

BLACKLAND PRAIRIE RESTORATION IN CENTRAL TEXAS

THESIS

Presented to the Graduate Council of  
Southwest Texas State University  
in Partial Fulfillment of  
the Requirements

For the Degree

Master of Science

By

Jennifer R. Mittelhauser, B.S.

San Marcos, Texas

December 2002

**COPYRIGHT**

**by**

**Jennifer R. Mittelhauser**

**2002**

## ACKNOWLEDGEMENTS

To my parents, (Kathy, Bob, Crystal, and Carl) I thank you with all of my heart for your love, support, and encouragement throughout my academic career. They knew I could do it even when I didn't.

Many thanks to my excellent advisor, Dr. Paul Barnes, who gave me just what I needed, and nothing I didn't. I couldn't have done this project without your support and patience. To my other committee members, Drs. David Gris  and Paula Williamson, thank you for your time and input, and for listening to me panic about finishing on time...and Paula, thanks for all the summer employment!

Fieldwork and data collection were facilitated by a number of important people. Tom Barnes from the University of Kentucky, Lexington, not only provided all of the herbicides and application equipment, he also personally applied the herbicides at two different times during this study. His guidance, advice, and literature sources were an invaluable help during this project. Paula Power at the National Fish Hatchery and Technology Center in San Marcos (U.S. Fish and Wildlife Service) was instrumental in providing the site, seed, plowing and seeding equipment (driven by Murray Owen), irrigation, photos, and hours of guidance and method details. She also provided many wonderful FWS employees to assist me, including Luz Morris, Randy Gibson, Lynn Lindsay, Lori Tolley, and Dusty McDonald.

Drs. Paul Barnes, Paul Raffeld, David Gris , and Butch Weckerly graciously donated statistical guidance throughout my thesis project, without which I would still be mired in endless ANOVAs and self-pity. Bethany Gabbard, a doctoral student at The University of Texas at Austin was generous enough to share her literature list with me and for that I am very grateful. Thank you to Dr. Francis Rose for making our lives here as graduate students as painless as possible, and to the Biology staff, Rhonda Acker, Martha Miller, Paula Egerton, and Charles Laffere, many thanks for your daily help.

Finally, to all of my friends and lab companions, thank you for helping, listening, and being my friend. I would like to thank Carrie Preite, Kirk Jessup, Cody Richardson, and Diana McHenry for their tireless hours with me in the field. Thanks to Kristy Barker, Steve Reagan, Kristine Elliott, Amanda Kenney, Minette Marr, Patty Ramirez, Carolyn Meredith, Anna Strong, Brian Scott, Chris McGowan, Jenny Gumm, and Ed Cen for your endless love and support.

## TABLE OF CONTENTS

LIST OF TABLES .....	vii
LIST OF FIGURES .....	ix
ABSTRACT .....	xii
INTRODUCTION .....	1
MATERIALS AND METHODS .....	8
Study Area .....	8
Seeding and Site Preparation .....	11
Herbicide Treatments .....	14
Plant Measurements .....	16
Experimental Design and Statistical Analyses .....	20
RESULTS .....	21
Seedling Density .....	21
Shoot Growth .....	25
End-of-Season Biomass .....	33
Flowering Measurements .....	39
DISCUSSION .....	43
Effects on Establishment .....	43
Effects on Shoot Growth .....	47
Effects on Aboveground Biomass .....	49
Effects on Flowering .....	51
Summary and Conclusions .....	52
LITERATURE CITED .....	54

## LIST OF TABLES

Table 1.	Species and seedling rates of the native grasses and forbs included in the seeding regime at the prairie restoration site. Specifications of each are reported by Native American Seed, Junction, Texas. ....	15
Table 2.	Univariate ANOVA results for seedling density three months after sowing for all four native grasses between treatments and species. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F statistic, and p = level of significance. ....	22
Table 3.	Multivariate ANOVA results for seedling densities for native grasses between treatments three months after sowing. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F statistic, p = level of significance. ....	24
Table 4.	Repeated measures ANOVA results for shoot height data for native grass species between treatments. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F statistic, p = level of significance. ....	27
Table 5.	Repeated measures multivariate ANOVA results for shoot height averaged between treatments and time. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F statistic, p = level of significance. ....	28
Table 6.	Univariate ANOVA results for biomass data for three plant types (native grasses, exotic bluestems, and broadleaf species) between treatments. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F-statistic, p = level of significance. ....	34
Table 7.	Multivariate ANOVA results for biomass of three plant types (native grasses, exotic bluestems, and dicots) between treatments. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F-statistic, p = level of significance. ....	36
Table 8.	Univariate ANOVA results for native grass biomass. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F-statistic, p = level of significance. ....	37
Table 9.	Multivariate ANOVA results of biomass data for all four native grass species between treatments. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F-statistic, p = level of significance. ....	38

Table 10.	Univariate ANOVA results for flowering data of all four native grasses between treatments and species. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F-statistic, p = level of significance. ....	40
Table 11.	Multivariate ANOVA results for flowering data for all four native grass species between treatments. D. F. = degrees of freedom, M. S. = mean square, F = the calculated value for the F-statistic, p = level of significance. ....	42

## LIST OF FIGURES

Figure 1.	Map of the natural ecoregions of Texas. Blackland prairie is represented as region 4 in purple (Damude and Bender, 1999). Red star indicates location of the study site. ....	9
Figure 2.	Soil and topographic map of the National Fish Hatchery in San Marcos, Texas showing the location of the 0.8 ha study site in red to approximate size, position, and shape on the Heiden clay 3-5% slope soil. Topographic lines are represented in three-foot increments (map by Schultze and Rundnickl, provided by P. Power of the NFHTC). ....	10
Figure 3.	Long-term (30 years) and 2001 mean monthly maximum temperatures for San Marcos, Texas. ....	12
Figure 4.	Long-term (30 years) and 2001 mean monthly precipitation for San Marcos, Texas. ....	12
Figure 5.	Application of herbicide according to Washburn et al. (1999). Applicator is mounted onto a 4-wheel ATV and chemical is applied at a known concentration. ....	13
Figure 6.	Schematic of restoration site with blocked topography (n=3) and treatment strips within each block. ....	16
Figure 7.	Sampling belts within representative treatments approximately two months after planting. ....	18
Figure 8.	Seedlings selected at random were marked as target individuals for shoot height measurements throughout the growing season. ....	19
Figure 9.	Native grass seedlings that have been marked with colored swizzle sticks according to species. Keys in foreground are to suggest scale. ....	19
Figure 10.	Univariate ANOVA results for absolute seedling density ( $\pm$ SE) of all four native grass species in the different imazapic treatments three months after sowing. Means with different letters are significantly different at $p < 0.05$ as determined by LSD tests. See Materials and Methods for a description of the imazapic treatments. ....	23

Figure 11.	Univariate ANOVA results for absolute seedling density ( $\pm$ SE) of the four native grass species across treatments three months after sowing. Means with different letters are significantly different at $p < 0.05$ as determined by LSD tests. ....	23
Figure 12.	Multivariate ANOVA results for seedling density ( $\pm$ SE) of the four native grass species in the different imazapic treatments three months after sowing. See Materials and Methods for a description of imazapic treatments. ....	24
Figure 13.	Repeated measures ANOVA results for mean shoot height averaged over the 88-day measurement period ( $\pm$ SE) for all four native grasses between imazapic treatments. Means with different letters are significantly different at $p < 0.05$ as determined by LSD tests. ....	27
Figure 14.	Repeated measures ANOVA results for mean shoot height ( $\pm$ SE) averaged over treatments and time for all four native grass species. Means with different letters are significantly different at $p < 0.05$ . as determined by LSD tests. ....	28
Figure 15.	Mean shoot height of combined native grasses for each treatment as a function of time. ....	29
Figure 16.	Mean shoot height of native grass species across treatments as a function of time. ....	29
Figure 17.	Mean shoot height response of <i>Andropogon gerardii</i> to controls and imazapic treatments over time. ....	30
Figure 18.	Mean shoot height response of <i>Schizachyrium scoparium</i> to controls and imazapic treatments over time. ....	30
Figure 19.	Mean shoot height response of <i>Sorghastrum nutans</i> to controls and imazapic treatments over time. ....	31
Figure 20.	Mean shoot height response of <i>Bouteloua curtipendula</i> to controls and imazapic treatments over time. ....	31
Figure 21.	Repeated measures multivariate ANOVA results for mean shoot height averaged over the measurement period ( $\pm$ SE) for all four native grasses between treatments. Means with different letters are significantly different at $p < 0.05$ as determined by LSD tests. ....	32

Figure 22.	Univariate ANOVA results for total end-of season biomass ( $\pm$ SE) between treatments. ....	35
Figure 23.	Univariate ANOVA results of end-of-season biomass ( $\pm$ SE) for three plant types (native grasses, exotic bluestems, and dicots). Plant types with different letters are significantly different at $p < 0.05$ as determined by LSD analysis. ....	35
Figure 24.	Multivariate ANOVA results for end-of-season biomass ( $\pm$ SE) for three plant types (native grasses, exotic bluestems, and dicots) between treatments. Within a group, bars with different letters indicate significant differences at $p < 0.05$ as determined by LSD analysis. ....	36
Figure 25.	Univariate ANOVA results for mean end-of-season biomass ( $\pm$ SE) for each native grass species. Means with different letters show significant differences at $p < 0.05$ as determined by LSD analysis. ....	37
Figure 26.	Multivariate ANOVA results for mean end-of-season biomass ( $\pm$ SE) for native grasses between treatments. Means with different letters show marginally significant differences at $p < 0.05$ as determined by LSD analysis. *Indicates marginal differences at $p < 0.1$ . ....	38
Figure 27.	Univariate ANOVA results for percent flowering ( $\pm$ SE) for native grasses across imazapic treatments at the end of the growing season (Oct. 2001). Bars with different letters are significantly different at $p < 0.05$ as determined by LSD analysis. ....	41
Figure 28.	Univariate ANOVA results for percent flowering ( $\pm$ SE) at the end of the growing season (Oct. 2001) for all four native grass species. Bars with different letters indicate significant differences at $p < 0.05$ as determined by LSD tests. ....	41
Figure 29.	Multivariate ANOVA results for percent flowering ( $\pm$ SE) at the end of the growing season (Oct. 2001) for native grasses across treatments. Means with different letters indicate differences at $p < 0.05$ as determined by LSD tests. *Indicates marginally significant differences at $p < 0.05$ . Lack of control bar for <i>S. nutans</i> represents a mean of zero. ....	42

## ABSTRACT

### BLACKLAND PRAIRIE RESTORATION IN CENTRAL TEXAS

by

JENNIFER R. MITTELHAUSER, B.S.

