversity will be more productive (in terms of total aboveground biomass production and ANPP) and will take up more nutrients over the length of the growing season relative to plant communities with lower species diversity. Although productivity and nutrient uptake of annual crop species may exceed that of perennial monocultures and polycultures during the peak growing season, their performance will be substantially lower during the critical early and late season time periods.

The objective of this study is to compare the performance of monocultures and polycultures of four native perennial prairie species having different functional traits (e.g., forb, grass, nitrogen-fixer) as well as comparing these four prairie species to monocultures of corn, soybean, brome, and switchgrass in terms of aboveground biomass production, nutrient uptake, light interception, plant area index (PAI), and across the growing season. An additional objective related to this study is to investigate the potential of using light interception as a nondestructive means for determining biomass. Such a technique has been tested in cropping systems such as rice (Casanova et al., 1998), onions (Challa et al., 2000), barley in monoculture and in polyculture with rape (Christensen and Goudriaan, 1993), and olive trees orchards (Mariscal et al., 2000) and its applicability in tallgrass prairie systems is of interest for future research related to this study. If feasible, this technique would help to reduce the amount of time needed in obtaining biomass data, as well as, reducing the amount of disturbed area in treatment plots for other measurements to be conducted in future research projects.

3.0 Materials and Methods

3.1 Study Site

This study examines the biomass production and nutrient uptake performance of plant communities from both species diversity and functional diversity perspectives. Eight plant species were established in monoculture and polyculture in plots at the Agronomy and Agricultural and Biosystems Engineering Research Farm (AABERF) located about 7 miles west of Ames, Iowa.

Eight plant species, listed in Table 3.1.1, were used to represent the following plant communities: a corn field, a soybean field, a brome pasture, a switchgrass buffer, and a restored prairie (see Table 3.1.2). The restored prairie was the only plant community that was planted at multiple levels of species diversity (richness). All the other plant communities consisted of a single species.

In total there were 15 treatments used, one treatment each for the corn field, soybean field, brome pasture, and switchgrass buffer; four treatments for the restored prairie in monoculture; and seven treatments for the restored prairie in polyculture (Table 3.1.2). Plots for each treatment were 5 m by 5 m in area and were established in a field previously planted to corn. This field contained Webster, Nicollet, and Clarion soils, and was divided into three blocks to account for these potential differences in soil type throughout the field site. Each treatment had three replicates, one in each of the three blocks.

Year-old transplants obtained from Prairie Nursery (Westfield, WI) and Spence Restoration Nursery (Muncie, IN) were used to establish the switchgrass, big bluestem, Canada wild rye, false blue indigo, and stiff goldenrod species, while the remaining species (corn, soybeans, and brome) were established by planting seed.

Table 3.1.1. Experiment Plant Species and Functional Traits

Plant Name	Species	Functional Traits			
		Duration	CO_2 Fixation	Life Form	Legume
Corn	Zea mays	Annual	C_4	Grass	N
Soybeans	Glycine max	Annual	C_3	Forb	Y
Brome	Bromus inermis	Perennial	C_3	Grass	N
Switchgrass	Panicum virgatum	Perennial	C_4	Grass	N
Big Bluestem	Andropogon gerardi	Perennial	C_4	Grass	N
Canada Wild Rye	Elymus Canadensis	Perennial	C_3	Grass	N
Stiff Goldenrod	Solidago rigida	Perennial	C_3	Forb	N
Blue False Indigo	Baptisia australis	perennial	C_3	Forb	Y
Bidwell et al. (2007); Prairie Nursery (2005); USDA, NRCS (2001, 2002a, 2002b, 2002c, 2004a, 2004b, 2004c)					

All treatments were established in May 2005 and measurements were collected from May to October of 2006. Weeding occurred throughout the growing season for all treatments and replications. The corn and soybean treatments were rotated the following year to mimic actual farming practices. Only plots planted to corn in a given year were fertilized (168 kg N from Urea Ammonium Nitrate (UAN) ha^{-1}, 150 lb UAN ac^{-1}). An alternative site adjacent to the research plots at the AABERF, planted to corn after soybeans with 168 kg N ha^{-1} (from UAN) applied, was used in place of the original experimental design corn plots due to damage by rodents. The alternative site was about 5 meters distance from the original experimental plots and possessed similar soil and climatic conditions. Standing residual biomass from 2005 was cut down prior to perennial emergence in 2006. Pruning shears were used to cut the residual biomass down to within 5cm above ground level and the cut residual biomass was removed from within the plots and placed in the allies between the plots.

Table 3.1.2. Experiment Treatments

Treatment	Plant Community	# Species	Plants Used	Plant Code
1	Corn Field	1	Corn	Cor
2	Soybean Field	1	Soybeans	Soy
3	Brome Pasture	1	Brome	Bro
4	Switchgrass Buffer	1	Switchgrass	Swi
5	Restored Prairie	1	Big Bluestem	BigB
6	Restored Prairie	1	Canada Wild Rye	Can
7	Restored Prairie	1	Blue False Indigo	BluF
8	Restored Prairie	1	Stiff Goldenrod	Sti
9	Restored Prairie	2	BigB + Can	BigB + Can
10	Restored Prairie	2	BigB + BluF	BigB + BluF
11	Restored Prairie	2	BigB + Sti	BigB + Sti
12	Restored Prairie	2	Can + BluF	Can + BluF
13	Restored Prairie	2	Can + Sti	Can + Sti
14	Restored Prairie	2	BluF + Sti	BluF + Sti
15	Restored Prairie	4	BigB + Can + BluF + Sti	BigB + Can + BluF + Sti

3.2 Data Collection

Precipitation

Weather information was obtained from a weather monitoring station set up at the research farm (AABERF) near the treatment plots (approximately 0.41 km from the plots). Daily temperature, precipitation, solar radiation, and wind direction were monitored.

Light Interception

Light interception measurements were taken every two weeks throughout the growing season for all fifteen treatments using a Decagon AccuPAR PAR/LAI Ceptometer (Decagon Devices, Inc, Pullman, WA). For each treatment replicate, six measurements were taken, each consisting of an average of 10 rapid readings above the vegetation and 10 below (Flénet et al., 1996; Kiniry et al., 2001; Kiniry et al., 2002d). Measurements were taken between 10am and 2pm on days when the skies were relatively cloud-free (Flénet et al., 1996; Kiniry et al., 2001; Kiniry et al., 2002d).

Aboveground Biomass Collection and Processing

Biomass sampling occurred every 6 weeks throughout the growing season starting at emergence when growth across the plots was consistent and ending in October after corn/soybean harvest (Flénet et al., 1996). Due to the size of the plots, there were 5 collection times throughout the season with only one sample taken from a plot per scheduled collection. A measuring square constructed of PVC tubing was used to clip an area of aboveground plant material (1m x 1m) and the areas were marked to prevent future sampling in the same location within the same year (Kiniry et al., 2002d). All biomass samples were separated into live and dead categories, and mixed-species treatments were also separated by species. All components for each treatment replicate were weighed together and individually.

A 20% by weight subsample of each treatment sample was measured for leaf area (Flénet et al. 1996), using a LI-3100C Area Meter (LI-COR, Lincoln, NE). Leaf area of component species within polyculture treatment samples was determined for each species separately. Additionally, live and dead components were run through the leaf area meter separately for each species and treatment. Subsamples were added back into their respective component groups within each total sample, and treatment samples were dried at 60°C (140°F) for four to seven days and weighed. Once weights had stabilized, dry-weight biomass was determined (Kiniry et al. 2002c).

Plant Nutrient Uptake

After the aboveground plant biomass samples of each treatment for all collection periods were oven dried, the live component (of each treatment sample) was ground to fit through a 1mm sieve using a Model 4 Wiley Laboratory Mill (Thomas Scientific, Swedesboro, NJ). Each replicate sample and within sample species was analyzed separately. These ground samples were then sent to the USDA Forestry Service Northern Research Station Lab (Grand Rapids, MN) to be analyzed for plant total nitrogen and total phosphorus. Samples were analyzed for nitrogen using a combustion method on a Leco TruSpec Carbon/Hydrogen/Nitrogen Determinator combustion analyzer (LECO Corporation; St. Joseph, MI); while samples were ashed, brought into solution using HCl, and then colorimeterically analyzed for phosphorus (Alban, 1971) using a Thermo Elemental IRIS Intrepid Inductively Coupled Plasma-Optical Emission Spectroscopy instrument (Thermo Fisher Scientific, Inc.; Waltham, MA). Some treatments had missing samples for component species during certain collection periods due to differences in timing of plant emergence, senescence, harvesting, or to insufficient sample quantity.

3.3 Analysis of Biomass Overyielding and Underyielding

To make yield comparisons between treatments we have chosen use the following indices: D_{max}, D_{min}, RY, and RYT.

The D_{max} and D_{min} indices indicate whether the total aboveground biomass of a polyculture treatment has exceeded the total aboveground biomass of the highest yielding component species in monoculture (D_{max}) or is less than the total aboveground biomass of the lowest component species in monoculture (D_{min}) (Loureau, 1998, Hooper and Dukes, 2004).

$$D_{max} = (O_T - Max\ (M_i))/Max\ (M_i) \quad (1)$$

$$D_{min} = (O_T - Min\ (M_i))/Min\ (M_i) \quad (2)$$

where $Max(M_i)$ is the monoculture yield of the highest yielding component species in monoculture, $Min(M_i)$ is the monoculture yield of the lowest yielding component species in monoculture, and $O_T = \Sigma\ O_i$ or the sum of the observed mixture yields of each component species within a mixture. According to this concept, the presence of over/underyielding is termed transgressive, whereas its lack is referred to as nontransgressive (Trenbath, 1974). Thus, if $D_{max} > 0$, the polyculture is transgressively overyielding, and if $D_{min} < 0$, the polyculture is transgressively underyielding.

Relative yield (RY) refers to the how well the observed yields of each component species in the mixture meet the expected yields for those species, and the relative yield total (RYT) shows how well the observed yield of the total mixture meets the expected yield for that total mixture. These terms are expressed by the following indices:

$$RY_i = O_i/M_i \quad (3)$$

$$RYT = \Sigma\ RY_i \quad (4)$$

where O_i is the observed yield of component species i when in mixture, M_i is the yield of component species i when in monoculture, and ΣRY_i is the sum of all component species' RY_i in a given mixture. If RY < 1/s (where s is the number of species in the mixture), the component species has underyielded; if RY > 1/s, then the component species has overyielded; and if RY = 1/s, the component species performed as expected (Loureau, 1998, Hooper and Dukes, 2004). The sum of the relative yields for all species in a mixture gives a relative yield total (RYT), and it is given as a fraction. Thus, RYT < 1 indicates the total mixture has underyielded; RYT > 1 indicates the total mixture has overyielded, and RYT =1 indicates that the mixture has performed as expected (Loureau, 1998, Hooper and Dukes, 2004). RY and RYT do not indicate whether the total mixture transgressively over/underyields, just whether the yield is greater or less than what would be expected based on yields in monoculture.

3.4 Analysis of Aboveground Net Primary Productivity (ANPP)

For this study, we calculated ANPP, defined here as "the total photosynthetic gain, less respiratory losses, of vegetation per unit ground area" "for a given period of measure" (Scurlock et al, 2002), based on a model that uses both the live and standing dead components of biomass samples and sums the positive change in these two components for each sample interval to obtain ANPP (Scurlock et al, 2002; Singh et al., 1975).

$$ANPP = Sum\ (\Delta L + \Delta D)_I \quad (8)$$

where ΔL is the change in live biomass, ΔD is the change in standing dead biomass, and i is the sample time interval. To determine which components to include in the model for each sampling interval, a decision matrix, the "Smalley method" (Smalley 1959, Linthurst and Reimold, 1978; Scurlock et la., 2002) was used (increase (↑*); decrease (*↓*); no change (0), (-) sums to a negative value; (+) sums to a positive value):*

1) *When ↑live & ↑dead, use Σ(live +dead)*
2) *When ↓live & ↓dead, use "0"*
3) *When ↑live & ↓dead, use live*
4) *When ↓live & ↑dead*

   if Σ(live +dead) = —, use "0"

   if Σ(live +dead) = +, use Σ (live +dead)

All the values for each sampling interval are summed to obtain the value for the whole growing season.

In using this approach for computing ANPP, it is assumed that growth, death, and decomposition do not occur at the same time, and that the ANPP at any given time interval is never negative (Scurlock et al, 2002). It's also assumed that a partial estimation of live biomass mortality occurs when there is an increase in dead biomass (Linthurst and Reimold, 1978; Scurlock et al, 2002). The model does not take into account growth of new biomass when the mortality of live biomass is high and is most subject to error when there is a decrease in both live and dead biomass components (Linthurst and Reimold, 1978). Based on these assumptions, the method being used in this study to determine ANPP gives a better indication of NPP than solely using a one time peak value, but it still may underestimate actual values particularly since only aboveground biomass is being considered.

3.5 Analysis

Analysis of variance (ANOVA) was used to analyze each data set for significance, and a Tukey's multiple comparison test was used to make comparisons between treatments within individual collection times. Prior to analyzing the data, each data set was tested for normality (whether the data set meets model assumptions) and the data was transformed by obtaining the logarithm, square, square root, or, other of the data when needed to stabilize the variances in the data set for analysis (Kuehl, 2000). In addition, a linear regression was used to determine fit of light interception as a non-destructive means for determining aboveground biomass. All statistical analyses were conducted using SAS 9.1 (SAS, 2003)

4.0 Results

4.1 Precipitation

The precipitation at the research site during 2006 was lower during much of the growing season than the 57 year average (1951-2007 period) for the research farm site in Boone County, Iowa (Herzmann, 2007) (Figure 4.1.1). Only in the latter quarter of the growing season did precipitation reach typical values experienced at the research farm. These weather conditions may have affected the growth of the plants used in this study, but comparable data obtained under weather conditions closer to average would be needed to determine to what extent the weather impacted plant growth.

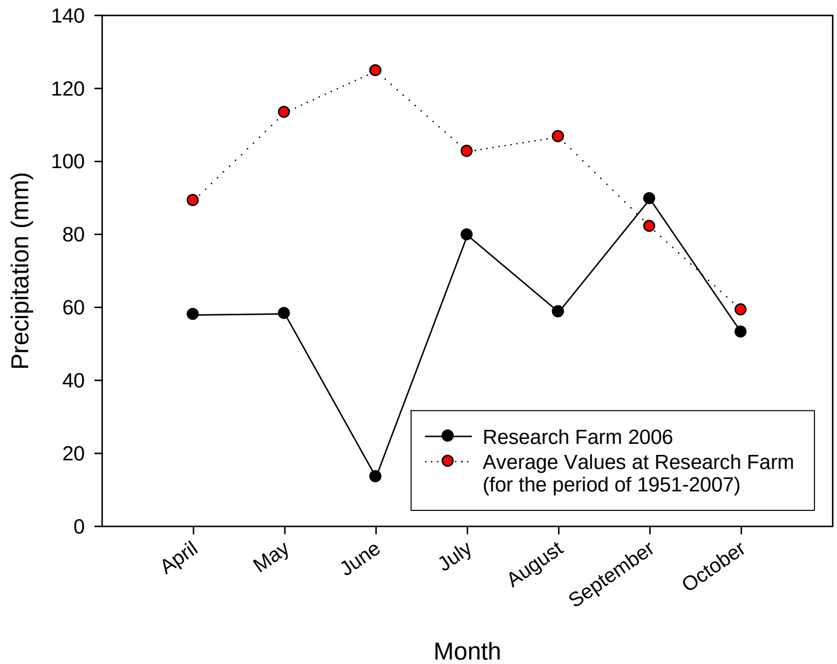

Figure 4.1.1. Monthly Cumulative Precipitation in 2006
*AAERF average monthly precipitation averaged using data from 1951-2007 (57 yrs)

4.2 Aboveground Biomass

General patterns

The *Sti* and *Cor* treatments had the highest peak aboveground biomass values at a single point in time (Figure 4.2.1A). The *Sti* treatment, which received no fertilizer, produced statistically similar values of peak aboveground biomass compared to the *Cor* which received 168 kg N ha^{-1} (Figure 4.2.1A). An unfertilized corn treatment, planted near the plots used in this study, produced 1220 g m^{-2} of peak aboveground biomass and the *Sti* treatment exceeded this value at 1494 g m^{-2} (Figure 4.2.1A). The most diverse treatment (*BigB+Can+BluF+Sti*) had the highest ANPP over the whole growing season (Figure 4.2.1B). Of all the treatments the *BluF* in monoculture was the lowest producing treatment both at individual sampling times and over the whole growing season (ANPP) (Figure 4.2.1)

In the spring, the perennial vegetation had initiated growth around April 18th in 2006 and thus had more biomass than the annual crops which had not yet started growing by the first data collection period on May 15th. Among the perennial treatments, the polyculture treatments did not produce significantly more biomass than their component species in monoculture (Figure 4.2.2A). A few of the perennial treatments did however have greater biomass than the *Swi* treatment (*Can*, *Sti*, *Can+Sti, BluF+Sti*). All of these treatments contained C_3 species and the *Swi* treatment is a C_4 species; and the C_3 species tend to start growing sooner than the C_4 species.

By October 30, 2006, the C_3 species were the only plants that were still producing live biomass with the exception of the *BluF* treatment which senesced (prior to the fifth collection period on October 30, 2006) like the C_4 species (Figure 4.2.2B). No polyculture treatment out performed its component species in monoculture and none of the treatments (monoculture and polyculture) out performed the *Bro* treatment. When the polyculture treatments were considered on a total aboveground biomass basis (Figure 4.2.2C), they still had not outperformed their component species in monoculture, and one polyculture treatment (*BigB+Can*) performed worse than both of its component species in monoculture (transgressively underyielded) (Figure 4.2.2C). In addition, the *Sti* and *BigB+Sti* treatments had greater total aboveground biomass than the *Bro* treatment.