Southwest Texas State University

December 21, 2002

SUPERVISING PROFESSOR: PAUL BARNES

The Blackland Prairie of Texas is the southernmost tip of the tallgrass prairie that spreads across the United States into Canada. Once covering over 48 million hectares in the east-central part of the state, Blackland Prairie has been reduced to less than 21,000 hectares in modern times, and this type of tallgrass prairie has been given a high priority for preservation and restoration. Reestablishment of Blackland Prairie is often difficult as a result of competition from exotic C<sub>4</sub> grasses. In a randomized complete block field experiment (n=3) conducted near San Marcos, Texas, I tested the effectiveness of four levels of post-emergent herbicide, imazapic, on weed control, and establishment and growth of four native C<sub>4</sub> grasses: *Schizachyrium scoparium*, *Andropogon gerardii*, *Sorghastrum nutans*, and *Bouteloua curtipendula*. Native grass densities, shoot growth, biomass, and percent flowering were analyzed using univariate and multivariate ANOVAs. For seedling density, all three imazapic treatments had greater seedling

density than controls across species. Plants in the low imazapic treatments showed significantly greater shoot growth than those in the other two imazapic treatments and controls. End-of-season aboveground biomass for broadleaf species decreased in the imazapic treatments relative to controls, whereas biomass of the native grasses increased with imazapic treatment. Biomass of exotic grasses, however, did not differ between treatments, and despite pretreatment of the research site with Roundup® application, exotic bluestem grasses continued to dominate all treatment plots, including controls. Percent flowering of native grasses was highest in the medium imazapic treatments. Imazapic application is beneficial for native warm season grass establishment, but exotic bluestem domination prevents optimum native grass densities. Successful restoration of native grasses depends on control or elimination of exotic bluestem grasses.

## INTRODUCTION

The tallgrass prairie is considered to be one of the most threatened and endangered ecosystems in North America. Historically, the prairie biome of the United States, including tallgrass, midgrass, and shortgrass systems was thought to comprise about 35% of the landmass of the lower 48 states (Lemon 1975). At present, over 97 percent of the original, pre-settlement tallgrass prairie in the United States has given way to urbanization, or been converted to tame-grass pasture or cropland over the past 200 years (Sampson and Knopf 1996). The loss of native tallgrass prairie not only diminishes native plant diversity, but also negatively affects habitat and food availability for wildlife (Barnes et al. 1995).

The Blackland Prairie of Texas is the southernmost extension of the North American tallgrass prairie and once covered 6.8 million hectares in the east-central part of the state (Diamond and Smeins 1993). Today approximately 1% (or 43,000 ha) of Blackland Prairie remains (Riskind and Collins 1975). The Blackland Prairie is comprised of a main belt, often called the Grand or Fort Worth Prairie, along with smaller, disjunct sections called the San Antonio Prairie, and the Fayette Prairie (Diamond and Smeins 1985). The entire Blackland Prairie subregion is bordered to the north by the Red River on the Texas/Oklahoma border, to the northwest by the western Cross Timbers subregion, to the southwest by the Edwards Plateau subregion, and to the east by the Oak Woods and Prairies subregion (Diamond and Smeins 1985, Fig. 1).

Major geomorphic subprovinces of the Blackland Prairie run in a north-south direction (Montgomery 1993), creating characteristic soils that support different tallgrass communities. Soils in the Blackland prairie are dominated by three orders. 1) Vertisols are characterized by low calcium carbonate levels and high clay content, which impart considerable smectitic (shrink-swell) properties to the soil. Vertisols are also associated with microreliefs, including slickensides, which are planes of weakness associated with soil failure during swelling, and Gilgai, which are depressions in the ground whose formation is also associated with shrink-swell activity. Vertisols are dark soils high in clay content and organic matter. 2) Mollisols have higher calcium carbonate content than Vertisols and Alfisols. They are characteristically dark due to their high organic matter content. 3) Alfisols have higher sand content than Vertisols and Mollisols. They are also lighter in color and lower in organic matter than Mollisols and Vertisols (Hallmark 1993).

Diamond et al. (1987) delineated six major community types of Blackland Prairie according to distribution and abundance of the dominant grass species. Plant community names reflect dominant species within these groups. Little Bluestem (*Schizachyrium scoparium* (Michx.) Nash.)–Indiangrass (*Sorghastrum nutans* (Michx.) Nash.)–Big Bluestem (*Andropogon gerardii* Vitman.) communities are found on upland Vertisols of the main belt and the Fayette Prairie. Little Bluestem–Indiangrass types are associated with Alfisols of the main belt and the San Antonio Prairie. The Little Bluestem–Big Bluestem–Indiangrass associations typically occur on Mollisols within the main belt. Little Bluestem–Brownseed Paspalum (*Paspalum plicatulum* Michx.)–Indiangrass types are found over Alfisols of the Fayette Prairie. These four associations are found more in

upland areas with well-drained soils. The last two communities are found in low-lying areas and in upland areas with poorly drained soils. Eastern Gamagrass (*Tripsacum dactyloides* (L.) L.)-Switchgrass (*Panicum virgatum* L.)-Indiangrass associations occur in lowlands throughout the Blackland Prairie subregion. The Silveanus Dropseed (*Sporobolus silveanus* Swall.)-Mead Sedge (*Carex meadii* Dew.) group occurs in areas of lower pH and high precipitation, such as the Alfisols in the northern part of the subregion. Along with each of these dominant grass communities are associated forbs and legumes that also appear to change somewhat with changing soils and climate.

Some plant communities of the Blackland Prairie are considered to be among the most endangered plant communities in the world (Diamond et al. 1987). Today, less than 5,000 acres of virgin Blackland Prairie remains and this vegetation type has been recognized as a high priority for preservation by conservationists (Bartlett 1995). The vast majority of these associations have been destroyed by urbanization, overgrazing and agriculture (Diamond and Smeins 1985). Although this ecosystem has provided the soils and the foundation upon which modern-day, high-production agriculture has been built (Hallmark 1993), few people in the state of Texas have actually seen a native tallgrass prairie and there is a great public misunderstanding about what a "prairie" actually is. Thus, there is a need to educate the general public about the value of prairie and its contribution to the natural heritage of the people of this area. For these reasons, and others, there has been an increased interest in the restoration of tallgrass prairie for scientific as well as educational purposes.

Prairie restoration started in the 1930's when Aldo Leopold and Norman Fassett planned to re-plant a tallgrass prairie at the University of Wisconsin Arboretum (Cottam

and Wilson 1966, Meide 1988, Sperry 1994, Kindscher and Tieszen 1995). This site may be the oldest ecological restoration on record (Mlot 1990, Kindscher and Tieszen 1995). Restoration of prairie ecosystems provides insights into fundamental ecological processes, such as succession, competition, plant population dynamics (Kindscher and Tieszen 1995), and soil-vegetation relationships (Jastrow 1987). Soils that are highly aggregated in structure tend to be those that have had grasses growing in them for many years. This high degree of aggregation and soil stabilization is thought to be due to the effects of the grass rhizosphere and is one reason why these soils are so agriculturally productive (Jastrow 1987).

The dominant, perennial, warm-season grasses [i.e., Big bluestem (*Andropogon gerardii*), Little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), Switchgrass (*Panicum virgatum*)] and other key species of tallgrass prairie have historically been very difficult to establish in restoration efforts. For most plants, including these grasses, the seedling stage represents the most critical part of the lifecycle and events at this stage can have profound effects on the outcome of competition and subsequent community composition (Potvin 1993). In her 1993 study, Potvin noted that the establishment of native grasses in the Nebraska Sandhills was greatest during periods of abnormally high rainfall. These native warm-season grasses are known to be slow to establish and they are especially vulnerable to weed competition in seedling stages (McKenna et al. 1991). These species often require special equipment for seeding, show slow aboveground growth and can take up to five years to show positive results to restoration efforts (Washburn and Barnes 2000). Competition with fast-growing, exotic weeds is thought to be a major factor limiting successful restoration of tallgrass prairies

in many areas. To combat the competitive effects of weeds, some have utilized herbicides with varying degrees of success (Wilson and Gerry 1995, Washburn et al. 1999).

King Ranch Bluestem (*Bothriochloa ischaemum* L.) and Silky Bluestem (*Dichanthium. sericeum* (R.Br.)A. Camus.) are Asiatic (Jung et al. 1990), or old world bluestems, that were introduced into the United States in 1917 (Celarier and Harlan 1959, Coyne and Bradford 1985). The natural distribution of these species range from the Pacific coasts of Asia to the Atlantic coasts of Europe (Harlan 1963). Interest in old world bluestems comes from what some would consider superior [grazing] quality, production, persistence with grazing pressure, and response to increased fertilizer levels (Coyne and Bradford 1985). Eck and Sims (1984) found old world bluestems to dominate in grazed and ungrazed plots, and that *B. ischaemum* was one of the most persistent grasses they tested in research plots and that it had escaped from seedling plots to dominate several plots that had originally been seeded with native grasses. Since these Old World Bluestems respond favorably to grazing pressure and disturbances (Harlan et al. 1958), it is not surprising that Eck and Sims (1984) found greater species composition of these grasses in grazed plots versus ungrazed plots. Commonly called KR Bluestem due to its 1936 introduction as a forage grass onto the King Ranch in Kingsville, Texas, King Ranch Bluestem has escaped cultivation to dominate many Texas roadsides and disturbed fields. The ability of these old world bluestems to establish more quickly than native C<sub>4</sub> grasses (Jung et al. 1990), their ease of establishment and tolerance to drought and winter conditions ([www.tarleton.edu](http://www.tarleton.edu)) are traits that make exotic bluestems strong competitors to native prairie species

Some relatively recent studies suggest that with the use of a new American Cyanamid herbicide called imazapic (trade name Plateau®), warm-season tallgrass species can be successfully established in the first growing season (Washburn et al. 1999). Imazapic inhibits the enzyme acetohydroxyacid synthase that is involved in synthesis of the aliphatic amino acids leucine, isoleucine, and valine. This in turn disrupts protein synthesis, which consequently disrupts DNA synthesis and cell growth. In one study in Kentucky that examined seven herbicide mixtures, Washburn et al. (1999) showed that imazapic application yielded the highest establishment of warm-season tallgrasses and forbs by reducing competitive broadleaf weeds. These investigators also found that tall fescue (*Festuca arundinacea*), a cool season exotic grass, was reduced to zero percent cover in seven of the ten study sites they sampled and at five of those sites, native warm-season grasses were dominant. Imazapic has also been found to be effective at controlling Johnsongrass (*Sorghum halepense*), an exotic warm-season weedy species that is prevalent in many parts of the country. Although the use of imazapic has been shown to be successful in tallgrass restoration efforts in Kentucky, it is unknown if this herbicide will be useful in other regions which possess a different suite of competitors and exotic species. On sites in Texas once occupied by Blackland Prairie, potential competitors of tallgrass prairie species include the old world bluestems (*B. ischaemum* and *D. sericeum*), which are species that appear to show some tolerance to imazapic (American Cyanamid 1997). Most of the intolerant species listed by American Cyanamid (1997) are C<sub>3</sub> dicots and grasses, but C<sub>4</sub> broadleaf genera, such as *Amaranthus* and *Euphorbia* are also listed as intolerant to imazapic treatment.

The overall objectives of this research were to re-establish a parcel of Blackland Prairie in central Texas and to test the utility of imazapic as a tool in this restoration effort. The specific objectives were to 1) evaluate how imazapic application influences the establishment, growth, and flowering of dominant prairie grasses in concert with Roundup® application and mechanical disturbance, 2) examine the effectiveness of imazapic at controlling broadleaf plants and exotic warm season grasses in concert with Roundup® and mechanical disturbance, 3) evaluate the effectiveness of imazapic at different concentrations, and 4) examine competitive interactions between prairie species and associated weeds in these different treatments. I hypothesized that there would be greater native grass establishment, shoot growth, biomass, and percent flowering in imazapic treatments than in controls (no imazapic; water only) and that higher doses of imazapic would yield greater native grass performance due to the increased suppression of weedy competitors. I also hypothesized that there would be greater broadleaf biomass in controls than in imazapic treatments, and that broadleaf biomass would decrease with increased imazapic dose. Finally, I hypothesized that plots with greater native grass establishment would show lower old world bluestem biomass. Likewise, control plots with a large percentage of broadleaf biomass would show a reduction in old world bluestem biomass.

## MATERIALS AND METHODS

### Study Area

Studies were conducted at a 0.8 ha (~2 acres) parcel of land at the San Marcos National Fish Hatchery and Technology Center (NFHTC) in San Marcos, Hays County, Texas (29°50'15" N and 97°58'45" W) (Figs. 1, 2). This study site is located near the historic southern limit of the Blackland prairie in Texas. The NFHTC facility is situated on 46.9 ha of land that was donated to the U.S. Fish and Wildlife Service (FWS) by Southwest Texas State University (SWT) in the 1960's (Fig. 2). Prior to this time the land was used as pastureland by the university, although precise dates and management details are unknown. Exotic old world bluestems, mainly *B. ischaemum* (King Ranch Bluestem) and *D. sericeum* (Silky Bluestem), were presumably sown during the land's tenure with SWT and currently are the dominant species at this location. Field observations indicated that approximately 65% of the contemporary vegetation is *B. ischaemum*, about 25% is *D. sericeum*, and the remaining 10% is a mixture of native and non-native forbs and grasses.

The soils of the study site are classified as Heiden clay on 3-5% slopes (USDA soil survey of Comal and Hays counties Texas, 1984), which are upland vertisols. These soils are high in clay content and consequently subjected to considerable shrinking and swelling, depending on soil moisture levels. The surface layer is deep, (~33 cm), dark grayish-brown in color, and generally alkaline and calcareous. The NFHTC is situated at

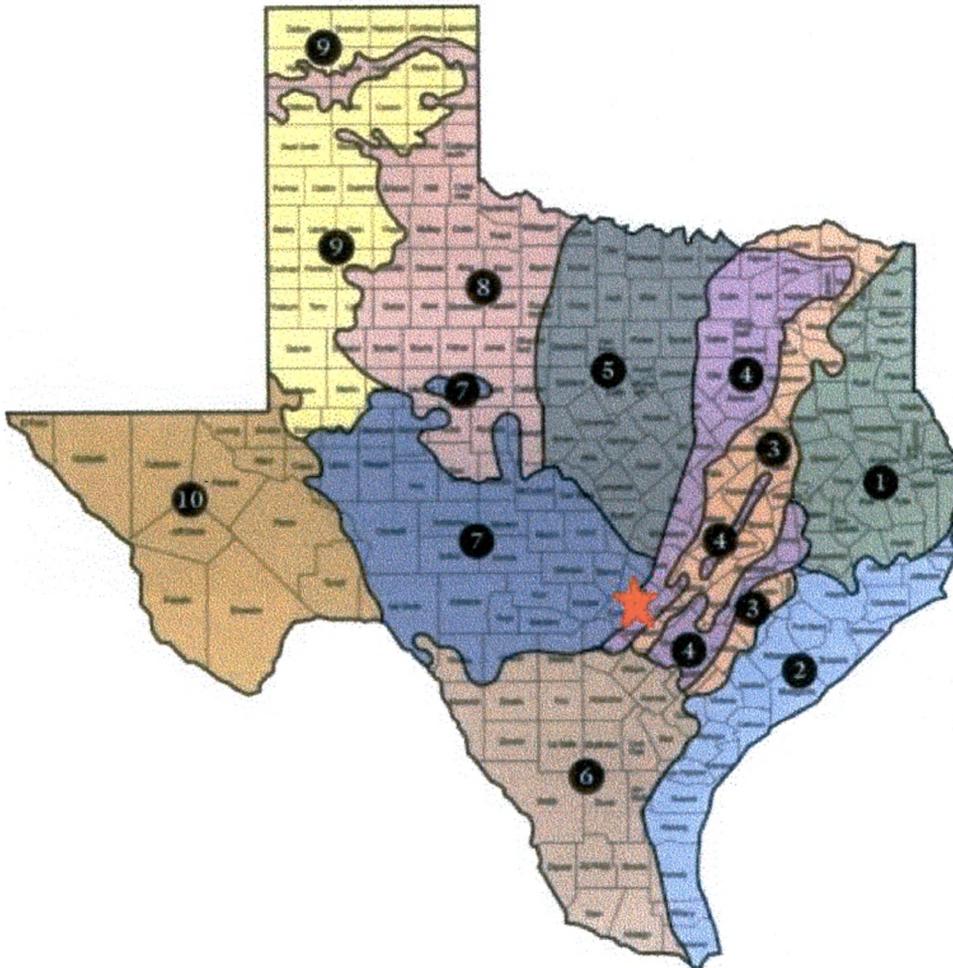


Figure 1. Map of the natural ecoregions of Texas. Blackland prairie is represented as region 4 in purple (Damude and Bender 1999). Red star indicates location of the study site.

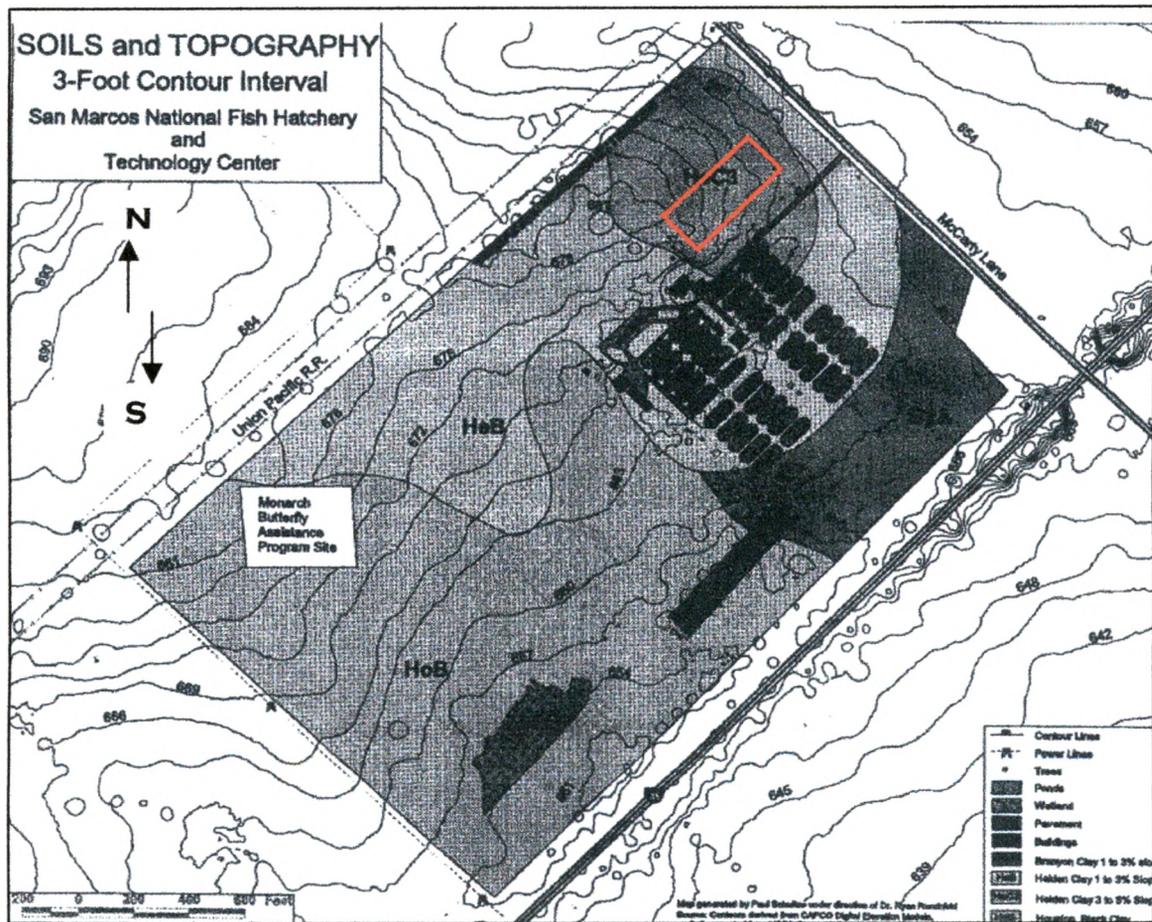


Figure 2. Soil and topographic map of the National Fish Hatchery in San Marcos, Texas showing the location of the 0.8 ha study site in red to approximate size, position, and shape on the Heiden clay 3-5% slope soil. Topographic lines are represented in three-foot increments (unpublished map by Schultze and Rundnickl, provided by P. Power of the NFHTC).

about 300 m above sea level and the topography of the study site slopes gently toward the northeast from 307 m to 304 m (Fig. 2).