Data for plant area index reflected similar results as those described for aboveground biomass and therefore is not presented.

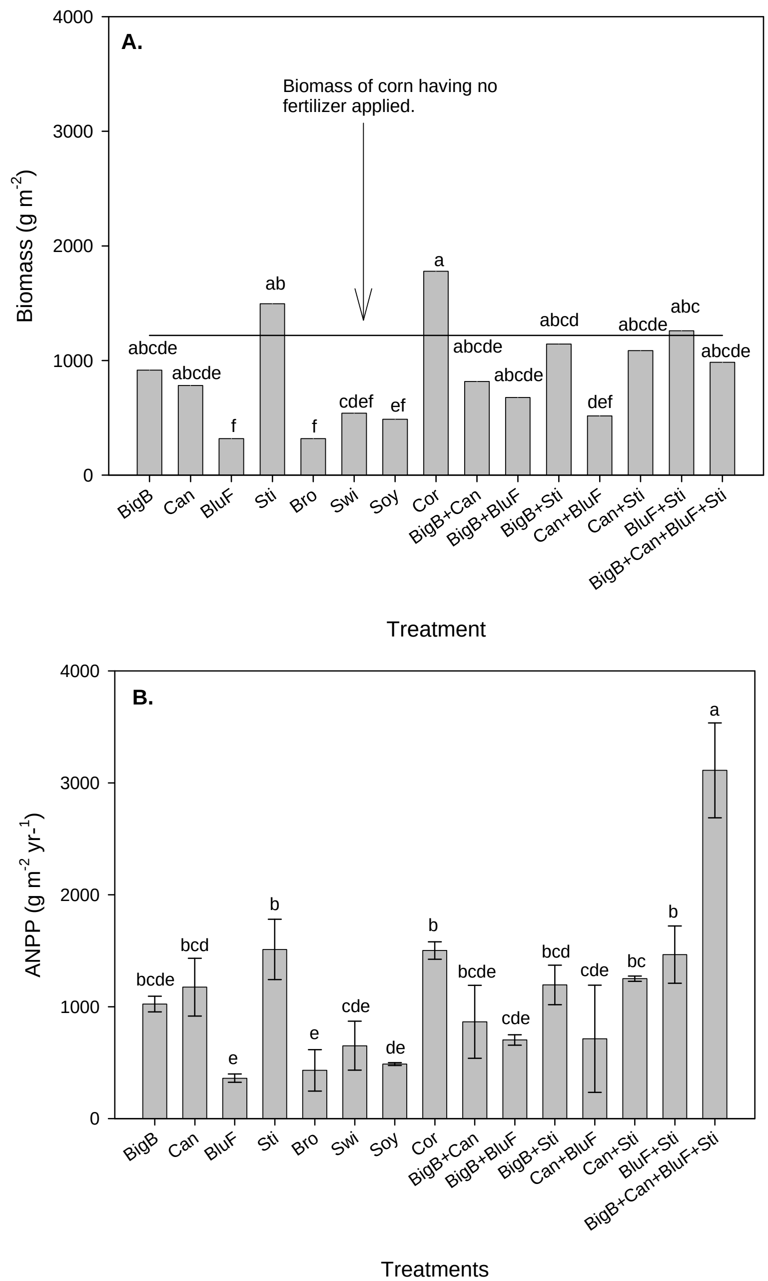

Figure 4.2.1. Aboveground Biomass over the 2006 Growing Season: A. Peak Total Aboveground Biomass*, and B. Aboveground Net Primary Productivity (ANPP)**

*Values for means and statistics obtained from log transformed data.
**Values for means and statistics obtained from un-transformed data; two reps used for Cor treatment to meet assumptions for normality.
***Treatments with the same letter are not significantly different from each other at the alpha = 0.05 level
****Total includes both live and dead aboveground biomass and biomass for all species in each treatment
***** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

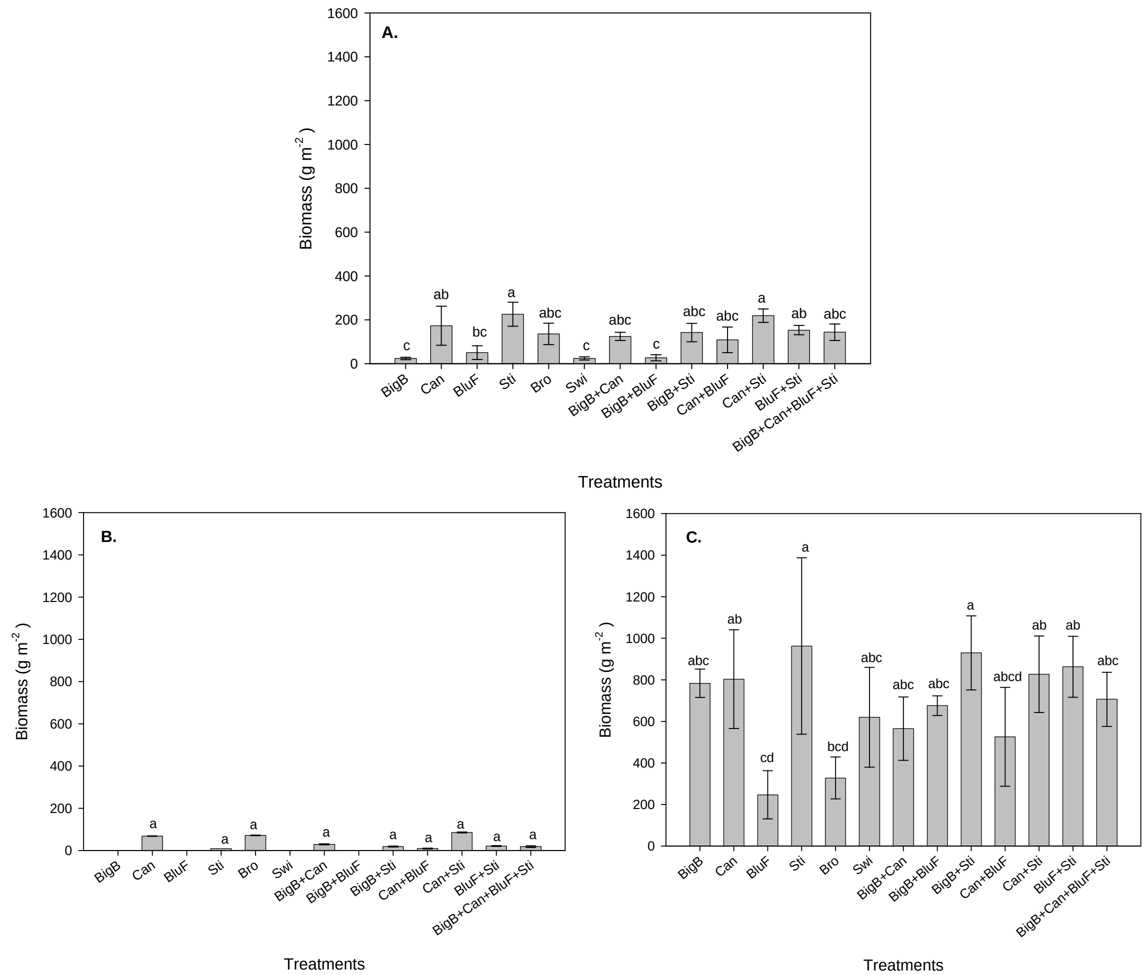

Figure 4.2.2 Aboveground Biomass at the Beginning and End of the Growing Season 2006. A. Live/Total Aboveground Biomass (May 15, 2006)*, B. Live Aboveground Biomass (October 30, 2006)**, and C. Total Aboveground Biomass (October 20, 2006)*.

* Values for means and statistics obtained from untransformed data.

**Values for means and statistics obtained from log transformed data.

***The Corn and Soybean treatments were not included in these figures as they had yet to begin growing (May 15, 2006) or had been harvested prior to this collection date (October 30, 2006).

**** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

<u>Effects of species diversity on productivity</u>

Overyielding/Underyielding. Indices for looking at overyielding/underyielding were used to examine diversity effects on peak aboveground biomass production and ANPP. None of the polyculture treatments transgressively overyielded (D_{max}) or underyielded (D_{min}) (Table 4.2.1). Whether a component species in polyculture exceeded its production in monoculture was dependant on how a polyculture's component species performed in monoculture relative to how other component species in the same polyculture performed in monoculture. In almost every case, one of the component species in each polyculture treatments had higher than expected biomass (0.5 for the two species mixtures and 0.25 for the 4 species mixtures) while the other component species had lower than expected biomass (column RY in Table 4.2.1). For the BigB+Can+BluF+Sti treatment, there were two species with greater than expected biomass and two with lower than expected biomass. Additionally, the component species in a given polyculture with the highest production in monoculture (see Figure 4.2.1) had higher than expected yields, thus the *Sti* treatment always had greater than expected biomass in polyculture and the *BluF* treatment always had lower than expected biomass in polyculture (Table 4.2.1). This indicates that there was probably competition occurring between the component species in each polyculture.

The performance of the total polyculture was dependant on whether the polyculture was being analyzed at a single point in time (ex. peak values) or as cumulative production over the whole growing season (ex. ANPP). The *BigB+Can+BluF+Sti* treatment had the highest ANPP for the whole season and greatly exceeded its highest component species in monoculture (D_{max}, Table 4.2.2), but when this same treatment is assessed at one point in time (peak values) the treatment has lower than expected biomass (RYT, Table 4.2.1). This is also seen regarding the *BigB+Can* treatment which had lower ANPP than its component species with the lowest biomass in monoculture (D_{min}, Table 4.2.2), but when this same treatment is analyzed at one point in time (peak values) the treatment does not transgressively underyield (D_{min}), it only has lower biomass than expected (RYT, Table 4.2.1). Of all the treatments, the *BlueF+Sti* treatment is the only one to exceed expected biomass (RYT, Table 4.2.1).

Table 4.2.1. Indices of Overyielding/Underyielding in Polyculture Treatments for Peak Aboveground Biomass

Treatment	Component Species	D_{max}	D_{min}	RY	RYT
BigB+Can		-0.11	0.06		0.95
	BigB			0.55	
	Can			0.40	
BigB+ BluF		-0.30	1.11		0.82
	BigB			0.65	
	BluF			0.17	
BigB+ Sti		-0.23	0.30		0.87
	BigB			0.30	
	Sti			0.57	
Can+ BluF		-0.27	0.84		0.78
	Can			0.71	
	BluF			0.07	
Can+Sti		-0.28	0.36		0.86
	Can			0.29	
	Sti			0.57	
BluF+Sti		-0.15	2.99		1.10
	BluF			0.32	
	Sti			0.78	
BigB+Can+BluF+Sti		-0.34	2.04		0.98
	BigB			0.18	
	Can			0.34	
	BluF			0.15	
	Sti			0.31	

*Data used in the calculations were from untransformed data.

** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

Table 4.2.2. Indices of Overyielding/Underyielding in Polyculture Treatments for ANPP

Treatment	D_{max}	D_{min}
BigB+Can	-0.26	-0.15
BigB+BluF	-0.31	0.95
BigB+Sti	-0.21	0.17
Can+BluF	-0.39	0.98
Can+Sti	-0.17	0.06
BluF+Sti	-0.03	3.06
BigB+Can+BluF+Sti	1.06	7.63

*Data used in the calculations were from untransformed data.
**Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

4.3 Plant Nutrients

General Trends

The nitrogen and phosphorus concentrations from live aboveground biomass were highest in the spring, declined throughout the summer, and then increased again at the end of the growing season (Figure 4.3.1C-F), which is the opposite trend for live biomass (Figure 4.3.1A and B). The highest values for total plant N and total plant P occurred when the nutrient concentrations were lower but live biomass was greater (Figure 4.3.2 and Table 4.3.1).

While nutrient concentrations vary by species, the amount of biomass produced by that species impacts the amount of plant N and P found. For example, when comparing the treatments *Soy* and *Sti* during the August 9th collection period, their phosphorus concentrations were 2551 ppm and 1429 ppm, their live aboveground biomass production was 275 g m^{-2} and 1455 g m^{-2}, and their plant phosphorus was 0.70 g m^{-2} and 2.07 g m^{-2}, respectively (Figure 4.3.3).

Although perennial vegetation was established and growing in the early spring (May) and late fall (October) collection times, plant total N and total P from the polyculture treatments were not significantly greater than their component species (Figure 4.3.4). In the spring, *Sti* exhibited highest N and P uptake next to Cor and *Soy*, as well as when compared to *BigB, BluF, Swi*, and most of the polycultures that did not contain the *Sti* species. Additionally, the *BigB+Sti* and *Can+Sti* treatments also utilized significantly more phosphorus than the *Bro* treatment (Figure 4.3.4A and Figure 4.3.4B). In the late fall there were no significant differences in nutrient uptake.

In the early spring the C_4 species (*BigB* and *Swi*) and the C_3 legume *BluF* had lower plant N and P than the C_3 forb *Sti* (Figure 4.3.4A and Figure 4.3.4B). This may have more to due with the amount of biomass produced up to that point (May) since in general C_3 plants tend to start growing sooner than C_4 plants (Figure 4.2.2A).

A similar trend occurs in the late fall, as only the C_3 species were actively growing during the October collection period (Figure 4.3.4C and Figure 4.3.4D). This is not completely consistent as not all perennial C_3 species in the study behaved similarly. The *BluF* species was one C_3 species that had senesced earlier than the other C_3 species behaving more like the C_4 species (Figure 4.3.4C and Figure 4.3.4D) and (Figure 4.2.2B).

<u>Effects of Species Diversity on Nutrient Uptake</u>

While the highest yielding component species in monoculture of a two species polyculture tended to have greater than expected biomass, this did not always hold true when considering plant N and plant P. In some cases the component species with the highest nutrient uptake in monoculture had higher than expected values (ex. *BluF+Sti* treatment, Figure 4.3.3, Table 4.3.2 and Table 4.3.3), sometimes the component species with higher nutrient uptake in monoculture had lower than expected values (ex. *BigB+Can* treatment, Figure 4.3.3, Table 4.3.2 and Table 4.3.3), and in a few cases, both component species in the

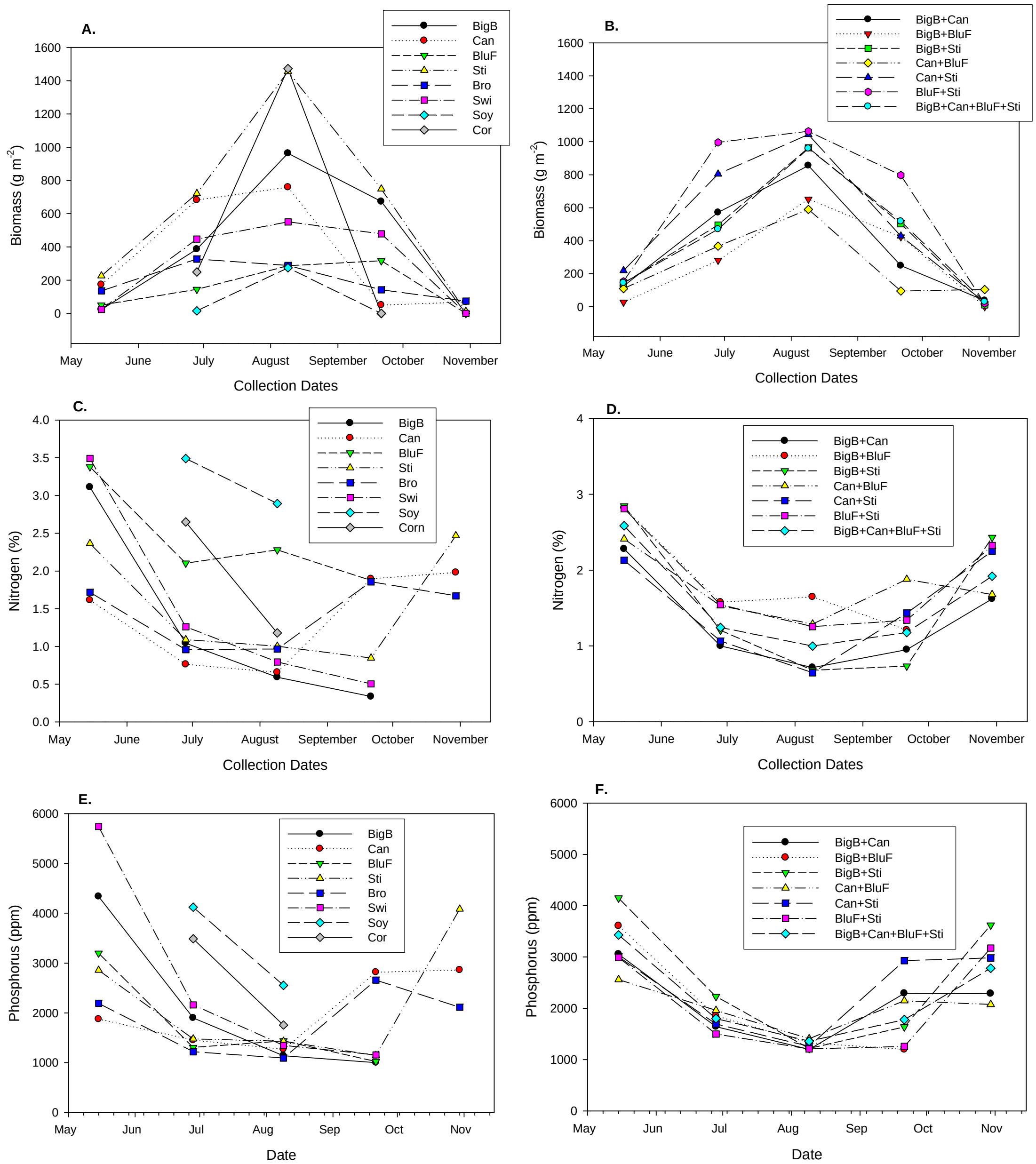

Figure 4.3.1. Comparison of Trends of Treatments throughout the 2006 growing season. A and B. Live Aboveground Biomass, C and D. Nitrogen Concentration from Live Aboveground Biomass, and E. and F. Phosphorus Concentration from Live Aboveground Biomass.

*Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye*, BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

**All values for means obtained from unchanged data.

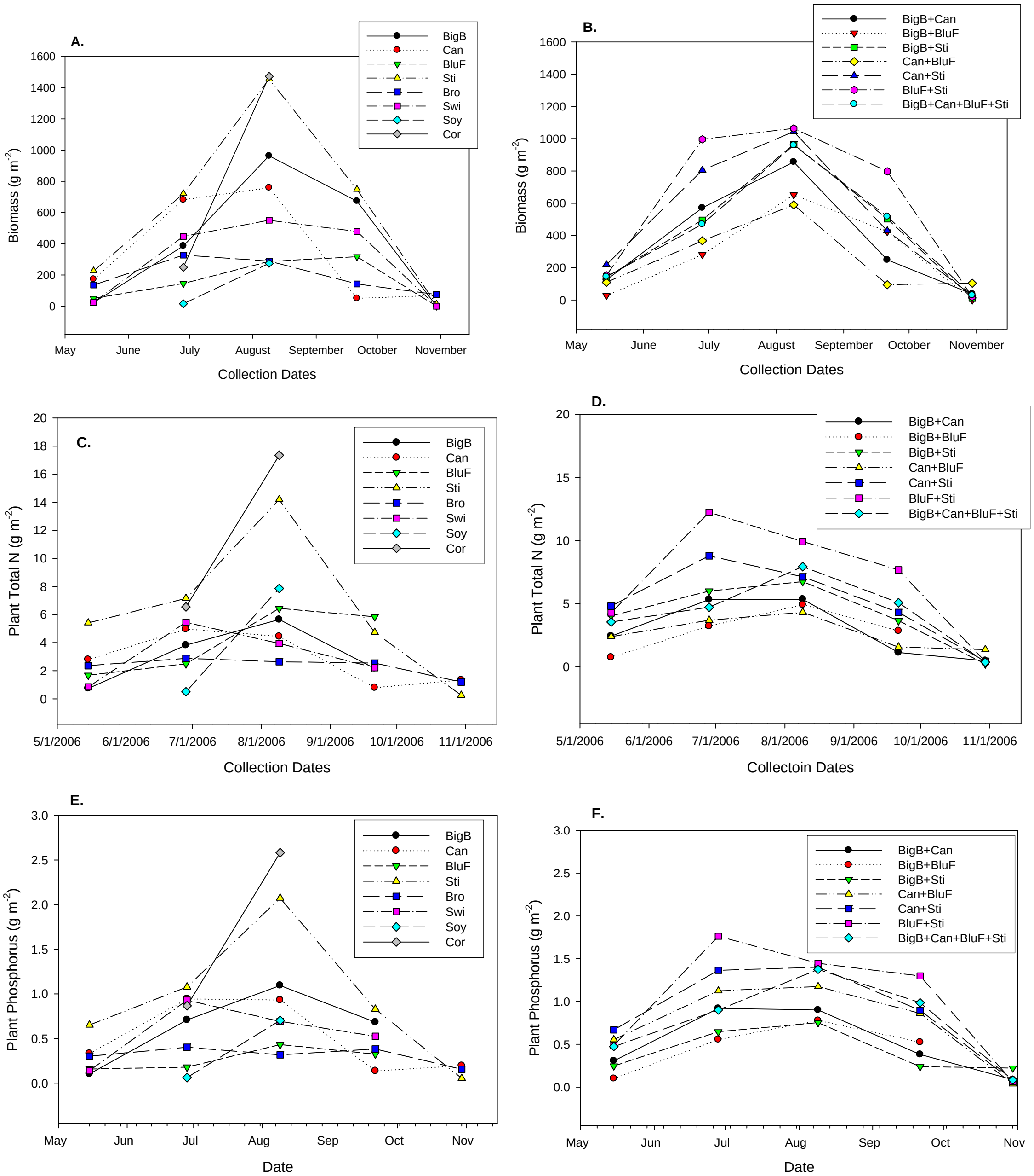

Figure 4.3.2. Comparison of Trends of Live Aboveground Biomass throughout the 2006 growing season. A. Live Aboveground Biomass (Monoculture Treatments), B. Live Aboveground Biomass (Polyculture Treatments), C. Plant Nitrogen (Monoculture Treatments), D. Plant Nitrogen (Polyculture Treatments), E. Plant Phosphorus (Monoculture Treatments), and F. Plant Phosphorus (Polyculture Treatments).

*Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

**All values for means obtained from unchanged data.

Table 4.3.1. Collection Period of Peak Values

Treatment	Live Aboveground Biomass	N (%)	Plant N (g m^{-2})	P (ppm)	Plant P (g m^{-2})
BigB	3	1	3	1	3
Can	3	5	2	5	2
BluF	4	1	3	1	3
Sti	3	5	3	5	3
Bro	2	4	2	4	2
Swi	3	1	2	1	2
Soy	3	2	3	2	3
Cor	3	2	3	2	3
BigB + Can	3	1	3	1	2
BigB + BluF	3	1	3	1	3
BigB + Sti	3	1	3	1	3
Can + BluF	3	1	3	1	3
Can + Sti	3	5	2	1	3
BluF + Sti	3	1	2	5	2
BigB + Can + BluF + Sti	3	1	3	1	3

**Values are for live aboveground biomass.
**Dates: 1 = May 15, 2006; 2 = June 28, 2006; 3 = August 9, 2006; 4 = September 21, 2006; and 5 = October 30, 2006.
***Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

polyculture had lower than expected values of plant N and/or plant P (ex. *BigB+Sti* and *Can+Sti* treatments, Figure 4.3.3A and Table 4.3.2) and (ex. *BigB+Sti* treatment, (Figure 4.3.3B and Table 4.3.3). The *BigB+Sti* treatment was one treatment that had lower than expected values of nutrient uptake for both plant N and plant P. In all cases, none of the polyculture treatments had both component species with higher than expected values. The *BigB+Can+BluF+Sti* treatment had two species with higher than expected values and two species with lower than expected values for both the plant N and plant P (Table 4.3.2 and Table 4.3.3), similar to what occurred regarding aboveground biomass. Two of the polyculture treatments (BigB+BluF and Can+BluF) containing BluF (an N-fixer) transgressively underyielded in plant N production (Table 4.3.2).

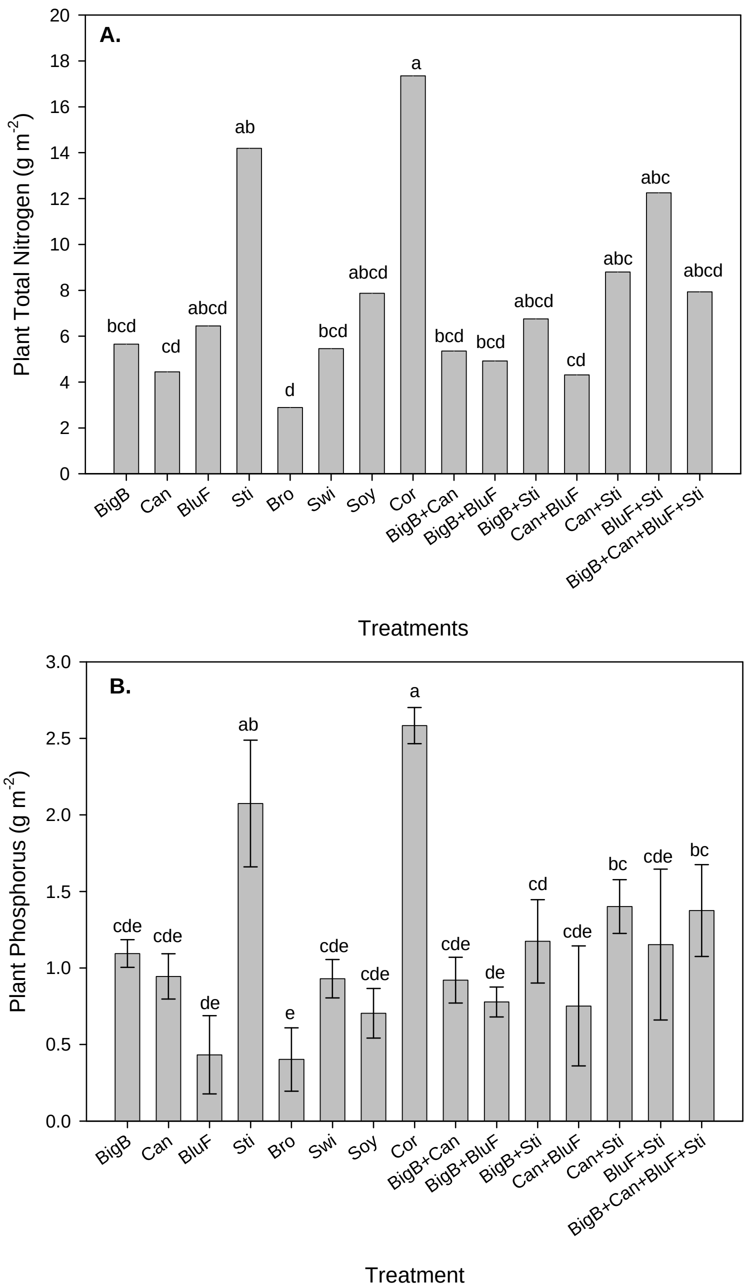

Figure 4.3.3. Peak Plant Nutrients from Live Aboveground Biomass over the 2006 Growing Season: A. Plant Nitrogen*, and B. Plant Phosphorus**.

*Values for means and statistics obtained from log transformed data.

**Values for means and statistics obtained from untransformed data; one replicate for the FS treatment was removed in order to meet assumption for normality

*** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

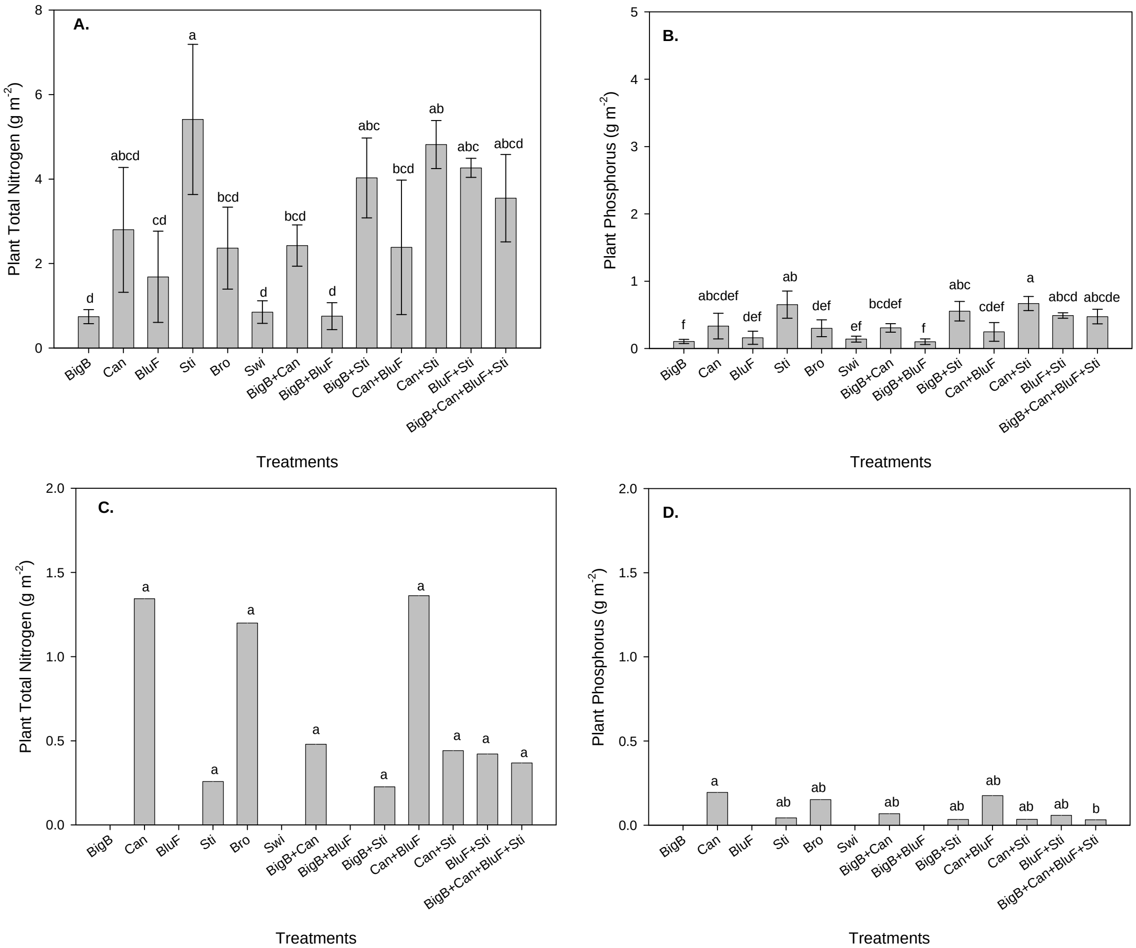

Figure 4.3.4 Plant Nutrients from Live Aboveground Biomass at the Beginning and End of the Growing Season 2006. A. Nitrogen (May 15, 2006)*, B. Phosphorus (May 15, 2006)*, C. Nitrogen (October 20, 2006)**, and D. Phosphorus (October 30, 2006)**.

* Values for means and statistics obtained from untransformed data.

**Values for means and statistics obtained from log transformed data.

***The Corn and Soybean treatments were not included in these figures as they had yet to begin growing (May 15, 2006) or had been harvested prior to this collection date (October 30, 2006).

**** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

Table 4.3.2. Plant N at Peak Live Biomass

Treatment	Component Species	D_{max}	D_{min}	RY	RYT
BigB+Can		0.00	0.21		1.15
	BigB			0.29	
	Can			0.85	
BigB+ BluF		-0.17	-0.14		0.85
	BigB			0.69	
	BluF			0.16	
BigB+ Sti		-0.52	0.24		0.62
	BigB			0.23	
	Sti			0.39	
Can+ BluF		-0.24	-0.05		0.93
	Can			0.85	
	BluF			0.08	
Can+Sti		-0.52	0.51		0.71
	Can			0.34	
	Sti			0.37	
BluF+Sti		-0.34	0.68		0.76
	BluF			0.16	
	Sti			0.60	
BigB+Can+BluF+Sti		-0.47	0.67		0.98
	BigB			0.18	
	Can			0.36	
	BluF			0.14	
	Sti			0.29	

*Data used in the calculations were from untransformed data.
**Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

Of the two species (*Can* and *Sti*) that had higher than expected values for plant N and plant P, the *Can* species performed the best in both cases (Tables 4.3.2 and Table 4.3.3). For all polyculture treatments except the *Can+Sti*, the *Can* treatment performed better than expected when other species were present. This seems to be the opposite of what occurs for the *BigB* species in polycultures of greater diversity since the *BigB* had less than expected plant N and P in all cases except when grown with *BluF* (Table 4.3.2 and Table 4.3.3)

Of all the polyculture treatments only the *BigB+Can* treatment transgressively overyielded for plant N (D_{max}, Table 4.3.2) but this same treatment transgressively

Table 4.3.3. Plant P at Peak Live Biomass

Treatment	Component Species	D_{max}	D_{min}	RY	RYT
BigB+Can		-0.18	-0.03		0.92
	BigB			0.28	
	Can			0.64	
BigB+ BluF		-0.29	1.39		0.81
	BigB			0.67	
	BluF			0.14	
BigB+ Sti		-0.43	0.07		0.69
	BigB			0.27	
	Sti			0.43	
Can+ BluF		-0.19	1.31		0.87
	Can			0.77	
	BluF			0.10	
Can+Sti		-0.32	0.51		0.87
	Can			0.34	
	Sti			0.52	
BluF+Sti		-0.30	3.45		0.83
	BluF			0.15	
	Sti			0.67	
BigB+Can+BluF+Sti		-0.34	3.23		1.12
	BigB			0.20	
	Can			0.43	
	BluF			0.15	
	Sti			0.34	

*Data used in the calculations were from untransformed data.
**Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye*, BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

underyielded for plant P (D_{min}, Table 4.3.3). *BigB+BluF* and *Can+BluF* were two that underyielded but only for plant N (D_{min}, Table 4.3.2)

4.4 Indirect Measurement Techniques

Determining how much aboveground biomass a treatment produces takes a considerable amount of time especially if one wants to take samples at multiple periods throughout the growing season. For each collection, destructive samples must be taken which reduces the amount of undisturbed area in a given treatment plot (area that could potentially be used for other measurements). The samples then have to be dried and weighed which takes more time.

If a technique could be used to obtain the same information with less destructive methods and steps, much time and resources could be saved. Potential limitations of such a method would be the inability to distinguish individual plant species or components of a total treatment.