Long-term mean monthly maximum temperatures for San Marcos range from 16.2 – 35.2 °C, with an average annual temperature of 20.2 °C (Fig. 3). Average monthly maximum temperatures for San Marcos in 2001 exceed long-term maximum means in all months. Average precipitation for the region ranges from 762– 1016 mm annually, with the low end of this range representing the southwestern portion of the Blackland prairie region. Annual rainfall for San Marcos averages 944 mm and the majority of it occurs in May and September. Precipitation for 2001 (1072 mm) exceeded the long-term mean (1455 mm), largely due to an exceptional rainfall event at the end of August (Fig. 4).

### **Seeding and Site Preparation**

Prior to planting, the site was disked twice (spring and fall of 2000), and then treated with Roundup ProDry®, a broad-spectrum herbicide, on March 4, 2001 in an attempt to reduce the cover of the exotic bluestems. Roundup ProDry® was applied to the research area according to the procedure described by Washburn et al. (1999) (Fig. 5).

Seeds of four dominant native grasses and an assortment of native annual and perennial broadleaf species were obtained from the Native American Seed Company located in Junction, Texas (Table 1). Seed (caryopses) of the native grasses was sown by being dropped in furrows at depths of 5-15 cm using a JThom 42 Wildseeder® on March 22, 2001 at a rate of 3.5 kg/ha of pure live seed (PLS). Seeding density for combined

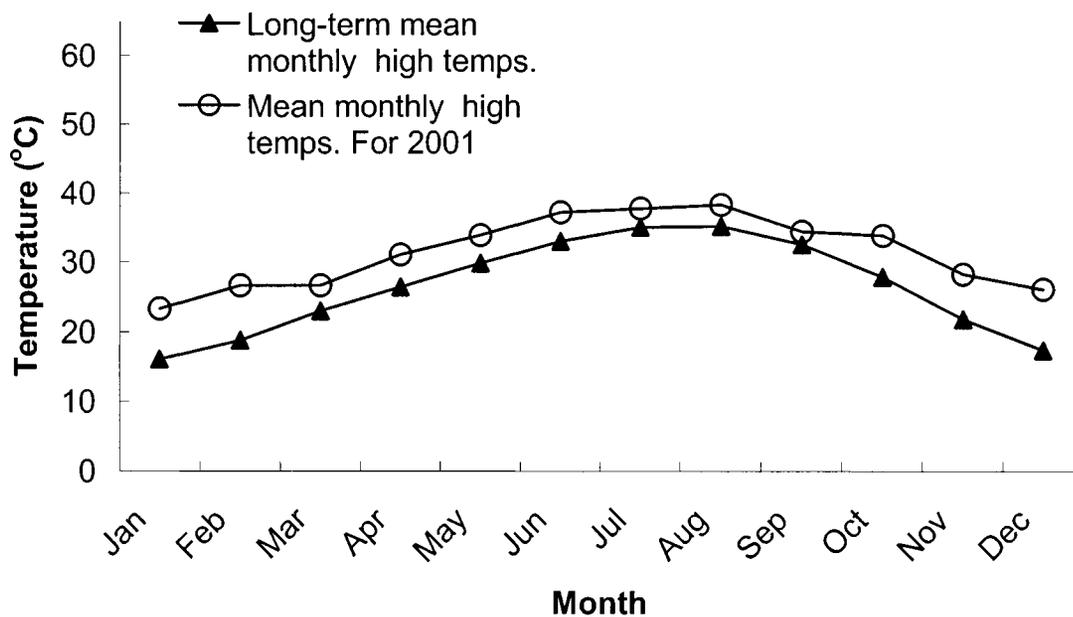


Figure 3. Long-term (30 years) and 2001 mean monthly maximum temperatures for San Marcos, Texas.

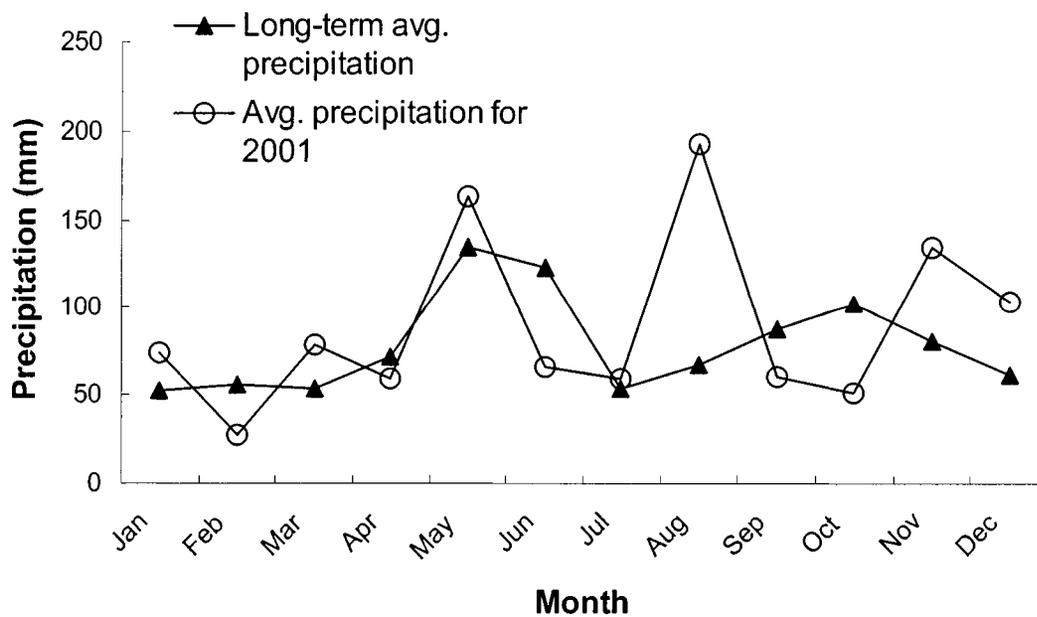


Figure 4. Long-term (30 years) and 2001 mean monthly precipitation for San Marcos, Texas.



Figure 5. Application of herbicide according to Washburn et al. (1999). Applicator is mounted onto a 4-wheel ATV and chemical is applied at a known concentration.

native grasses based on weight and kg PLS (pure live seed) was approximately 220 seeds/m<sup>2</sup>. Forbs and legumes were hand-broadcast behind the seeder for a total seeding density of 1.3 kg PLS/ha. Percent live seed (PLS) is a value calculated by multiplying percent germination by percent purity.

During dry summer months the study site periodically received supplemental water from a mobile irrigation system (Kifco Water-Reel® B110). It was not possible to irrigate the entire site at one time with this system. Rather, one-tenth of the site was watered daily over a ten day period and this cycle was repeated every ten days. Irrigation came from rainfall that had collected in nearby unoccupied clean fishponds on NFHTC property. Watering began in late May of 2001 and was concluded at the end of August of that year. Supplemental watering was carried out daily from 9:00 pm to 6:00 am Central Daylight Time with a 0.56 cm diameter nozzle that released water at a flow rate of 36.15 l/min. This system simulated a weekly rainfall of approximately 455 mm.

### **Herbicide Treatments**

Immediately after planting on March 22, imazapic was surface applied as described by Washburn et al. (1999) to randomized treatment strips within the research site (Fig. 6). Three treatment concentrations of imazapic were used (46 g/ha, 92 g/ha, and 138 g/ha, hereafter referred to as low, medium, and high treatments, respectively), as well as a water-only control. The treatments and controls were applied in a randomized block treatment arrangement in a randomized complete block design. Because the study site encompassed a topographic gradient from uplands to lowlands, blocking was

conducted to account for any possible effects of topography. The four herbicide treatments were replicated three times (n = 3).

Table 1. Species and seedling rates of the native grasses and forbs included in the seeding regime at the prairie restoration site. Specifications of each are reported by Native American Seed, Junction, Texas.