When the light interception as log of IPAR (intercepted photosynthetically active radiation) data was plotted against the log of total aboveground biomass data, it was found that the results of the linear regressions for each treatment varied depending on the particular species involved (Table 4.4.1). The *BigB* (see Figure 4.4.1a), *BigB+Can*, and *BigB+Can+BluF+Sti* treatments had the best fit regression lines with R^2 values of 0.91, 0.93, and 0.91 respectively., When data for all treatments were plotted to determine a single regression (Figure 4.4.2a), the equation only took into account 63% of variability suggesting that each treatment and species would require its own regression.

Values that occurred after the treatment's total aboveground biomass began to decline were not used in the regressions (Table 4.4.1). For the *BigB, Sti*, *BigB+Can*, and *Can+BluF* treatments, an R^2 value equal to or greater than those listed in Table 4.4.1 was observed when data points from one collection period after total aboveground biomass decline were used. In a few cases *(Swi, Soy, BigB+BluF, BigB+Sti, Can+Sti*, and *BluF+Sti*) using data points up to decline for live aboveground biomass (in reference to biomass collection periods) produced a better R^2 value for plotted regressions (Table 4.4.1). Decline in live aboveground biomass for these treatments occurred sooner than that of total aboveground biomass decline. The highest

R^2 value (0.90) for the Swi treatment occurred when including one extra collection period past decline of live aboveground biomass (Table 4.4.1).

The growth of the Bro and Can treatments were such that there was a decline in the summer followed by an second increase in growth in the fall, characteristic of C_3 species, where as the other species used had one main growth period of varying length during the growing season. When data points after the initial decline point were included in the regression of these species, the R^2 values declined.

An alternative method that has been used is plotting cumulative IPAR in place of IPAR for the regreassions (Casanova et al., 1998; Challa et al., 2000; Christensen and Goudriaan, 1993; and Mariscal et al., 2000). When the aboveground biomass of treatments were plotted against cumulative IPAR (Table 4.4.2) the fit of the regressions increased for all treatments particularly when using those data points that occur during the period of biomass decline for each treatment. This can be seen in the BigB+BluF treatment where data from all the collection periods were included in the regression using cumulative IPAR but only data from the first three collection periods was included when using IPAR (Tables 4.4.1 and 4.4.2). Some observations remained the same in spite of the change to using cumulative intercepted PAR such as low fit of the regression when plotting all treatments together (0.67, Table 4.4.2 and Figure 4.4.2b) and low fit of regressions for the C_3 species *Bro* and *Can* when using data point occurring after the first decline in biomass (data not shown).

Table 4.4.1. Regression of Log IPAR vs. Log Total Aboveground Biomass

Treatment	Data Used*	R^2	P-value (α = 0.05)	Equation for Log Regression
BigB $	1, 2, 3, 4	0.91	<0.0001	y = 1.0201x - 0.1941
Can	1, 2, 3	0.73	0.0033	y = 0.7166x + 0.7495
BluF	1, 2, 3, 4	0.88	<0.0001	y = 0.6825x + 0.4323
Sti $	1, 2, 3, 4	0.74	0.0003	y = 0.7074x + 0.8793
Bro	1, 2	0.88	0.0055	y = 0.9603x - 0.1169
Swi #$	1, 2, 3, 4	0.90	<0.0001	y = 0.9181x - 0.0026
Soy #	2, 3	0.87	0.0069	y = 1.6317x - 2.5462
Cor #	2, 3	0.87	0.0068	y = 11.306x - 32.159
BigB + Can $	1, 2, 3, 4	0.93	<0.0001	y = 0.608x + 1.0059
BigB + BluF #	1, 2, 3	0.82	0.0007	y = 0.875x + 0.0021
BigB + Sti #	1, 2, 3	0.83	0.0006	y = 0.4847x + 1.3668
Can + BluF $	1, 2, 3, 4	0.80	<0.0001	y = 0.5931x + 0.9328
Can + Sti #	1, 2, 3	0.83	0.0006	y = 0.5916x + 1.181
BluF + Sti	1, 2, 3, 4	0.83	<0.0001	y = 0.6353x + 1.1729
BigB + Can + BluF + Sti #	1, 2, 3	0.91	<0.0001	y = 0.7079x + 0.7776
all	---	0.63	<0.0001	y = 0.775x + 0.4899

*Data used refers to the particular collection time when the data was collected: 1= May 15, 2006; 2=June 28, 2006; 3=August 9, 2006; 4=September 21, 2006; and 5=October 30, 2006.
***Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.
Treatments using data points up to decline in live aboveground biomass.
$Treatments using data points one collection period past aboveground biomass decline.

Table 4.4.2. Regression of Log Cumulative IPAR vs. Log Total Aboveground Biomass

Treatment	Data Used*	R^2	P-value (α = 0.05)	Equation for Log Regression
BigB $	1, 2, 3, 4	0.95	<0.0001	y = 0.8575x + 0.0611
Can	1, 2, 3	0.75	0.0024	y = 0.5857x + 1.024
BluF	1, 2, 3, 4	0.87	<0.0001	y = 0.5629x + 0.6477
Sti $	1, 2, 3, 4	0.81	<0.0001	y = 0.5475x + 1.211
Bro	1, 2	0.87	0.0069	y = 0.7726x + 0.2893
Swi #	1, 2, 3	0.90	0.0001	y = 0.8198x + 0.1559
Soy	2, 3, 4	0.93	<0.0001	y = 1.4815x - 2.2152
Cor #	2, 3	0.99	<0.0001	y = 2.3513x - 4.8045
BigB + Can	1, 2, 3	0.95	<0.0001	y = 0.5377x + 1.1349
BigB + BluF	1, 2, 3, 4, 5	0.89	<0.0001	y = 0.7731x + 0.1719
BigB + Sti $	1, 2, 3, 4, 5	0.92	<0.0001	y = 0.46x + 1.3898
Can + BluF	1, 2, 3	0.80	0.0012	y = 0.5462x + 1.0187
Can + Sti #	1, 2, 3	0.87	0.0002	y = 0.5125x + 1.3372
BluF + Sti #	1, 2, 3	0.82	0.0008	y = 0.566x + 1.2909
BigB + Can + BluF + Sti	1, 2, 3	0.94	<0.0001	y = 0.6174x + 0.9527
all	---	0.67	<0.0001	y = 0.6497x + 0.7125

*Data used refers to the particular collection time when the data was collected: 1= May 15, 2006; 2=June 28, 2006; 3=August 9, 2006; 4=September 21, 2006; and 5=October 30, 2006.
**Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.
Treatments using data points up to decline in live aboveground biomass.
$Treatments using data points one collection period past aboveground biomass decline.

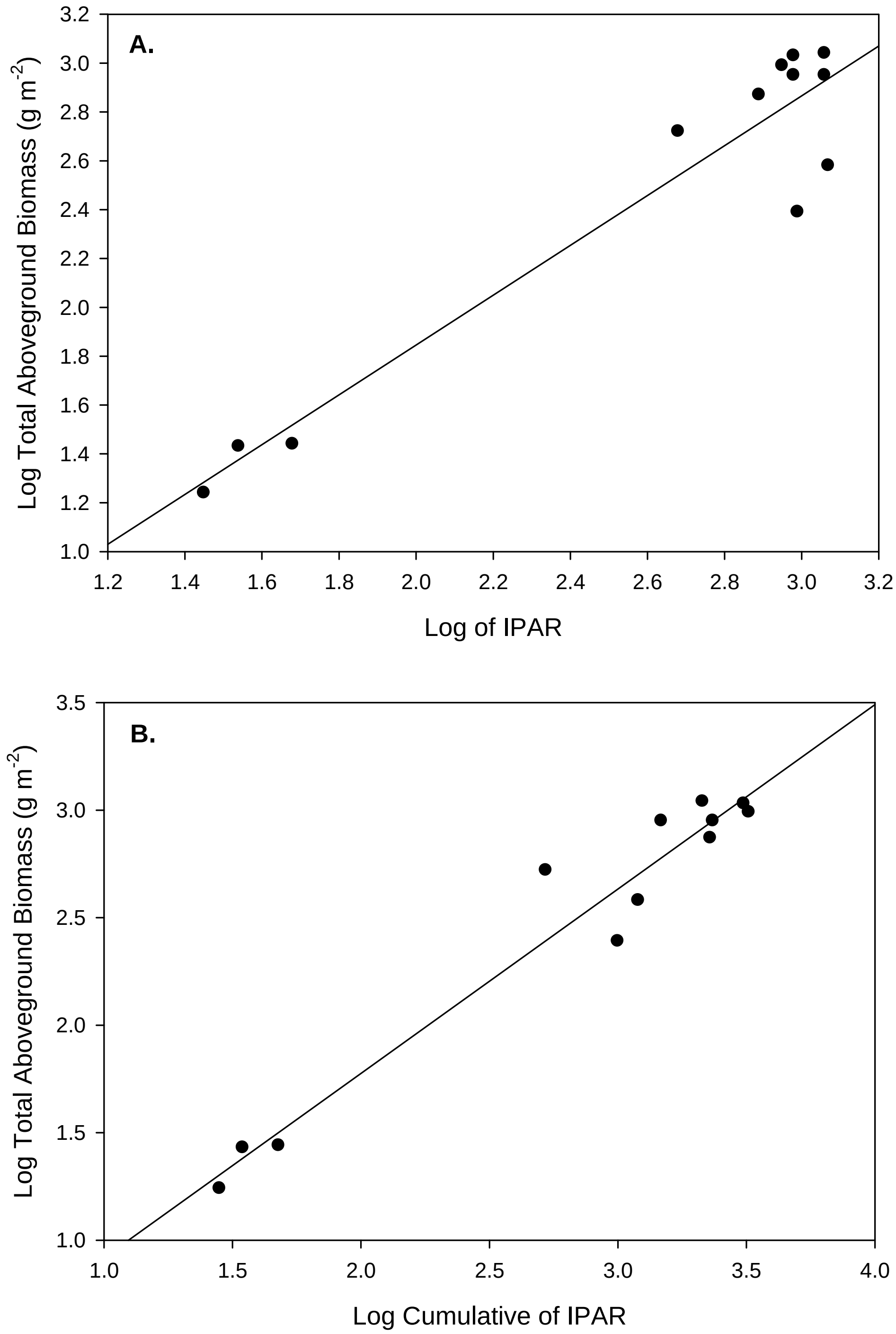

Figure 4.4.1. Log of IPAR vs Log of Total Aboveground Biomass for Big Bluestem: A. BigB Data Points using Fraction of IPAR from Table 4.4.1 and B. BigB Data Points using Cumulative IPAR from Table 4.4.2.

*Values for means and statistics obtained from log transformed data.

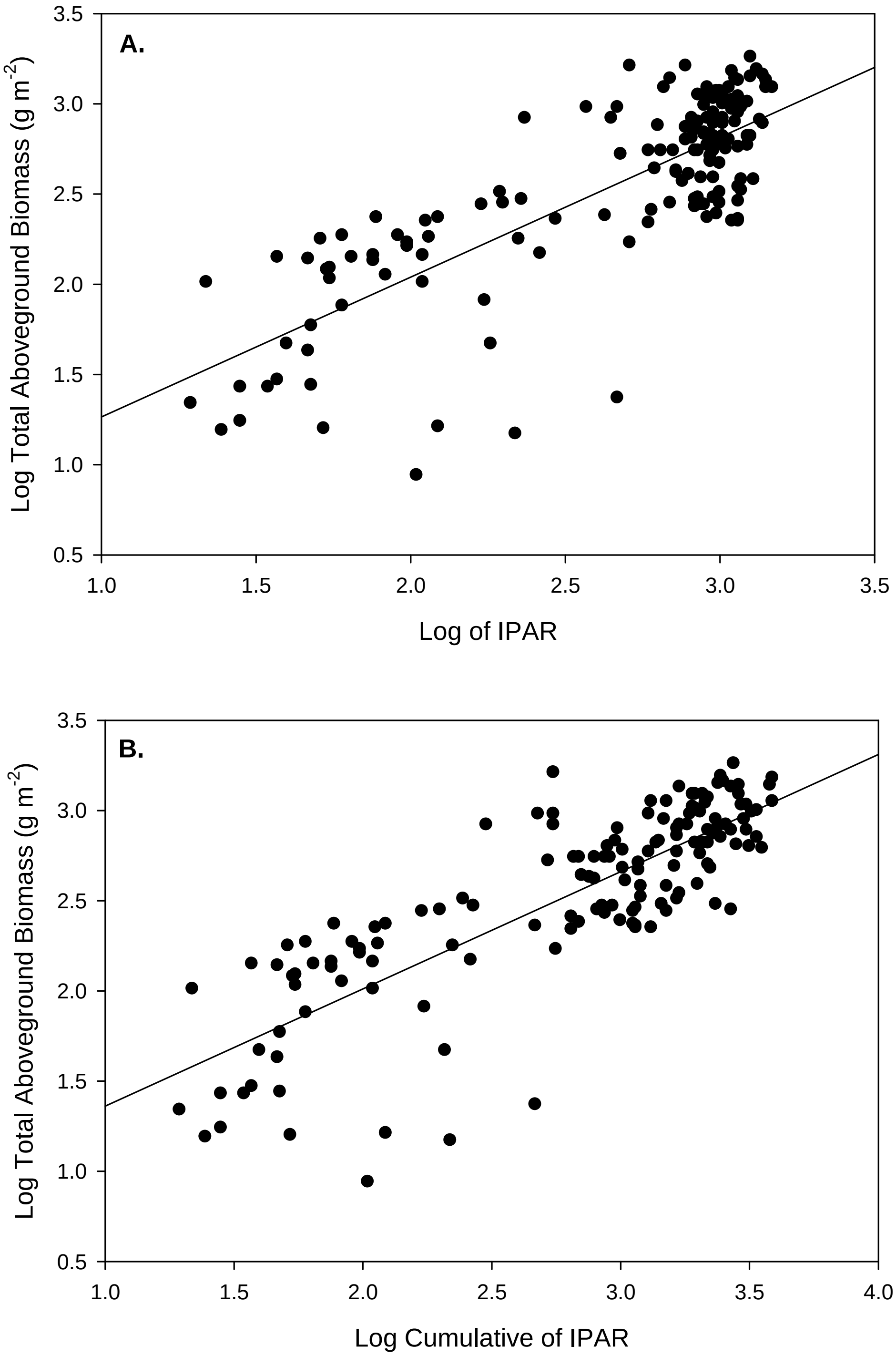

Figure 4.4.2. Log of IPAR vs Log of Total Aboveground Biomass for All Treatments Together: A. All data points from Table 4.4.1 and B. All data points from Table 4.4.2.
*Values for means and statistics obtained from log transformed data.

5.0 Discussion

5.1 Biomass Production and Nutrient Utilization

Monocultures and Polycultures

When the performance of monocultures and polycultures were compared at peak production, it was found that the polycultures did not outperform the monocultures and in several cases (e.g. *Sti, in BigB+Sti, Can+Sti, BluF+Sti, and BigB+Can+BluF+Sti; BigB in BigB+Can and BigB+BluF; and Can in Can+BluF*) the component species with the highest performance in monoculture outperformed their respective polycultures. This trend occurred for both biomass production and for nitrogen and phosphorus utilization. Similar trends were observed by Aarssen (1997), Huston (1997), and Tilman et al. (1997), such that the polyculture treatments produced as much as but not more biomass than the highest producing species in monoculture. In the case of this study, *Sti* was the highest producing perennial species in monoculture and none of the polycultures had peak values that outperformed the *Sti* monoculture. This “initial exponential takeover by the faster-growing species” (Pacala and Tilman, 2001) has also been termed “sampling effect” in experiments because the highest producing species tends to be randomly chosen as a part of the experimental design. As the treatments begin to have more species assigned to them, the probability that a high producing species will be chosen increases. As Pacala and Tilman (2002) and Tilman et al. (2001) suggest, this trend will potentially change with time, generally starting in the third year of growth and transitioning to a system affected by “niche complementarity.” Under this effect, the growth of the highest producing species reaches a maximum and levels off (Donald, 1951) while competition takes effect with the lower producing species in the community starting to increase their production. This results in the biomass of the total mixture exceeding that of the highest producing species in monoculture (overyielding). This idea is consistent with findings by MacArthur and Levins (1967), Tilman et al. (1997), and Tilman et al. (2001), and Camill et. (2004). For example, Camill et al. (2004) observed that *Sti* in an 8 year chronosequence of re-established tallgrass prairie increased production up through the 4^{th} year after which there was a decline in production into the 6^{th} year followed by another cycle of increasing production up through the end of the 8^{th} year. Similarly, with time, we might expect a transition from "initial exponential takeover by the faster-growing species" to "niche complementarity" (Pacala and Tilman 2002) in our treatment plots.

A difference in the previous trends was observed when the same monocultures and polycultures were compared as ANPP. When the 4 species polyculture treatment was compared to the monocultures and 2 species polycultures over the whole growing season the 4 species polyculture out performed all other treatments (monocultures and 2 species polycultures) regarding ANPP. There is the potential that this observation also extends to nutrient utilization as well based on how closely plant N and P production reflects, though not in all cases, the amount of aboveground biomass produced; but this could not be determined conclusively in our study. This observation of ANPP supports the hypothesis that more diverse plant communities will be more productive and utilize more nutrients than less diverse plant communities over the length of the growing season.

<u>Introduced and Native Species</u>

As part of the hypotheses, it was suggested that native species would prove to be more resistant and resilient to climatic and environmental changes making native species a better choice in plant communities used for conservation methods; however, this hypothesis was beyond the scope of this experiment to examine and further testing would be required to make this determination.

Functional Groups

Functional type was important in identifying different patterns of production and nutrient utilization among species at specific sampling times during the growing season. In general, the C_3 species began their growth earlier in the spring and continued their growth later into the fall (senesced later) than the C_4 species; and the C_4 species had higher production in the summer than the C_3 species. However, there were limitations in using these general descriptions of functional group growth patterns as not all species in a given functional group behaved in the same manner. For example, *BluF* (a C_3 species) senesced early (as typically seen in C_4 species), while the C_3 forb *Sti* had high production in the summer like the C_4 species. Craine et al. (2003) used the principal component analysis (PCA) to group a series of grassland plant species into categories using 62 traits of the plants. In doing this they, observed the same occurrence of high biomass production from Sti being similar to C_4 grass species. Symstad and Tilman (2001) reported a few shortcomings in using the functional groups they did for their study. The first was that the category of forb as a functional group may have been too broad based on no change in production when another functional group in mixture with the forbs was removed. Additionally, they suggested looking beyond just the traits of interest (such as nutrient uptake) being investigated as other traits like rooting structure can also impact those traits of interest and need to be considered in defining different functional groups. This would imply that solely using functional groups to categorize different species may not be a satisfactory approach to use when trying to identify common patterns in performance or other species' traits among species within a plant community. This is contrary to the assumption that plant communities can be generalized based on their functional attributes and instead suggests a need to characterize individual species and use species specific information when designing plant communities for a given purpose.

5.2 Management Implications

One concern with using native plants in conservation practices is the length of time it takes for these plants to become established when used in areas that may have high rates of erosion and plants communities are being used to stabilize a site from further deterioration (NRCS (IA)-USDA, 2003). The sooner the vegetation produces a cover, particularly in the spring when peak runoff tends to occurs, the sooner soil erosion will be reduced. Thus, certain plants may not be considered an option if fast establishment is necessary. Choosing native species that perform well in monoculture, particularly C_3 species with high growth in the spring, can help to boost the total biomass of a mixture during the initial establishment years (compared to how mixtures may perform without the higher yielding species) until the other species in the mixture increase their biomass production in later years.

If nutrient utilization is a concern regarding use of plants in conservation methods, choosing plants that have high N and P concentrations may be an option, however, one would need to consider how much biomass these same plants produce. A species may have high plant nutrient concentrations (the ratio of nutrients to biomass produced by a plant), but the same species can have a lower quantity of plant nutrients relative to another species that had lower plant nutrient concentrations if that second species produces a greater amount of biomass. This can be seen when comparing the N concentrations (Figure 4.3.1c and d) and plant N (Figure 4.3.2c and d) of the Sti and BluF treatments. The BluF treatment had higher nutrient concentrations but the Sti treatment had a higher quantity of plant nutrients. Craine et al. (2002) observed that plants with higher N concentrations tended to have lower biomass production relative to plants with low N concentrations. As long as there are ample nutrients available for plants with higher nutrient requirements to use, these plants will be productive, but if soil nutrients become low, these same plants may perform poorly (Craine et al. 2002). An alternative may be to use plants having low nutrient concentrations but high biomass production. These plants' total plant N and P would likely be greater relative to plants with high nutrient concentrations, and would have the added advantage of maintaining high productivity even if soil nutrient concentrations become low (Craine et al. 2002). In the study by Symstad and Tilman (2001) it was noted that the C3 grasses had the ability to close in gaps of open ground due to their rhizomatous growth form which allowed these species to reduce soil N in the rooting zone as well as reduce N leaching. This suggests that using C3 grasses in mixtures would also be beneficial in nutrient utilization.

Highly diverse mixtures of perennial vegetation can be beneficial in in-field buffer conservation methods when the goal is to achieve high biomass production and nutrient uptake over the course of the whole growing season. However if biomass production or nutrient utilization is needed for a certain critical point in the growing season, installing monocultures of a species with the highest production during that portion of the growing season would be best. Craine et al. (2003) suggested that the greater the diversity in a plant communities, the greater the chance of having species that have differences in "seasonality of production, successional status, or response to variation in climate." This would increase the likelihood of the plant community having other species present to compensate for decreases in some species' production.

Depending on the objectives for installing in-field buffers, different specific species may be desirable. Ultimately, more species-specific information, about growth habits and functions of different perennial species, is needed to better guide the design of conservation practices, as currently data is extremely limited.

5.3 Non-destruction Biomass Measurement

The applicability of using intercepted PAR (obtained using the Decagon Ceptometer) as a non destructive means of determining total aboveground biomass is related to how well individual treatments can be plotted in regression. In the literature, it was reported that intercepted PAR could be used to determine aboveground biomass in crops such as rice (Casanova et al., 1998), onions (Challa et al., 2000), barley in monoculture and in polyculture with rape (Christensen and Goudriaan, 1993), and olive trees (Mariscal et al., 2000). Unlike the method initially used in this study, these other studies reported plotted biomass against cumulative intercepted PAR instead of against intercepted PAR. When the treatments in the study were plotted using cumulative intercepted PAR, the fit of the regressions increased for all treatments particularly when using those data points that occur during decline in plant community biomass. Some observations remained the same in spite of the change to using cumulative intercepted PAR such as low fit of the regression when plotting all treatments together and low fit of regressions for the C_3 species *Bro* and *Can* when using data point occurring after the first decline in biomass.

Because each treatment and particularly each species had differing regressions, each treatment in an experiment would require its own set of collected data by destructive means to obtain an appropriate regression as a proxy for estimating aboveground biomass. Further, given the expected changes in plant community growth patterns over time (Pacala and Tilman 2002), new data would need to be collected by destructive techniques in order to derive accurate regression equations. Thus, although the light interception technique has the potential of greatly reducing measurement time, its application may be constrained by changes in plant community performance over time, as well as by variation in responses due to changing weather conditions (Mariscal et al., 2000). Testing the regression obtained in this study in the years to follow will help to verify whether this particular technique is practical for biomass determination. Additional testing using C_3 species would also be needed.

6.0 Conclusions

The findings supported the hypothesis that diverse mixtures of native perennial plant species have greater capacity for biomass production and nutrient uptake relative to monocultures of annual or perennial plants when considered over the course of the entire growing season. The increase in ANPP was observed in a mixture of four species based on review of ANPP but mixtures with two species did not have an increase in production over high yielding monocultures. While annual crops such as Cor experienced higher production and nutrient utilization during peak growth periods in the growing season, one perennial species (Sti) produced similar amounts of biomass. This highlights the important of selecting high yielding species in mixture, such as stiff goldenrod, especially during the early establishment period if a high yielding plant community is the objective. As expected, the perennial plant communities also exhibited greater biomass production and nutrient capture during early spring and late fall periods when annual crop production was low or nonexistent.

In particular, species with early spring growth and extended late fall growth were most effective and should be considered in composing mixtures of perennial vegetation.

Using light interception as a means of non-destructively determining biomass may not work well in most experiments where constant changes in the total plant community's biomass may change from year to year as a new regression would need to be calculated for each change and each treatment being considered; however, testing of the regressions in the years to follow will help to verify the applicability of this technique.

More research is needed to understand how species diversity, particularly plant functional traits, and functional redundancy influence the resilience of native and introduced plant communities to changes in weather, climate or environment, and the trade-offs between short-term gains in productivity and long-term advantages of resilience. If such information supported that diverse native plant communities are more resilient and resistant to environmental and climatic changes relative to plant communities composed of introduced species, it would help give further credence in support of using native plant communities in in-field buffer conservation methods.

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CHAPTER 3: GENERAL CONCLUSIONS

1.0 Summary of Study

The objectives of this study were to compare the performance of monocultures and polycultures of four native perennial prairie species having different functional traits (e.g., forb, grass, nitrogen-fixer) relative to monocultures of corn, soybean, brome, and switchgrass in terms of aboveground biomass production, nutrient uptake, light interception, plant area index (PAI), and temporal patterns at the beginning, ending, and over the length of growing season. In it was hypothesized that perennial plant communities having higher species diversity would be more productive and would take up more nutrients over the length of the growing season relative to plant communities with lower species diversity.

An additional objective related to this study was to test the feasibility of using light interception as a nondestructive means for determining biomass. It was hypothesized that using a such a technique would help to reduce the amount of time needed to obtain biomass data, as well as, reduce the amount of disturbed area in treatment plots for other measurements to be conducted in regarding future research.

Based on the results of this study it was concluded that plant communities of at least four species have greater ANPP over the length of the growing season as well as having the added benefit of early season and late season production and N and P uptake in acceptance of the hypothesis suggested. It was also noted that the traits of plant species used in diverse plant communities are important in allowing the mixture to perform well throughout the growing season. For example, including high yielding species will contribute to peak performance, and including early and late season growers will allow for production and nutrients utilization at critical times of nutrient loss. Additionally, high producing species could provide the added benefit of fuller vegetative cover for the first couple of years until the plant community becomes more established particularly when such a requirement is necessary for installing in-field buffers.

Results on the non-destructive biomass method proposed showed that the technique would require separate initial collections of biomass for all treatments involved to obtain the regressions that would be needed for biomass determination. In addition, treatment specific regressions would be needed due to variations in the trends of each species and treatment. Because it is highly likely that there would be changes in plant community production with time, new regressions would need to be obtained to accurately determine each treatments biomass, thus in light of this findings, the technique would not be practical in opposition to what was hypothesized. Still testing the regression obtained against future field season observations will help to verify these conclusions.

2.0 Implications for Management

Using diverse mixtures of perennial vegetation in in-field conservation methods would help to improve on in-field buffer conservation methods based on the results mentioned earlier. Care needs to be taken in choosing those species that would comprise the plant community as some species that might be considered for inclusion are listed as being of one functional group but may have a tendency to behave differently than expected. High yielding species would be beneficial to add to a plant community if early establishment is necessary in the operation of the in-field buffer conservation method. For situations requiring nutrient utilization, having high production species with low nutrient concentrations in the mixture would be beneficial as these plants will potentially uptake as much if not more nutrients than species with high nutrient concentrations with the added benefit of appreciable levels of production when nutrient levels are low.

3.0 Recommendations for Future Study

Potential future work base on this study include the need to obtain more baseline information concerning species specific traits particularly for those species that are less well studied, to better understand how these species perform individually as well as in mixtures throughout the length of and at critical points in the growing season.

Investigating belowground biomass and nutrient utilization in addition to aboveground biomass and nutrient utilization would give a better picture of total plant community functions for determining whether more diverse plant communities outperform monoculture plant communities.

A longer term study would also be of benefit in determining how individual species in a mixture perform over many years well past the establishment period and to determine if diverse plant communities as a whole increase their production and capacity to utilize nutrients with time.

Another beneficial study would make comparisons between diverse mixtures of native versus introduced species, to learn whether native plant communities are more resistant and resilient in situations of environmental and climatic change. Redundancy in species traits used in plant communities for increased resistance and resilience could also be studied.

Transplants were used to establish many of the plots used in this study. For future study, using seed to establish the plots would be beneficial to determining how seeding rates impact success of plot establishment. In addition, weeding by hand was used to suppress weed growth in the plots but such methods would probably not be used by those who would seek to utilize in-field buffer conservation methods. Investigating different methods of weed suppression in diverse native plant communities would be beneficial to promoting the use of these plant communities in conservation methods.

A study to better understand productivity relationships in diverse plant communities would be beneficial to composing plant communities for conservation practices. Such a study could use two species mixtures with treatments planted at different ratios of each species so that there is a whole spectrum ranging from all of one species to all of the other species. This would allow for observation of whether one species or the other is dominating the mixture or if there is complementary or facilitation occurring.

Lastly, along with field testing of the regressions obtained in this study, other potential methods of non-destructive biomass determination could be investigated to help in the reduction of time spent collecting and measuring plant biomass from the field thus increasing the amount of time available for other measurements. This could decrease the amount of disturbed area present in treatment plots for conducting other field measurements. It would also provide the option of planning smaller treatment plots for space to have more treatments for those starting new projects.

APPENDIX

A.1.0 Aboveground Biomass

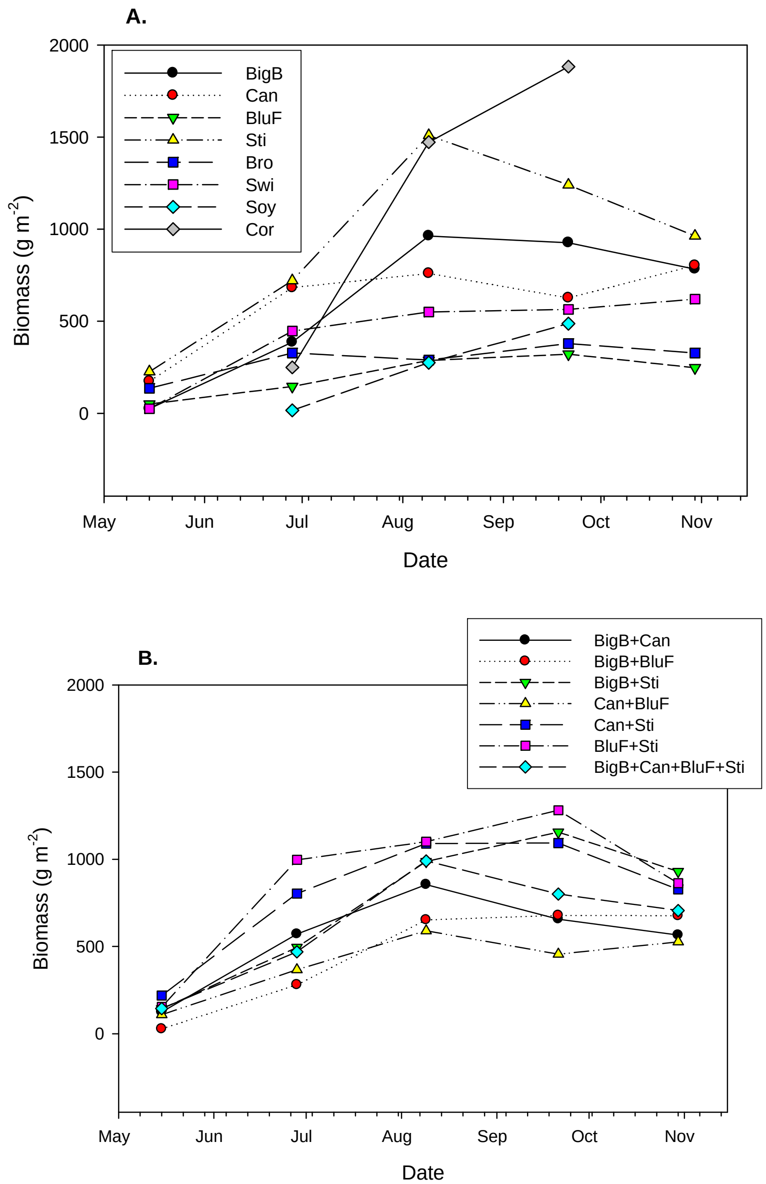


Figure A.1.1. Total Aboveground Biomass over the 2006 Growing Season
A. Monoculture Treatments and B. Polyculture Treatments
*Live includes only live (not dead) aboveground biomass and biomass for all species in each treatment
** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.
***Values of means from untransformed data

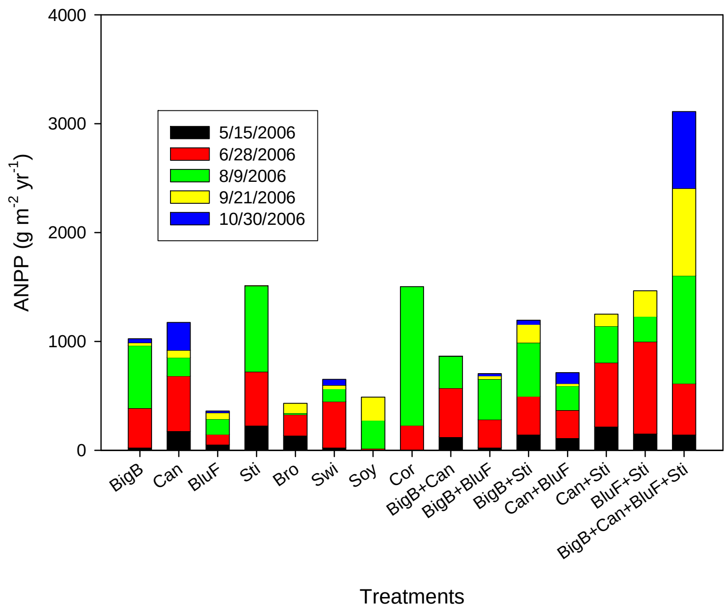


Figure A.1.2. Aboveground Net Primary Productivity for the 2006 Growing Season. With Biomass For Each Time Increment

*Total includes both live and dead aboveground biomass and biomass for all species in each treatment

** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

***Treatments with the same letter are not significantly different from each other at the alpha = 0.05 level; values for means and statistics obtained from un-transformed data, Corn treatment utilizes 2 reps to meet assumptions for normality.

Table A.1.1. Comparative Values for Aboveground Biomass.