SPECIES	VARIETY	ORIGIN	PURITY (%)	WEED (%)	PLS* (%)	SEEDING RATE (kg/ha PLS)
<b><u>Native Grasses</u></b>						
<i>Andropogon gerardii</i>	Kaw	TX	82.50	0.15	76.73	0.9
<i>Bouteloua curtipendula</i>	Haskell	TX	94.11	0.26	87.52	0.9
<i>Sorghastrum nutans</i>	Cheyenne	TX	78.20	0.03	71.94	0.9
<i>Schizachyrium scoparium</i>	Cimarron	TX	69.99	0.05	65.79	0.8
<b><u>Native Forbs</u></b>						
<i>Coreopsis lanceolata</i>	_____	USA	98.71	_____	89.83	0.09
<i>Petalostemum pulcherrimum</i>	_____	TX	98.00	0.00	_____	0.09
<i>Desmanthus illinoensis</i>	_____	USA	99.38	0.00	39.75	0.09
<i>Rudbeckia hirta</i>	_____	TX	98.69	0.00	91.78	0.05
<i>Monarda punctata</i> **	_____	_____	_____	_____	_____	0.05
<i>Chamaecrista fasciculata</i>	_____	TX	98.92	0.00	30.17	0.09

\* PLS = pure live seed (germination x purity)

\*\* conservancy seed = collected wild and not tested

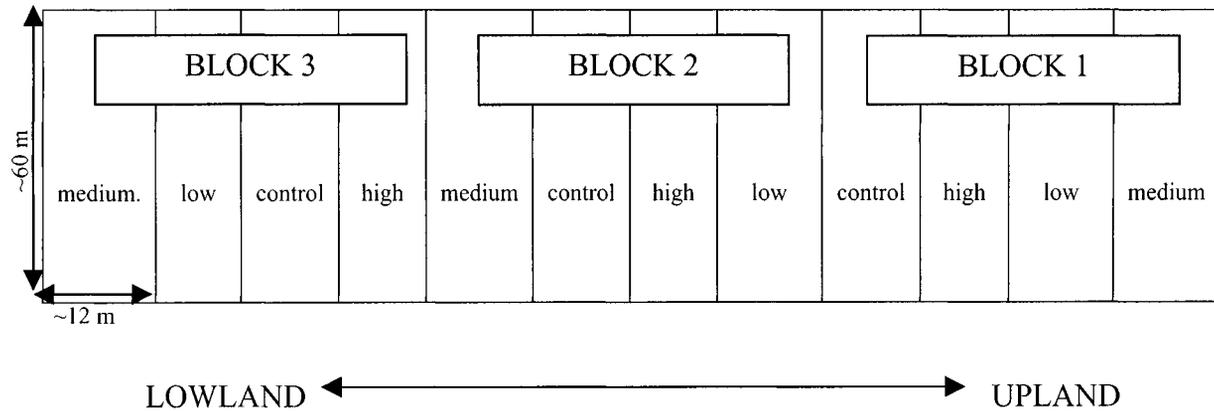


Figure 6. Schematic of restoration site with blocked topography ( $n=3$ ) and treatment strips within each block.

### Plant Measurements

In late May to early June, 2001 (approximately two months after sowing), densities of the native grasses were assessed by marking and counting all individuals within 1 m x 40 m plots located within each treatment strip (Fig. 7). Forb establishment was very poor; hence they were not included in analyses. Of the native grass seedlings that were marked within each treatment belt, ten individuals of each species were randomly selected for detailed growth measurements (shoot height), which were taken at five different times during the growing season (Figs. 8 and 9). In several cases, ten individuals of a certain species were not available within a given sampling plot. For these cases all individuals of native grasses were marked for growth measurements ( $n = 2 - 5/\text{plot}$ ).

Maximum shoot height of target seedlings was determined five different times during the 2001 growing season (23 June, 5 July, 18 July, 8 August, and 15 September). For these measurements, height was measured from ground level to the tallest portion of the plant at natural height (i.e., leaves were not extended beyond the height of the plant's

natural position). I also noted bolting or flowering individuals. Individuals were assumed dead if there was no green tissue observed. However, in some cases these “dead” individuals re-sprouted following precipitation events and they were then included in the measurements.

End-of season aboveground biomass and community composition data were collected October 4, 5, and 6, 2001. For these measurements, three, 1 m<sup>2</sup> quadrats were placed twelve-meters apart within each sampling belt. All plant tissue within each quadrat was clipped at ground level, separated by taxa, bagged, oven dried at 60 °C for three or more days, and weighed. Native grasses were separated by species, whereas old world bluestems (*Bothriochloa ischaemum* and *Dicanthium sericeum*) were combined. Broadleaf species were separated by species when possible.

Flowering data were collected in October near the end of the growing season. For these data, individuals that were marked for shoot growth measurements were censused to determine if they were reproductive (i.e., presence of inflorescence(s)). The number of reproductive individuals of each flagged native grass was recorded.



Figure 7. Sampling belts within representative treatments approximately two months after planting.



Figure 8. Seedlings selected at random were marked as target individuals for shoot height measurements throughout the growing season.



Figure 9. Native grass seedlings that have been marked with colored swizzle sticks according to species. Keys in foreground are to suggest scale.

## **Experimental Design and Statistical Analyses**

Data were statistically analyzed as a randomized block treatment arrangement in a randomized complete block design. Mean differences were analyzed using LSD analysis. There were four treatments replicated three times ( $n = 3$ ). Prior to statistical analysis shoot growth data were log-transformed and flowering percent data were arcsine-transformed to achieve normal distributions (Zar 1984). Shoot growth data were analyzed using repeated measures univariate and multivariate ANOVAs. Seedling density, biomass, and flowering data were analyzed using randomized complete block univariate and multivariate ANOVAs. All data were transformed and analyzed using SPSS 9.0 for Windows. All tables and figures were generated using Microsoft Word 2000 and Excel 2000, respectively.

Native grass seedling density was determined following data collection in May 2001; native grasses across treatments and species were analyzed. End-of season biomass data for combined native grasses, exotic bluestem grasses, and broadleaf species were analyzed between treatments and plant types. Biomass data for native grasses were also analyzed between treatments and species. Data analysis for native grass shoot height between treatments species was conducted. Percent flowering data taken at the end of the growing season (October 2001) were analyzed between treatments and species.

## RESULTS

### Seedling Density

The density of native grass seedlings three months after planting was significantly different between imazapic treatments and species (Table 2). When averaged over species, controls (water only) showed lower seedling densities than those of low, medium, and high imazapic treatments ( $p < 0.01$  for all), but no differences were detected among the three herbicide treatments (Fig. 10). When averaged across treatments and controls, *S. scoparium* had higher densities than *A. gerardii*, *S. nutans*, and *B. curtipendula* ( $p < 0.01$  for all, Fig. 11). There were also significantly more *S. nutans* seedlings than *A. gerardii* and *B. curtipendula* ( $p < 0.01$  for both), but seedling densities were similar for *A. gerardii* and *B. curtipendula*. Absolute seedling densities for all treatments were very low (3.9 plants/m<sup>2</sup>), especially when compared to sowing densities (~220 seeds/m<sup>2</sup>). A significant block effect indicated that seedling densities changed with changes possibly in topography or in edaphic differences, and LSD tests showed that native grass seedling establishment was greater in block 1 (lowland site) versus the other two blocks that were at higher elevations ( $p < 0.01$  for both; data not shown). A significant treatment\*block interaction was found, indicating that changes in treatment effects were affected by changes in topography. There was also a significant species\*treatment interaction, indicating that species responded differently to the imazapic treatments.

When seedling density data for individual grass species were examined using multivariate analysis of variance there were no significant treatment effects ( $p > 0.1$ ) within any of the species (Table 3, Fig. 12). However, Figure 12 shows some general trends that were consistent in most of the four species, such as a tendency toward higher establishment in low imazapic plots versus all other treatments. For *S. nutans*, medium treatments appeared to rival controls for seedling density, unlike the other species of native grasses.

Table 2. Univariate ANOVA results for seedling density three months after sowing for all four native grasses between treatments and species. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F statistic, and p = level of significance.

<b>EFFECTS</b>	<b>D. F.</b>	<b>M. S.</b>	<b>F</b>	<b>p</b>
Treatment	3	1951.833	8.889	< 0.01
Species	3	5850.389	26.643	< 0.01
Block	2	1525.271	6.946	< 0.01
Treatment*Block	6	1088.687	4.963	< 0.01
Treatment*Species	9	646.926	2.946	0.017
Error	30	219.505		

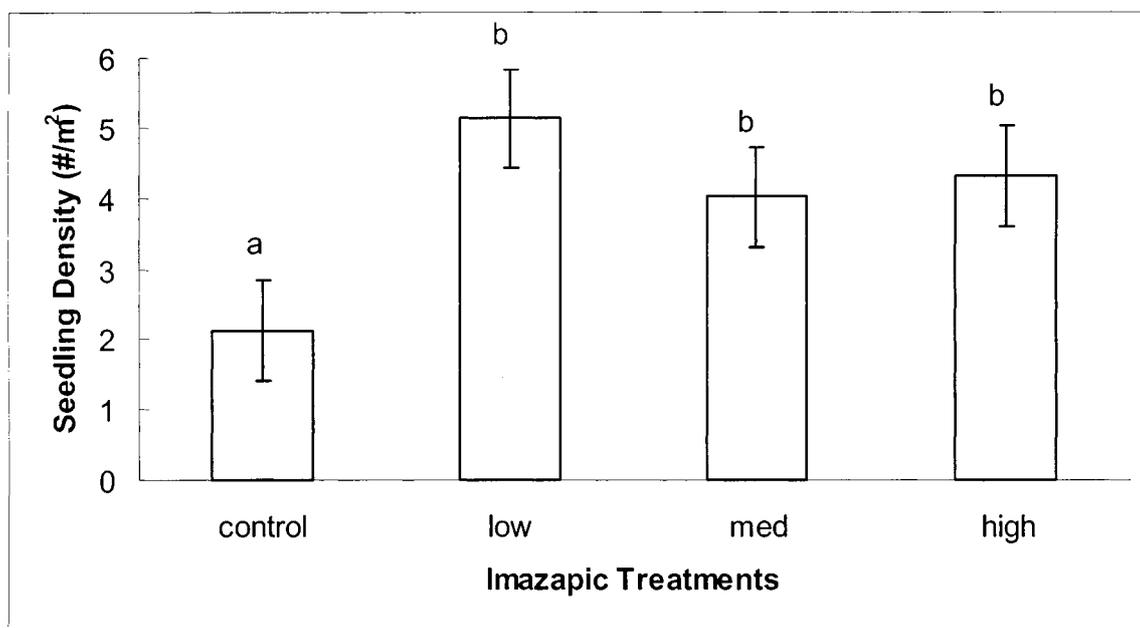


Figure 10. Univariate ANOVA results for absolute seedling density ( $\pm$  SE) of all four native grass species in the different imazapic treatments three months after sowing. Means with different letters are significantly different at  $p < 0.05$  as determined by LSD tests. See Materials and Methods for a description of the imazapic treatments.