Species	Time During Growing Season	Location	Aboveground Biomass (g m^{-2})	Reference
Big Bluestem	July	Oklahoma	580	Springer, et al., 2007
	July	Minnesota	~71.43 (live AGB in monoculture)* ~70.0 (live AGB in 16 species polyculture)	Fargione, et al., 2006**
	July 1998, 1999 Sept. 1998, 1999	Pennsylvania	551, 242 655, 349	Sanderson, et al., 2004
Canada Wild Rye	July	Minnesota	~60.00 (live AGB in monoculture) ~3.00 (live AGB in 16 species polyculture)	Fargione, et al., 2006**
Blue False Indigo	August 2000 August 2001	Minnesota	100 (BluF part in mix with little bluestem) (site 1) 15 (BluF part in mix with little bluestem) (site 2)	Fischbach, et al., 2006
Stiff Goldenrod	August 2002 August 2003	Minnesota	439.92 (unfertilized), 747.87 (fertilized) 517.23 (unfertilized), 880.23 (fertilized)	Strengbom, et al., 2006
	Aug. 2002 and Aug. 2003	Minnesota		Strengbom, et al., 2006
	July	Minnesota	~60.0 (live AGB in monoculture) ~15.0 (live AGB in 16 species polyculture)	Fargione, et al., 2006**
Smooth Brome	June End Year Average	Iowa	320.2 431.5	Haan, et al., 2006
	June 27, 2005	Iowa	498.0 (peak live AGB)***	Unpublished Data
Switchgrass	Mid August	Iowa	~1000.0 (peak live AGB)	Tufekcioglu, et al., 2003
	July 1998, 1999 September 1998, 1999	Pennsylvania	472, 205 1046, 368	Sanderson, et al., 2004
	July	Minnesota	~142.86 (live AGB in monoculture) ~10.0 (live AGB in 16 species polyculture)	Fargione, et al., 2006**
	End Year Average	Canada	1143.33 (average of 3 cultivars)	Madakadze, et al., 1998
Soybean	Mid August	Iowa	~550 (peak live AGB) + ~400 (litter AGB)	Tufekcioglu, et al., 2003
	August 8, 2005	Iowa	1700.2 (total AGB)	Unpublished Data
Corn	Mid August	Iowa	~1800 (peak live AGB)	Tufekcioglu, et al., 2003
	August 8, 2005	Iowa	6191.3 (total AGB)	Unpublished Data

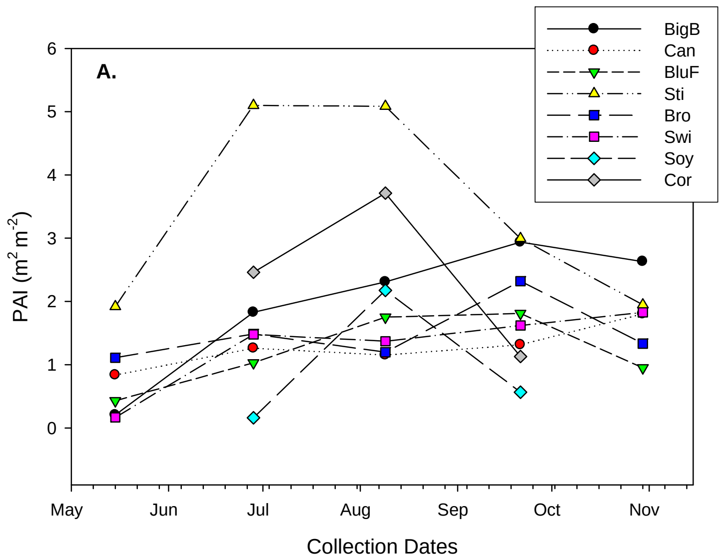
*AGB = aboveground biomass, **Values were back calculated from data presented in the journal article, ****BluF* = Blue False Indigo,

Table A.1.2. Indices of Overyielding/Underyielding in Polyculture Treatments for Peak Aboveground Biomass

Treatment	Component Species	D_{max}	D_{min}	RY	RYT	D_i	D_T	D_μ
BigB+Can		-0.11	0.06		0.95		-0.03	-0.05
	BigB			0.55		0.11		
	Can			0.40		-0.20		
BigB+ BluF		-0.30	1.11		0.82		0.06	-0.18
	BigB			0.65		0.29		
	BluF			0.17		-0.66		
BigB+ Sti		-0.23	0.30		0.87		-0.07	-0.13
	BigB			0.30		-0.40		
	Sti			0.57		0.15		
Can+ BluF		-0.27	0.84		0.78		0.05	-0.22
	Can			0.71		0.41		
	BluF			0.07		-0.86		
Can+Sti		-0.28	0.36		0.86		-0.05	-0.14
	Can			0.29		-0.42		
	Sti			0.57		0.14		
BluF+Sti		-0.15	2.99		1.10		0.40	0.10
	BluF			0.32		-0.36		
	Sti			0.78		0.56		
BigB+Can+BluF+Sti		-0.34	2.04		0.98		-0.47	-0.02
	BigB			0.18		-0.29		
	Can			0.34		0.35		
	BluF			0.15		-0.40		
	Sti			0.31		0.24		

*Data used in the calculations were from untransformed data.
** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

A.2.0 Plant Area Index (PAI)



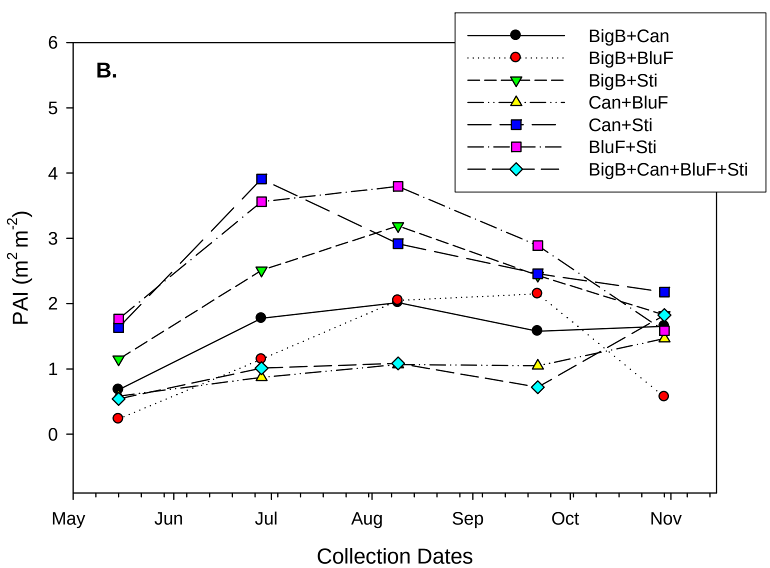


Figure A.2.1. PAI from Total Aboveground Biomass over the 2006 Growing Season
A. Monoculture Treatments and B. Polyculture Treatments
* Total includes both live and dead aboveground biomass and biomass for all species in each treatment
** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod..
***Corn treatment values are based on leaves only
****Values of means for June, and Sept. were converted from log transformed data

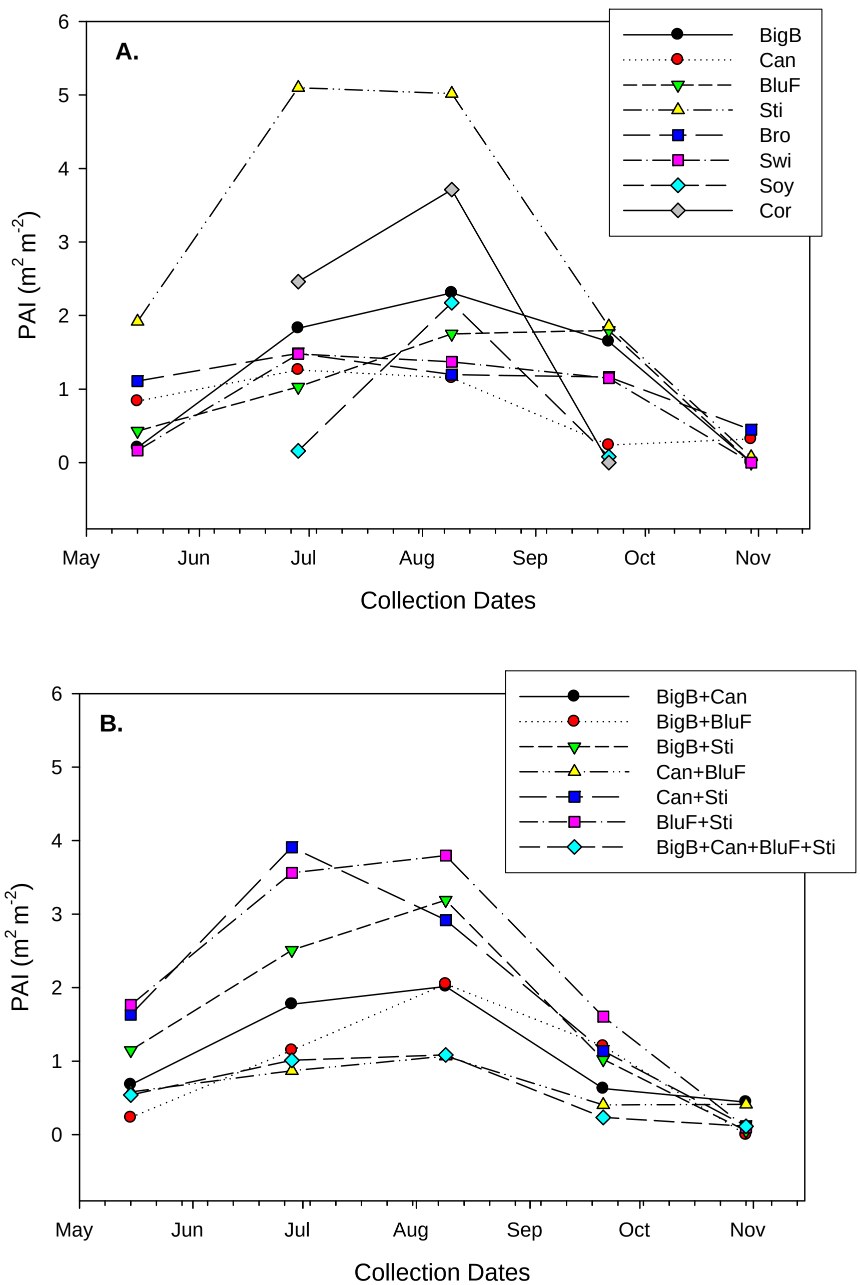


Figure A.2.2. PAI from Live Aboveground Biomass over the 2006 Growing Season

A. Monoculture Treatments and B. Polyculture Treatments

*Live includes only live (not dead) aboveground biomass and biomass for all species in each treatment

** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

***Corn treatment values are based on leaves only

****Values of means for June, and Sept. were converted from log transformed data

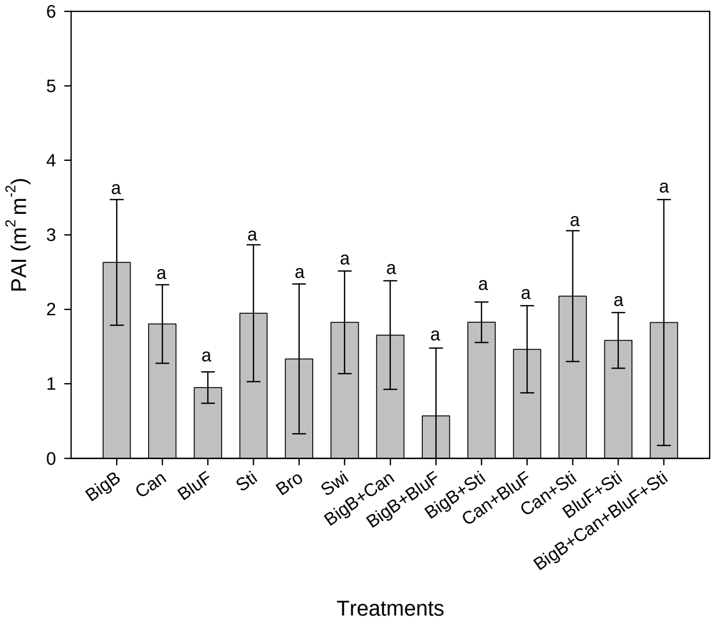


Figure A.2.3. PAI from Total* aboveground biomass on October 30, 2006.

*(includes both live and dead plant material)

** Values for means and statistics obtained from unchanged data.

*** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye*, BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

****The Corn and Soybean treatments were not included in these figures as they had been harvested prior to this collection date.

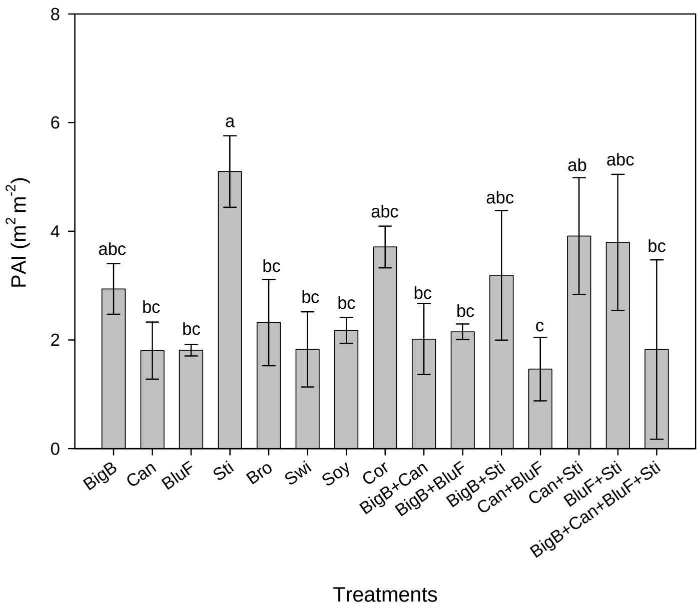


Figure A.2.4 Peak PAI from Total Aboveground Biomass over the 2006 Growing Season
*Total includes both live and dead aboveground biomass and biomass for all species in each treatment
** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye*, BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.
***Treatments with the same letter are not significantly different from each other at the alpha = 0.05 level
****Values for means and statistics obtained from unchanged data..
*****The lines across the graph indicate the values of the BB, CWR, FBI, and STF treatment in monoculture for ease of comparison with the polyculture treatments

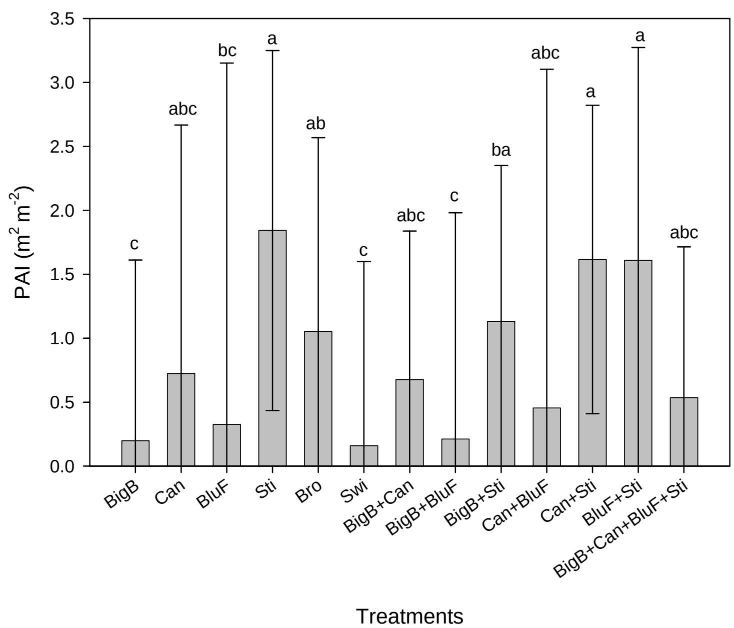


Figure A.2.5. PAI from Aboveground Biomass* on May 15, 2006.
*Values for live aboveground biomass (excludes dead plant material) and total aboveground biomass (includes both live and dead plant material) were the same for this collection period.
**Values for means and statistics obtained from log transformed data.
*** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.
****The Corn and Soybean treatments were not included in these figures as they had not started growing by this collection date.

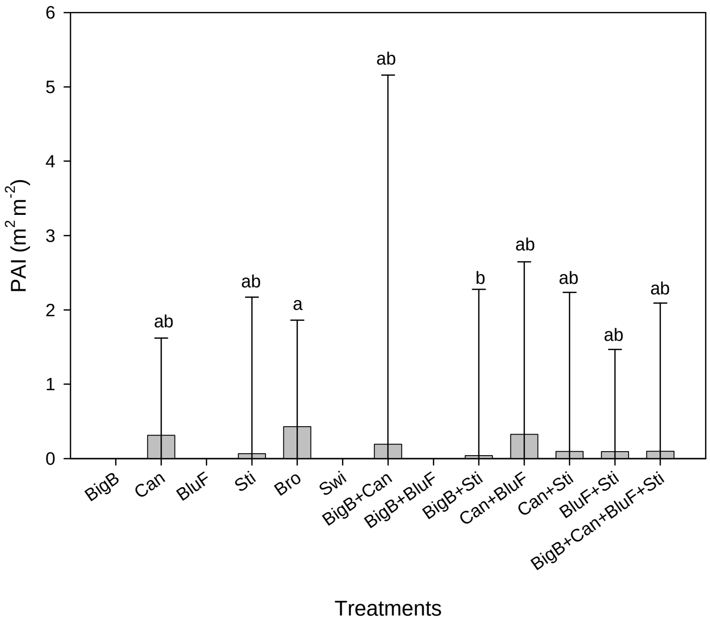


Figure A.2.6. PAI from Live Aboveground Biomass* on October 30, 2006.
*Live aboveground biomass (excludes dead plant material)
**Values for means and statistics obtained from log transformed data. ** Values for means and statistics obtained from unchanged data.
*** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye*, BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.
****The Corn and Soybean treatments were not included in these figures as they had been harvested prior to this collection date.