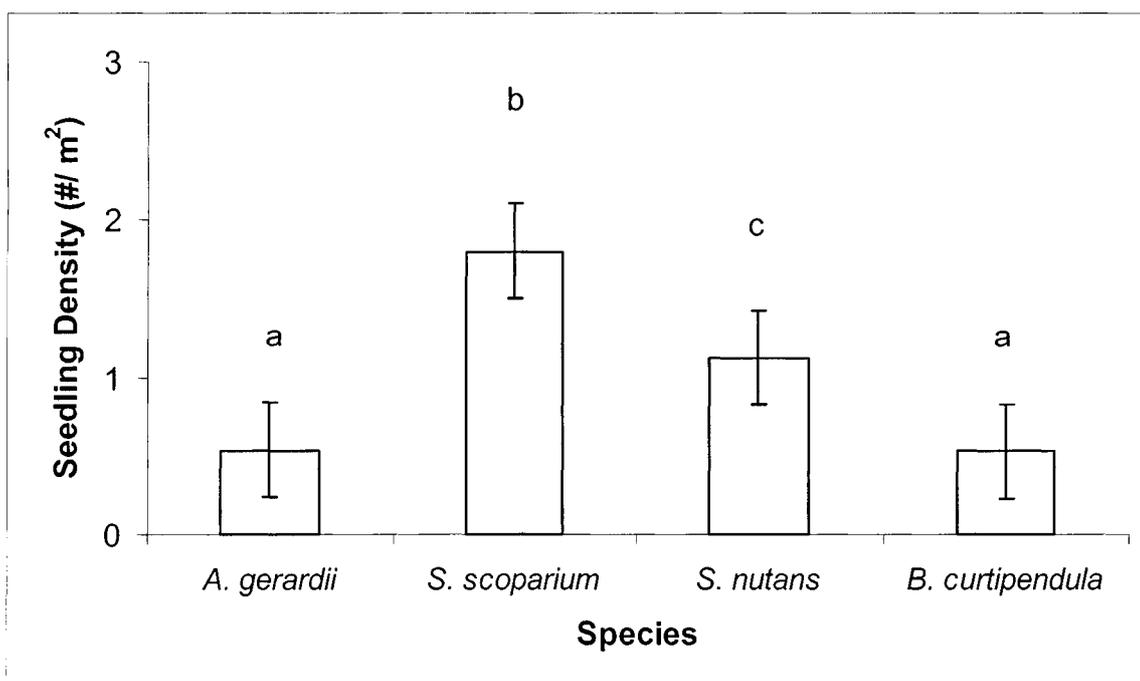


Figure 11. Univariate ANOVA results for absolute seedling density ( $\pm$  SE) of the four native grass species across treatments three months after sowing. Means with different letters are significantly different at  $p < 0.01$  as determined by LSD tests.

Table 3. Multivariate ANOVA results for seedling densities for native grasses between treatments three months after sowing. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F statistic, p = level of significance.

EFFECTS		D. F.	M. S.	F	p
Treatment for:	A. gerardii	3	79.3333	1.053	0.421
	S. scoparium	3	1906.972	1.916	0.206
	S. nutans	3	1623.778	2.840	0.106
	B. curtipendula	3	282.528	1.316	0.335
Error for:	A. gerardii	8	75.3333		
	S. scoparium	8	995.500		
	S. nutans	8	571.833		
	B. curtipendula	8	214.667		

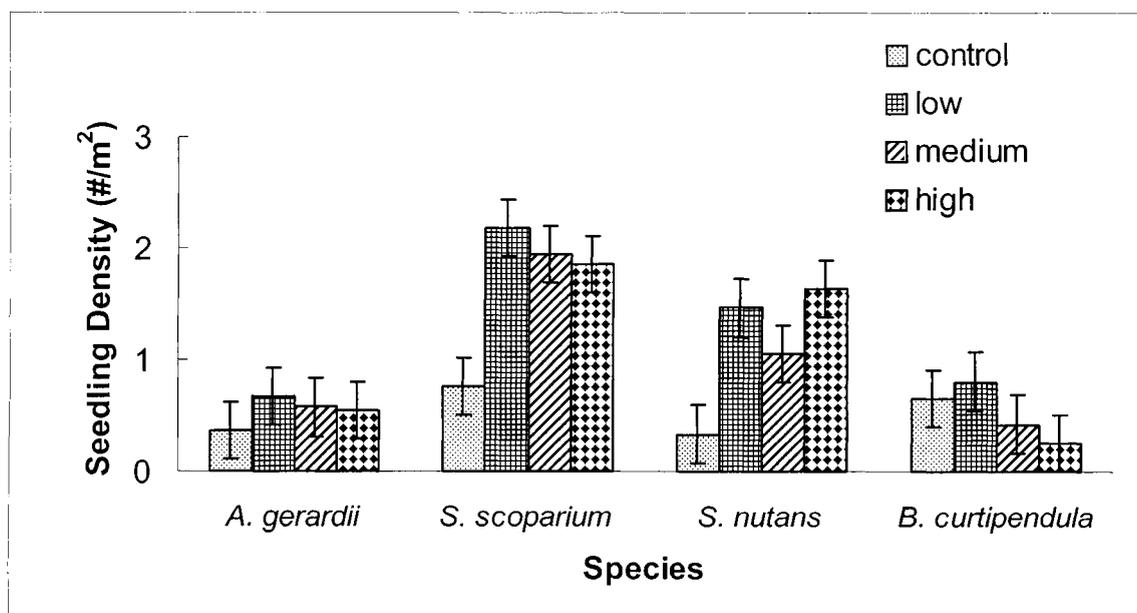


Figure 12. Multivariate ANOVA results for seedling density ( $\pm$  SE) of the four native grass species in the different imazapic treatments three months after sowing. See Materials and Methods for a description of imazapic treatments.

## Shoot Growth

The shoot growth of native grass seedlings was also significantly affected by imazapic treatment, block, and species (Table 4). When averaged over species and time, height of native grasses in the low imazapic treatment was significantly greater than in controls and the other herbicide treatments ( $p < 0.01$  for all, Fig. 13). In addition, controls showed significantly lower shoot growth than all three of the imazapic treatments ( $p < 0.01$  for all). Analysis of growth between native grass species (Fig. 14) showed significant differences between all species except *S. nutans* and *B. curtipendula* ( $p = 0.993$ ). Shoot growth for *A. gerardii* was significantly greater than all three other native grasses ( $p < 0.01$  for all); *S. scoparium* showed the lowest shoot growth of all the grasses ( $p < 0.01$  for all). Plants in blocks 1 (lowland) and 3 (upland) had significantly higher growth than block 2 (mid-slope;  $p < 0.01$  and  $p = 0.015$ , respectively; data not shown).

There was a significant treatment\*species interaction for shoot height, indicating differential effects of herbicide treatments on seedling growth for different species. Results of univariate repeated measures analysis also showed a significant treatment\*time interaction, indicating that treatment effects on native grass shoot growth changed over time. Specifically, height differences between controls and the imazapic treated plants for combined native grasses increased over time (Fig. 15). For each individual grass species, height also increased as a function of time (Fig. 16). Additionally, there was a significant treatment\*time\*species interaction, indicating that growth of different native grass species was affected by different treatments over time. Effects of treatments on native grass growth appeared to diverge for all four species over time (Figs. 17-20).

Controls showed lower shoot height for all four native grass species by the end of the growing season. General trends also show that low imazapic treatments produced greater shoot height for the native grass species except for *S. nutans* (Fig. 19).

Multivariate ANOVA results showed significant treatment effects for all native grass species for shoot growth except *B. curtipendula* (Table 5, Fig. 21). *Andropogon gerardii* and *S. scoparium* also showed significantly greater shoot growth in low imazapic treatments than in controls, medium, and high herbicide treatments ( $p < 0.01$  for all). *Sorghastrum nutans* differed from the other native grass species in that shoot growth was greatest in the medium imazapic treatments, but this observation was only significantly different from controls ( $p = 0.02$ ).

Block effect was also significant for all native grass species except *B. curtipendula*, indicating that topographic changes influenced shoot growth of *A. gerardii*, *S. scoparium*, and *S. nutans* (Table 5). However, block effect trends differed for all three grasses (data not shown). For *A. gerardii*, plants in block 2 (mid-slope site) showed greater shoot height than in blocks 1 (lowland site) and 3 (upland site,  $p < 0.01$  for both). For *S. scoparium*, plants in block 1 (lowland site) showed significantly greater height than in blocks 2 and 3 ( $p < 0.01$ ). For *S. nutans*, plants in block 3 (upland site) exhibited greater shoot growth than in block 2 ( $p < 0.01$ ).

Table 4. Repeated measures ANOVA results for shoot height data for native grass species between treatments. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F statistic, p = level of significance.