Table A.2.1. Comparative Values for LAI/PAI

Species	Sample Date	Location	LAI	References
Big Bluestem	July	Oklahoma	8 at 2.7 plants m^{-2}	Springer, et al., 2007
Canada Wild Rye	---	---	---	---
Blue False Indigo	---	---	---	---
Stiff Goldenrod	---	---	---	---
Smooth Brome	---	---	---	---
Switchgrass	---	---	---	---
Soybeans	---	---	---	---
Corn	---	Nebraska	Peak values ranged from 4 to 8 depending on the year	Lindquist, et al., 2005

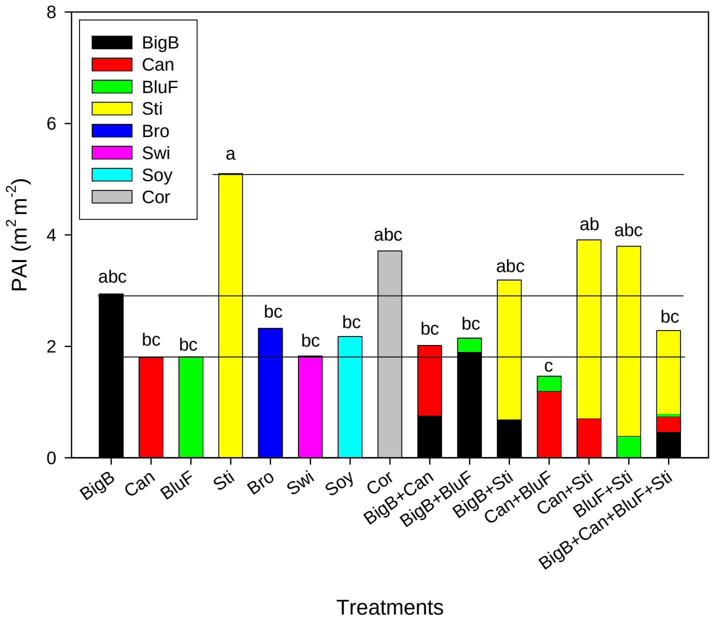
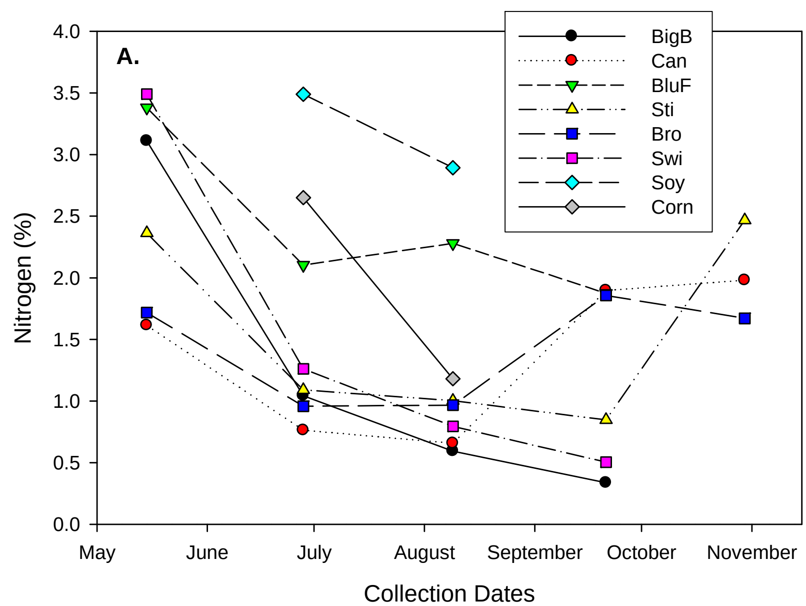


Figure A.2.7. Peak PAI from Total Aboveground Biomass over the 2006 Growing Season:
Totals with all species within polyculture treatments
*Total includes both live and dead aboveground biomass and biomass for all species in each treatment
** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod..
***Treatments with the same letter are not significantly different from each other at the alpha = 0.05 level
****Values for means and statistics obtained from unchanged data..
*****The lines across the graph indicate the values of the BigB, Can, BluF, and Sti treatment in monoculture for ease of comparison with the polyculture treatments

A.3.0 Percent Nitrogen from Live Aboveground Biomass



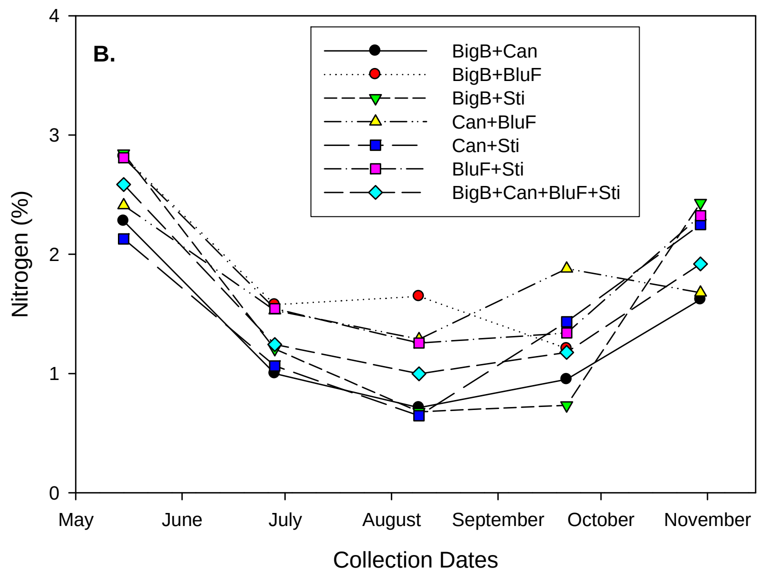


Figure A.3.1. Percent Nitrogen from Live Aboveground Biomass over the 2006 Growing Season A. Monoculture Treatments and B. Polyculture Treatments

*Live includes only live (not dead) aboveground biomass and biomass for all species in each treatment

** Abbreviations: BigB = big bluestem, Bro = brome, Can = Canada wild rye, BluF = blue false indigo, Soy = soybean, Cor = Corn, Sti = stiff goldenrod, Swi = switchgrass, BigB + Can = big bluestem and Canada wild rye, BigB + BluF = big bluestem and blue false indigo, BigB + Sti = big bluestem and stiff goldenrod, Can + BluF = Canada wild rye and blue false indigo, Can + Sti = Canada wild rye and stiff goldenrod, BluF + Sti = blue false indigo and stiff golden rod, BigB + Can + BluF + Sti = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

***All values for means and statistics obtained from unchanged data.

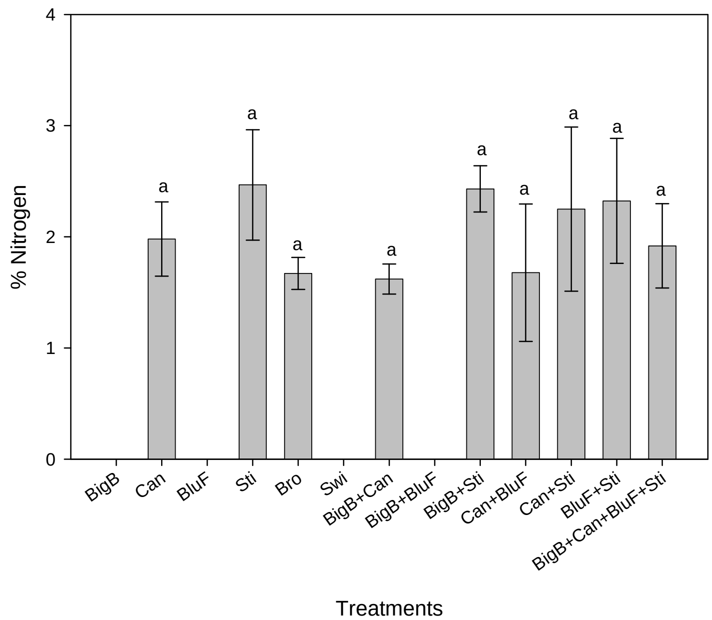


Figure A.3.2. Percent Nitrogen from Live Aboveground Biomass Collected on October 20, 2006**.

* Values for means and statistics obtained from untransformed data.

**Values for means and statistics obtained from untransformed data.

*** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

****The Corn and Soybean treatments were not included in these figures as they had been harvested prior to this collection date.

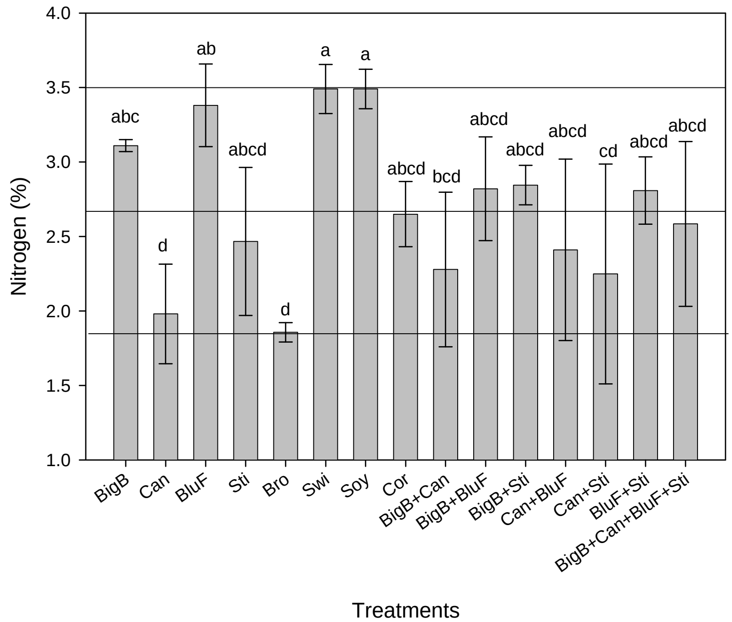


Figure A.3.3. Peak Percent Nitrogen from Live Aboveground Biomass over the 2006 Growing Season

*Live aboveground biomass excludes dead plant material but does include aboveground biomass for all species in each treatment
** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.
***Values for means and statistics obtained from unchanged data.
****Lines across the graph indicate mean values for CORN, SOY, SW, and BR treatments for comparison purposes.

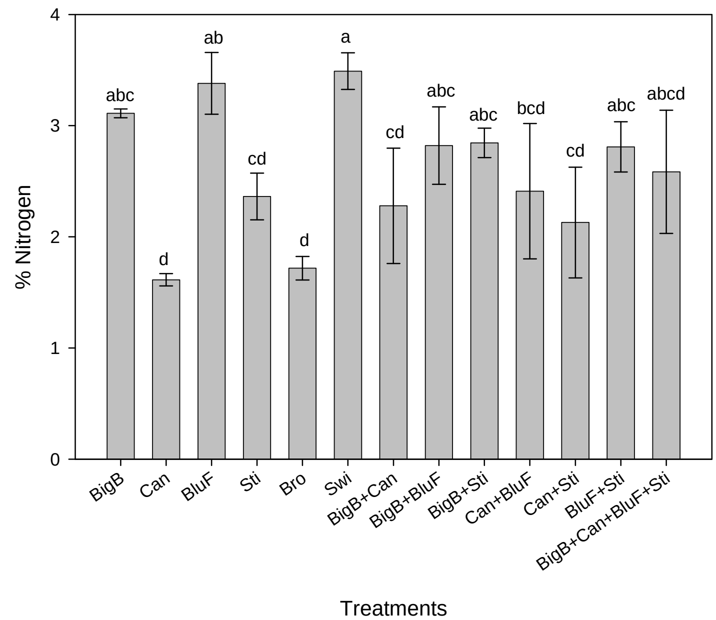


Figure A.3.4. Percent Nitrogen from Live Aboveground Biomass Collected on A. May 15, 2006*

* Values for means and statistics obtained from untransformed data.
**Values for means and statistics obtained from untransformed data.
*** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye*, BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.
****The Corn and Soybean treatments were not included in these figures as they had been harvested prior to this collection date.

Table A.3.1. Comparative Values for Percent Nitrogen Concentration

Species	Sample Date	Location	Percent Nitrogen	References
Big Bluestem	?	North Dakota	1.59 (32 ppm N fertilizer) 1.23 (1 ppm N fertilizer)	Levang-Brilz, et al., 2002
	August 1998	Illinois	1:1 $NO_3^-:NH_4^+$ 0.84 (0.1 mmol L^{-1}) 1.09 (1.0 mmol L^{-1}) 1.38 (3.0 mmol L^{-1})	Lane and BassiriRad, 2002
	August 1998	Illinois	4:1 $NO_3^-:NH_4^+$ 0.82 (0.1 mmol L^{-1}) 1.04 (1.0 mmol L^{-1}) 1.24 (3.0 mmol L^{-1})	Lane and BassiriRad, 2002
Canada Wild Rye	?	North Dakota	2.70 (32 ppm N fertilizer) 1.36 (1 ppm N fertilizer)	Levang-Brilz, et al., 2002
	August 1998	Illinois	1:1 $NO_3^-:NH_4^+$ 1.32 (0.1 mmol L^{-1}) 1.71 (1.0 mmol L^{-1}) 2.10 (3.0 mmol L^{-1})	Lane and BassiriRad, 2002
	August 1998	Illinois	4:1 $NO_3^-:NH_4^+$ 1.58 (0.1 mmol L^{-1}) 1.63 (1.0 mmol L^{-1}) 1.95 (3.0 mmol L^{-1})	Lane and BassiriRad, 2002
Blue False Indigo	---	---	---	---
Stiff Goldenrod	August 2002, 2003 August 2002, 2003	Minnesota	1.02, 1.01 (unfertilized) 1.08, 1.06 (fertilized)	Strengbom, et al., 2006
	August 1998	Illinois	1:1 $NO_3^-:NH_4^+$ 0.82 (0.1 mmol L^{-1}) 1.16 (1.0 mmol L^{-1}) 1.46 (3.0 mmol L^{-1})	Lane and BassiriRad, 2002
	August 1998	Illinois	4:1 $NO_3^-:NH_4^+$ 0.95 (0.1 mmol L^{-1}) 1.24 (1.0 mmol L^{-1}) 1.46 (3.0 mmol L^{-1})	Lane and BassiriRad, 2002
	?	North Dakota	2.76 (32 ppm N fertilizer) 1.22 (1 ppm N fertilizer)	Levang-Brilz, et al., 2002
Smooth Brome	?	North Dakota	2.38 (32 ppm N fertilizer) 0.01 (1 ppm N fertilizer)	Levang-Brilz, et al., 2002
Switchgrass	?	North Dakota	2.33 (32 ppm N fertilizer) 1.71 (1 ppm N fertilizer)	Levang-Brilz, et al., 2002
Soybeans	---	---	---	---
Corn	---	---	---	---

Table A.3.2. % Nitrogen at Peak Biomass

Treatment	Time	At Peak % N			Time	At Peak Live Biomass	
		D_{max}	D_{min}			D_{max}	D_{min}
BigB	1	---	---		3	---	---
Can	5	---	---		3	---	---
BluF	1	---	---		4	---	---
Sti	5	---	---		3	---	---
BigB+Can	1	-0.27	0.15		3	-0.64	0.20
BigB+BluF	1	-0.17	-0.09		3	-0.36	1.04
BigB+Sti	1	-0.09	0.15		3	-0.27	0.2360
Can+BluF	1	-0.29	0.22		3	-0.35	-0.31
Can+Sti	5	-0.09	0.14		3	-0.28	0.43
BluF+Sti	1	-0.17	0.14		3	-0.29	0.33
BigB+Can+BluF+Sti	1	-0.24	0.31		3	-0.50	0.68

Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

Dates: 1 = May 15, 2006; 2 = June 28, 2006; 3 = August 9, 2006; 4 = September 21, 2006; and 5 = October 30, 2006.