EFFECTS	D. F.	M. S.	F	p
Treatment	3	1.469	32.775	< 0.01
Species	3	11.964	266.856	< 0.01
Block	2	0.321	7.149	< 0.01
Time	4	12.198	272.059	< 0.01
Treatment*Species	9	0.282	6.290	< 0.01
Treatment*Time	12	0.359	8.012	< 0.01
Treatment*Species*Time	48	0.103	2.307	< 0.01
Error	30	0.04615		

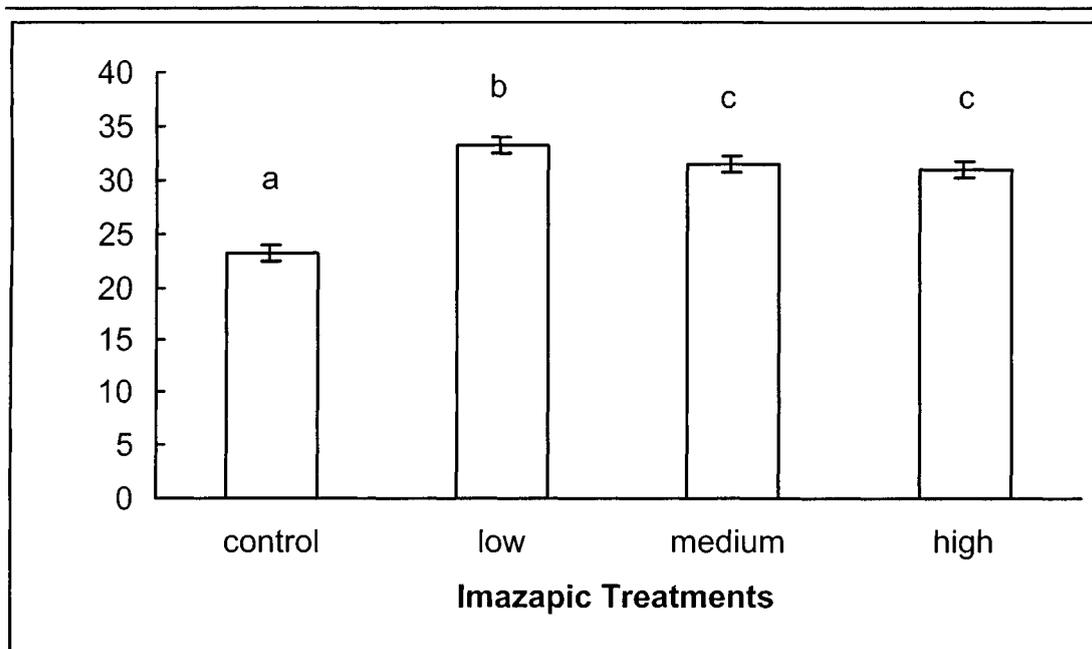


Figure 13. Repeated measures ANOVA results for mean shoot height averaged over the 88-day measurement period ( $\pm$  SE) for all four native grasses between imazapic treatments. Means with different letters are significantly different at  $p < 0.01$  as determined by LSD tests.

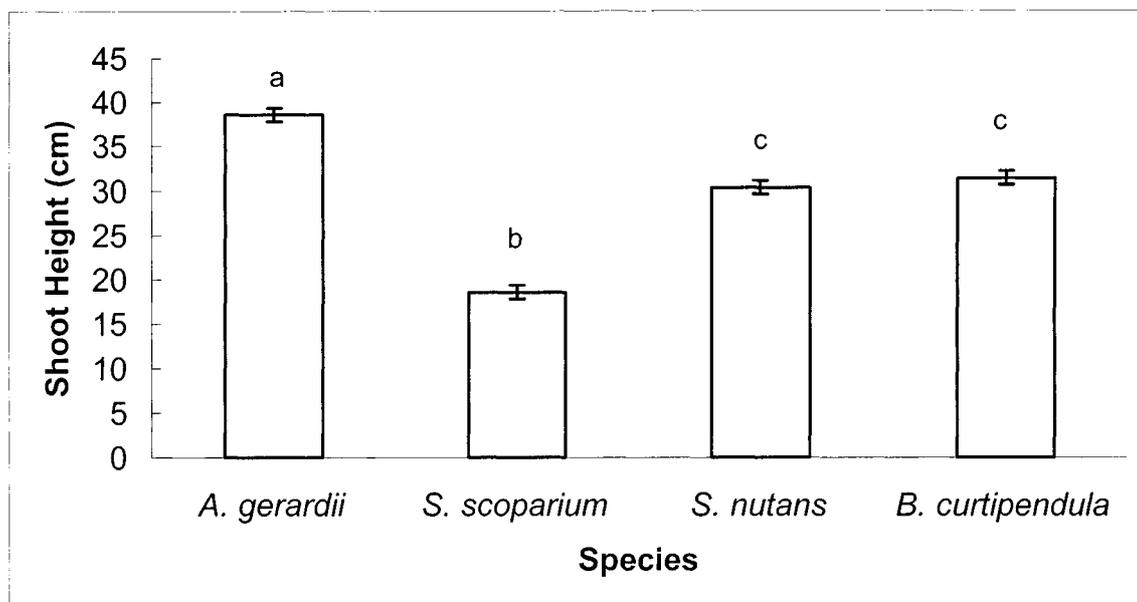


Figure 14. Repeated measures ANOVA results for mean shoot height ( $\pm$  SE) averaged over treatments and time for all four native grass species. Means with different letters are significantly different at  $p < 0.01$  as determined by LSD tests.

Table 5. Repeated measures multivariate ANOVA results for shoot height averaged between treatments and time. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F statistic,  $p$  = level of significance.

EFFECTS		D. F.	M. S.	F	p
Treatment for:	<i>A. gerardii</i>	3	0.406	12.109	< 0.01
	<i>S. scoparium</i>	3	0.881	21.108	< 0.01
	<i>S. nutans</i>	3	0.178	3.358	0.019
	<i>B. curtipendula</i>	3	0.05084	1.570	0.196
Block for:	<i>A. gerardii</i>	2	0.101	3.012	0.05
	<i>S. scoparium</i>	2	0.363	8.708	< 0.01
	<i>S. nutans</i>	2	0.352	6.648	< 0.01
	<i>B. curtipendula</i>	2	0.06992	2.159	0.117
Time for:	<i>A. gerardii</i>	4	1.299	38.762	< 0.01
	<i>S. scoparium</i>	4	2.854	68.372	< 0.01
	<i>S. nutans</i>	4	1.212	22.869	< 0.01
	<i>B. curtipendula</i>	4	5.237	161.728	< 0.01
Treatment*Time for:	<i>A. gerardii</i>	12	0.06054	1.806	0.045
	<i>S. scoparium</i>	12	0.06693	1.604	0.088
	<i>S. nutans</i>	12	0.08353	1.577	0.096
	<i>B. curtipendula</i>	12	0.06115	1.888	0.034
Error for:	<i>A. gerardii</i>	409	0.03352		
	<i>S. scoparium</i>	409	0.04174		
	<i>S. nutans</i>	409	0.05298		
	<i>B. curtipendula</i>	409	0.03238		

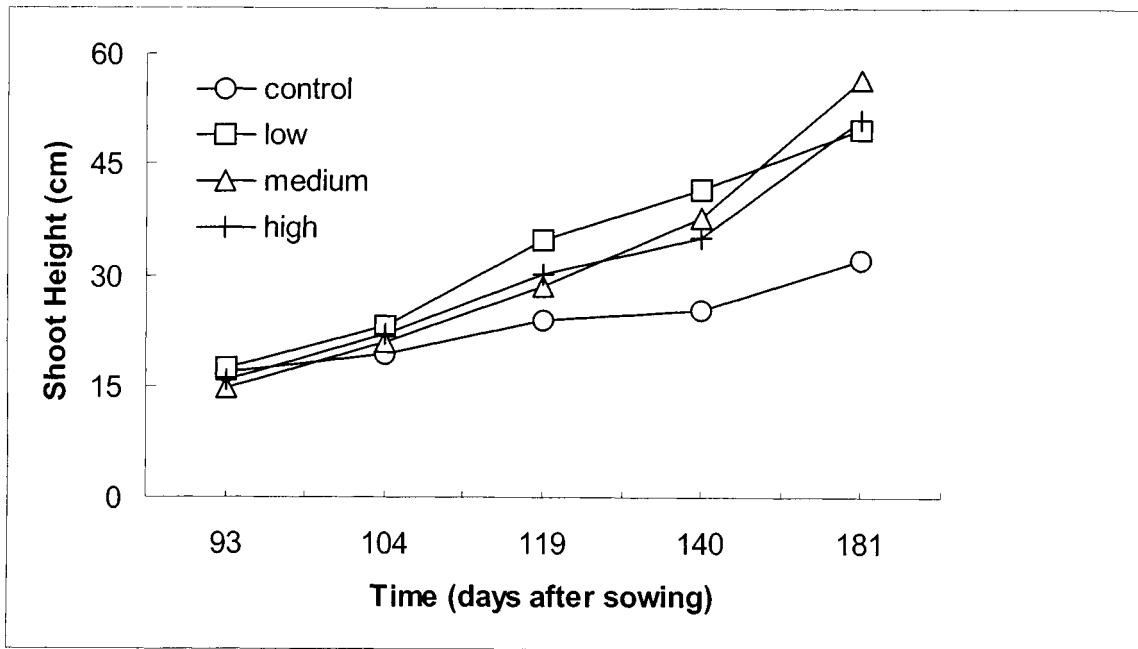


Figure 15. Mean shoot height of combined native grasses for each treatment as a function of time.

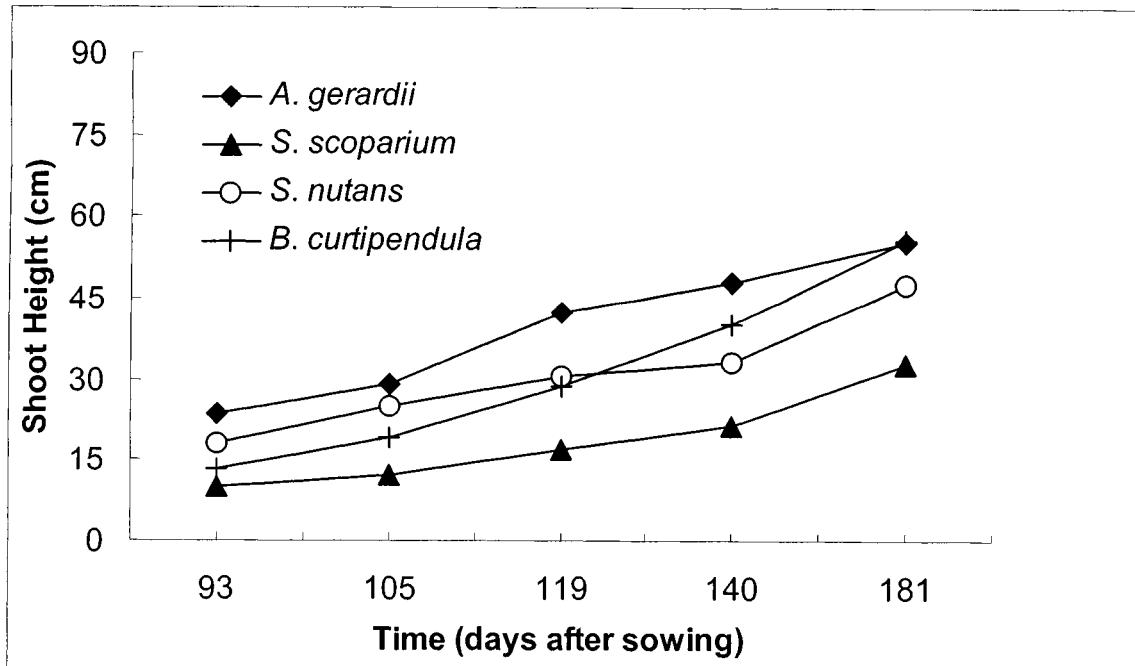


Figure 16. Mean shoot height of native grass species across treatments as a function of time.