A.4.0 Plant Nitrogen from Live Aboveground Biomass

Table A.4.1. Plant N at Peak Plant N

Treatment	Component Species	D_{max}	D_{min}	RY	RYT	D_i	D_T	D_μ
BigB+Can		0.00	0.21		1.15		0.10	0.15
	BigB			0.29		-0.41		
	Can			0.85		0.71		
BigB+ BluF		-0.25	-0.14		0.84		-0.20	-0.16
	BigB			0.69		0.39		
	BluF			0.14		-0.72		
BigB+ Sti		-0.52	0.24		0.62		-0.31	-0.38
	BigB			0.23		-0.54		
	Sti			0.39		-0.23		
Can+ BluF		-0.31	-0.05		0.96		-0.16	-0.04
	Can			0.85		0.71		
	BluF			0.10		-0.80		
Can+Sti		-0.41	0.85		0.95		-0.10	-0.05
	Can			0.53		0.05		
	Sti			0.42		-0.16		
BluF+Sti		-0.05	1.17		1.07		0.32	0.07
	BluF			0.22		-0.56		
	Sti			0.85		0.71		
BigB+Can+BluF+Sti		-0.47	0.67		0.96		-0.50	-0.04
	BigB			0.18		-0.29		
	Can			0.36		0.46		
	BluF			0.13		-0.50		
	Sti			0.29		0.17		

Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

Table A.4.2. Plant N at Peak Live Biomass

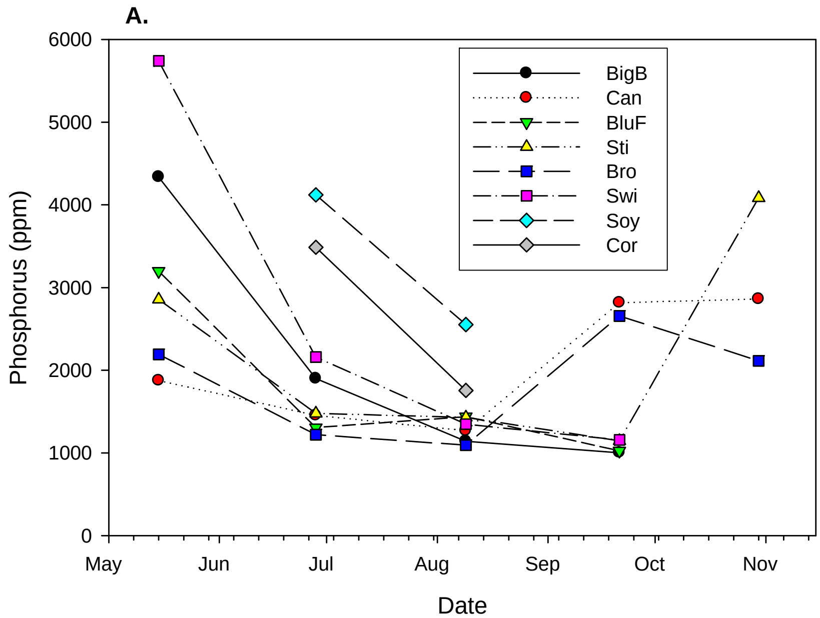
Treatment	Component Species	D_{max}	D_{min}	RY	RYT	D_i	D_T	D_μ
BigB+Can		0.0030	0.2096		1.1489		0.0966	0.1489
	BigB			0.2948		-0.410		
	Can			0.8540		0.708		
BigB+ BluF		-0.1689	-0.1446		0.8509		-0.1569	-0.1491
	BigB			0.6948		0.390		
	BluF			0.1560		-0.688		
BigB+ Sti		-0.5244	0.2393		0.6186		-0.3126	-0.3814
	BigB			0.2320		-0.536		
	Sti			0.3866		-0.227		
Can+ BluF		-0.2375	-0.0534		0.9284		-0.1553	-0.0716
	Can			0.8529		0.706		
	BluF			0.0755		-0.849		
Can+Sti		-0.5207	0.5063		0.7109		-0.2727	-0.2891
	Can			0.3396		-0.321		
	Sti			0.3713		-0.257		
BluF+Sti		-0.3350	0.6835		0.7615		-0.0466	-0.2385
	BluF			0.1595		-0.681		
	Sti			0.6020		0.204		
BigB+Can+BluF+Sti		-0.4675	0.6734		0.9753		-0.4921	-0.0247
	BigB			0.1788		-0.285		
	Can			0.3640		0.456		
	BluF			0.1397		-0.441		
	Sti			0.2929		0.172		

Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye*, BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

Table A.4.3 Comparative Values for Plant Nitrogen (g m^{-2})

Species	Sample Date	Location	Plant Nitrogen	References
Big Bluestem	?	North Dakota	1.59 (32 ppm N fertilizer) 1.25 (1 ppm N fertilizer)	Levang-Brilz, et al., 2002
Canada Wild Rye	---	---	---	---
Blue False Indigo	---	---	---	---
Stiff Goldenrod	August 2002, 2003 August 2002, 2003	Minnesota	4.48, 5.27 (unfertilized) 7.52, 8.75 (fertilized)	Strengbom, et al., 2006
Smooth Brome	---	---	---	---
Switchgrass	---	---	---	---
Soybeans	---	---	---	---
Corn	---	---	---	---

A.5.0 Phosphorus Concentration from Live Aboveground Biomass



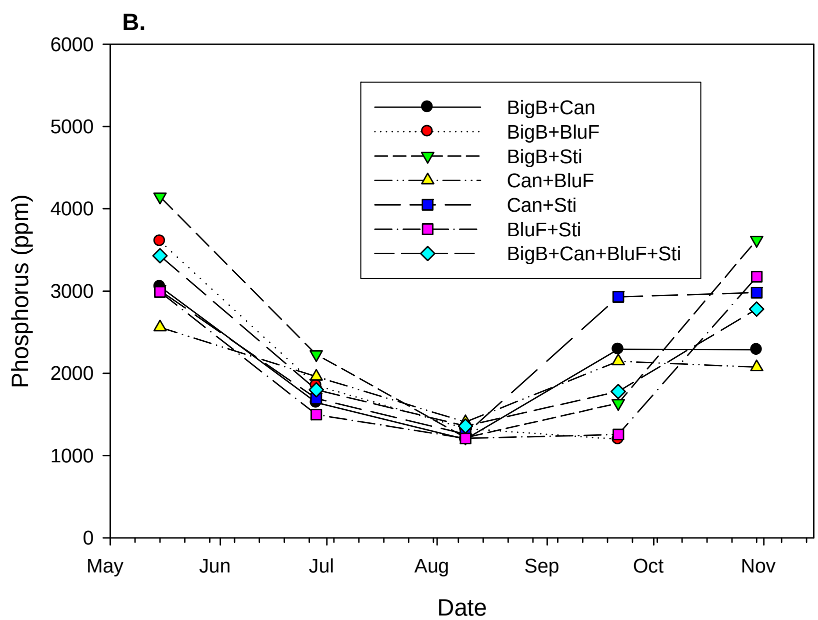


Figure A.5.1. Phosphorus Concentration from Live Aboveground Biomass over the 2006 Growing Season

A. Monoculture Treatments and B. Polyculture Treatments

*Live includes only live (not dead) aboveground biomass and biomass for all species in each treatment

** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

***All values for means and statistics obtained from unchanged data.

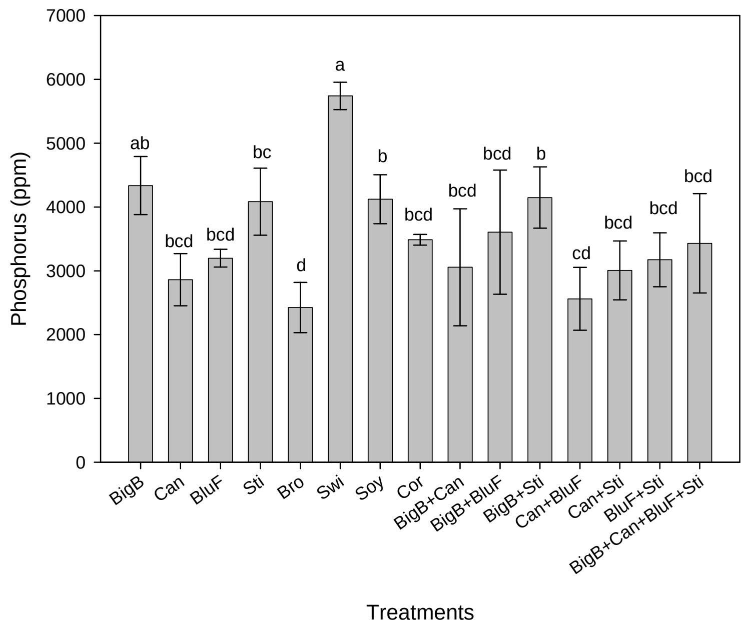


Figure A.5.2. Peak Phosphorus Concentration from Live Aboveground Biomass over the 2006 Growing Season

*Live aboveground biomass excludes dead plant material but does include aboveground biomass for all species in each treatment

** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

***Values for means and statistics obtained from unchanged data.

****Lines across the graph indicate mean values for CORN, SOY, SW, and BR treatments for comparison purposes

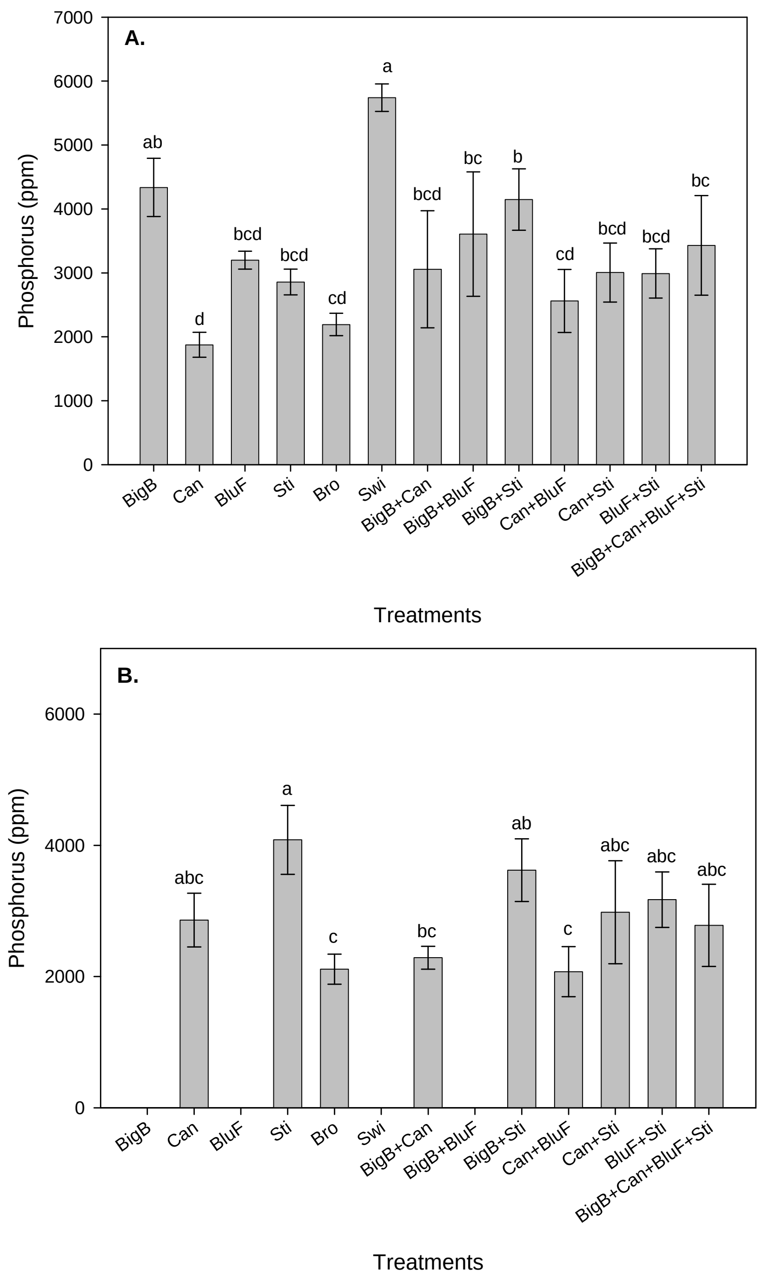


Figure A.5.3. Phosphorus Concentration from Live Aboveground Biomass Collected on A. May 15, 2006* and B. October 20, 2006**.

* Values for means and statistics obtained from untransformed data.

**Values for means and statistics obtained from log transformed data.

*** Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

****The Corn and Soybean treatments were not included in these figures as they had been harvested prior to this collection date.

Table A.5.1. Comparative Values for Percent Phosphorus Concentration

Species	Sample Date	Location	Fraction Phosphorus	References
Big Bluestem	?	North Dakota	0.0040 (32 ppm N fertilizer)	Levang-Brilz, et al., 2002
Canada Wild Rye	?	North Dakota	0.0053 (32 ppm N fertilizer)	Levang-Brilz, et al., 2002
Blue False Indigo	---	---	---	---
Stiff Goldenrod	?	North Dakota	0.0073 (32 ppm N fertilizer)	Levang-Brilz, et al., 2002
Smooth Brome	?	North Dakota	0.0058 (32 ppm N fertilizer)	Levang-Brilz, et al., 2002
Switchgrass	?	North Dakota	0.0076 (32 ppm N fertilizer)	Levang-Brilz, et al., 2002
Soybean	---	---	---	---
Corn	---	---	---	---

Table A.5.2. Phosphorus Concentration

Treatment	Time	At Peak P Concentration			Time	At Peak Live Biomass	
		D_{max}	D_{min}			D_{max}	D_{min}
BigB	3	---	---		3	---	---
Can	2	---	---		3	---	---
BluF	3	---	---		4	---	---
Sti	3	---	---		3	---	---
BigB+Can	2	-0.30	0.07		3	-0.18	-0.03
BigB+BluF	3	-0.17	0.13		3	-0.29	1.39
BigB+Sti	3	-0.04	0.02		3	-0.43	0.07
Can+BluF	3	-0.20	-0.11		3	-0.19	1.31
Can+Sti	3	-0.26	0.05		3	-0.32	0.51
BluF+Sti	2	-0.22	-0.01		3	-0.30	3.45
BigB+Can+BluF+Sti	3	-0.21	0.20		3	-0.34	3.23

Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.
Dates: 1 = May 15, 2006; 2 = June 28, 2006; 3 = August 9, 2006; 4 = September 21, 2006; and 5 = October 30, 2006.

A.6.0. Plant Phosphorus from Live Aboveground Biomass

Table A.6.1. Plant P at Peak Plant P

Treatment	Component Species	D_{max}	D_{min}	RY	RYT	D_i	D_T	D_μ
BigB+Can		-0.16	-0.03		0.93		-0.10	-0.07
	BigB			0.25		-0.51		
	Can			0.69		0.37		
BigB+ BluF		-0.29	0.80		0.77		0.02	-0.23
	BigB			0.67		0.34		
	BluF			0.10		-0.80		
BigB+ Sti		-0.43	0.07		0.69		-0.26	-0.31
	BigB			0.27		-0.47		
	Sti			0.43		-0.15		
Can+ BluF		-0.20	0.74		0.84		0.09	-0.16
	Can			0.76		0.53		
	BluF			0.07		-0.86		
Can+Sti		-0.32	0.48		0.86		-0.07	-0.14
	Can			0.34		-0.32		
	Sti			0.52		0.04		
BluF+Sti		-0.44	1.67		0.43	0.72	-0.08	-0.28
	BluF			0.21		-0.59		
	Sti			0.51		0.03		
BigB+Can+BluF+Sti		-0.34	2.18		1.08		-0.40	0.08
	BigB			0.20		-0.21		
	Can			0.42		0.68		
	BluF			0.12		-0.54		
	Sti			0.34		0.37		

Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

Table A.6.2. Plant P at Peak Live Biomass

Treatment	Component Species	D_{max}	D_{min}	RY	RYT	D_i	D_T	D_μ
BigB+Can		-0.18	-0.03		0.92		-0.11	-0.08
	BigB			0.28		-0.45		
	Can			0.64		0.29		
BigB+ BluF		-0.29	1.39		0.81		0.10	-0.19
	BigB			0.67		0.34		
	BluF			0.14		-0.73		
BigB+ Sti		-0.43	0.07		0.69		-0.26	-0.31
	BigB			0.27		-0.47		
	Sti			0.43		-0.15		
Can+ BluF		-0.19	1.31		0.87		0.20	-0.13
	Can			0.77		0.55		
	BluF			0.10		-0.81		
Can+Sti		-0.32	0.51		0.87		-0.07	-0.13
	Can			0.34		-0.31		
	Sti			0.52		0.04		
BluF+Sti		-0.30	3.45		0.83		0.21	-0.17
	BluF			0.15		-0.69		
	Sti			0.67		0.35		
BigB+Can+BluF+Sti		-0.34	3.23		1.12		-0.38	0.12
	BigB			0.20		-0.21		
	Can			0.43		0.71		
	BluF			0.15		-0.38		
	Sti			0.34		0.37		

Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

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A.7.0. Others

Table A.7.1. Collection Period of Peak Values

Treatment	Biomass*	PAI*	%N**	Bio N m^{-2}**	ppm P**	Bio P m^{-2}**
BigB	3	4	1	3	1	3
Can	5	5	5	2	5	2
BluF	4	4	1	3	1	3
Sti	3	2	5	3	5	3
Bro	4	4	4	2	4	2
Swi	5	5	1	2	1	2
Soy	4	3	2	3	2	3
Cor	4	3	2	3	2	3
BigB + Can	3	3	1	3	1	2
BigB + BluF	4	4	1	3	1	3
BigB + Sti	4	3	1	3	1	3
Can + BluF	3	5	1	3	1	3
Can + Sti	4	2	5	2	1	3
BluF + Sti	4	3	1	2	5	2
BigB + Can + BluF + Sti	3	5	1	3	1	3

*Values are for total aboveground biomass (live + dead material)
**Values are for live aboveground biomass.
***Dates: 1 = May 15, 2006; 2 = June 28, 2006; 3 = August 9, 2006; 4 = September 21, 2006; and 5 = October 30, 2006.
Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

Table A.7.2. Ranking* of Treatments for Peak Values Aboveground Biomass, PAI, Percent Nitrogen and Plant Total Nitrogen

Treatment	Biomass**	ANPP	PAI**	%N***	N g m^{-2} ***	P ppm***	P g m^{-2} ***
BigB	7	8	6	4	9	2	7
Can	9	7	14	14	13	13	8
BluF	14	15	13	3	8	9	14
Sti	2	2	1	10	2	5	2
Bro	15	14	7	15	15	15	15
Swi	11	12	11	1	10	1	9
Soy	13	13	8	2	6	4	13
Cor	1	3	4****	8	1	7	1
BigB + Can	8	9	10	12	11	11	10
BigB + BluF	10	11	9	6	12	6	11
BigB + Sti	4	6	5	5	7	3	5
Can + BluF	12	10	15	11	14	14	12
Can + Sti	5	5	2	13	4	12	3
BluF + Sti	3	4	3	7	3	10	6
BigB + Can + BluF + Sti	6	1	12	9	5	8	4

*Ranking: 1 is highest value and 15 is lowest value
**Values are for total aboveground biomass (live + dead material)
***Values are for live aboveground biomass.
****Corn treatment PAI is actually an LAI value.
Abbreviations: *BigB* = big bluestem, *Bro* = brome, *Can* = Canada wild rye, *BluF* = blue false indigo, *Soy* = soybean, *Cor* = Corn, *Sti* = stiff goldenrod, *Swi* = switchgrass, *BigB + Can* = big bluestem and Canada wild rye, *BigB + BluF* = big bluestem and blue false indigo, *BigB + Sti* = big bluestem and stiff goldenrod, *Can + BluF* = Canada wild rye and blue false indigo, *Can + Sti* = Canada wild rye and stiff goldenrod, *BluF + Sti* = blue false indigo and stiff golden rod, *BigB + Can + BluF + Sti* = big bluestem, Canada wild rye, blue false indigo, and stiff goldenrod.

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