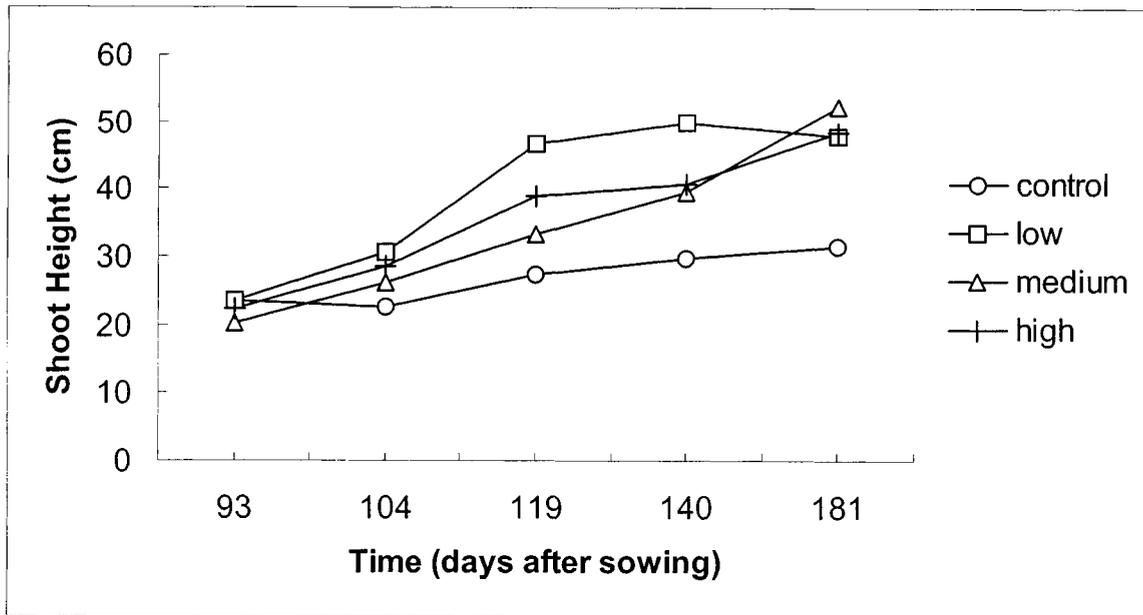


Figure 17. Mean shoot height response of *Andropogon gerardii* to controls and imazapic treatments over time.

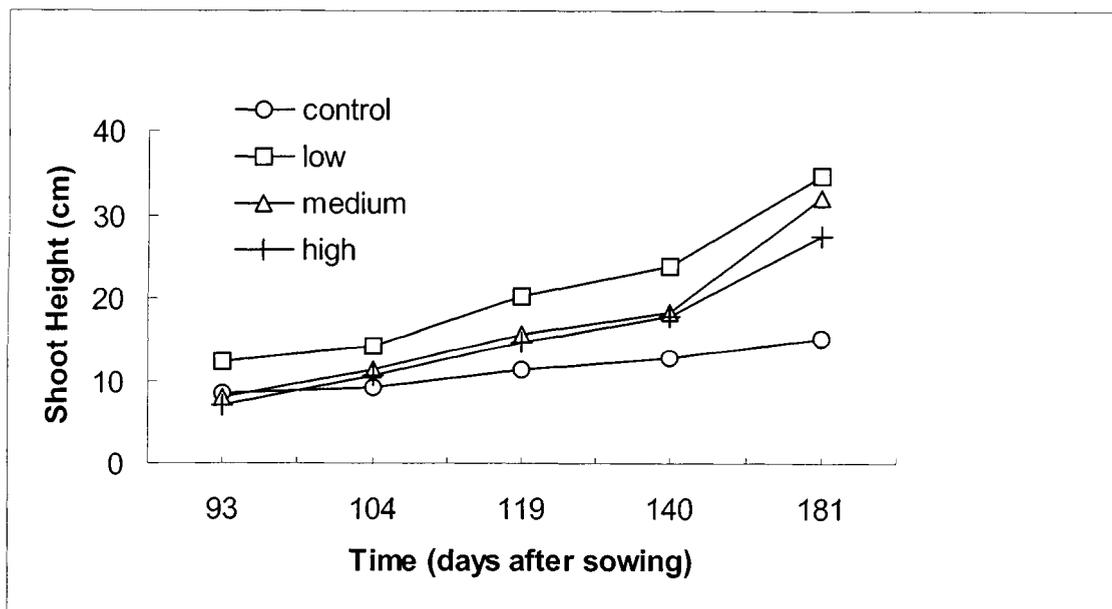


Figure 18. Mean shoot height response of *Schizachyrium scoparium* to controls and imazapic treatments over time.

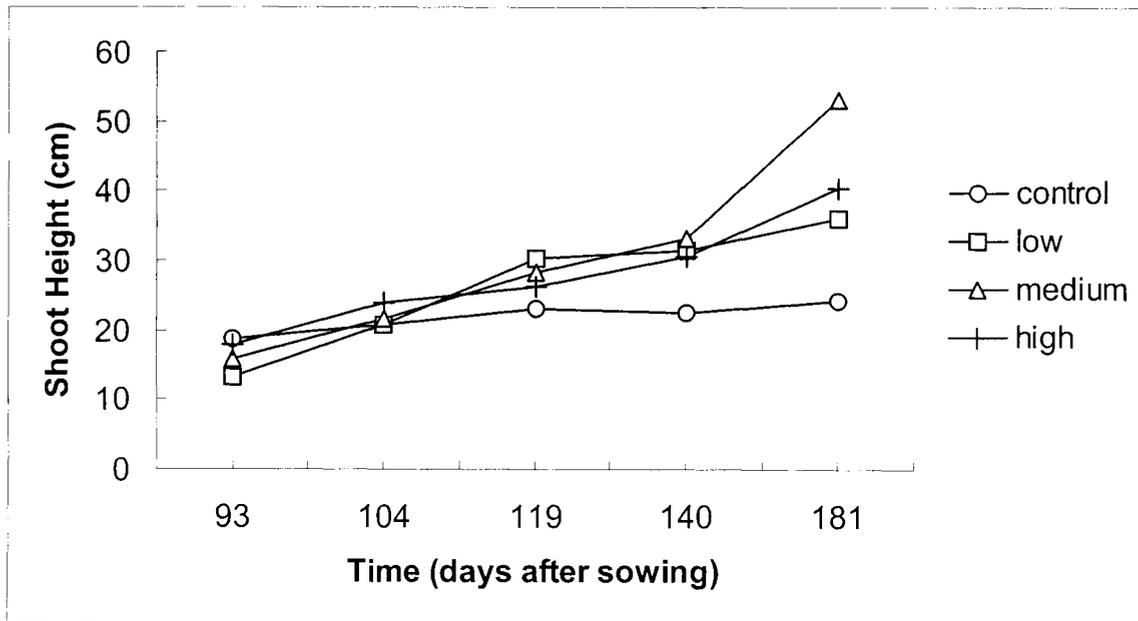


Figure 19. Mean shoot height response of *Sorghastrum nutans* to controls and imazapic treatments over time.

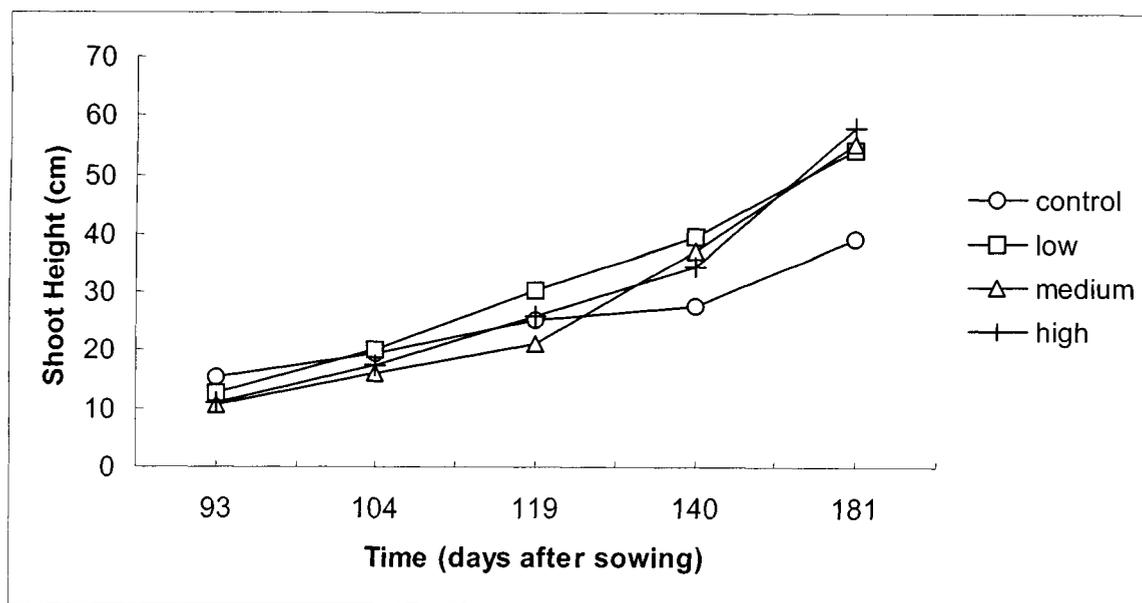


Figure 20. Mean shoot height response of *Bouteloua curtipendula* to controls and imazapic treatments over time.

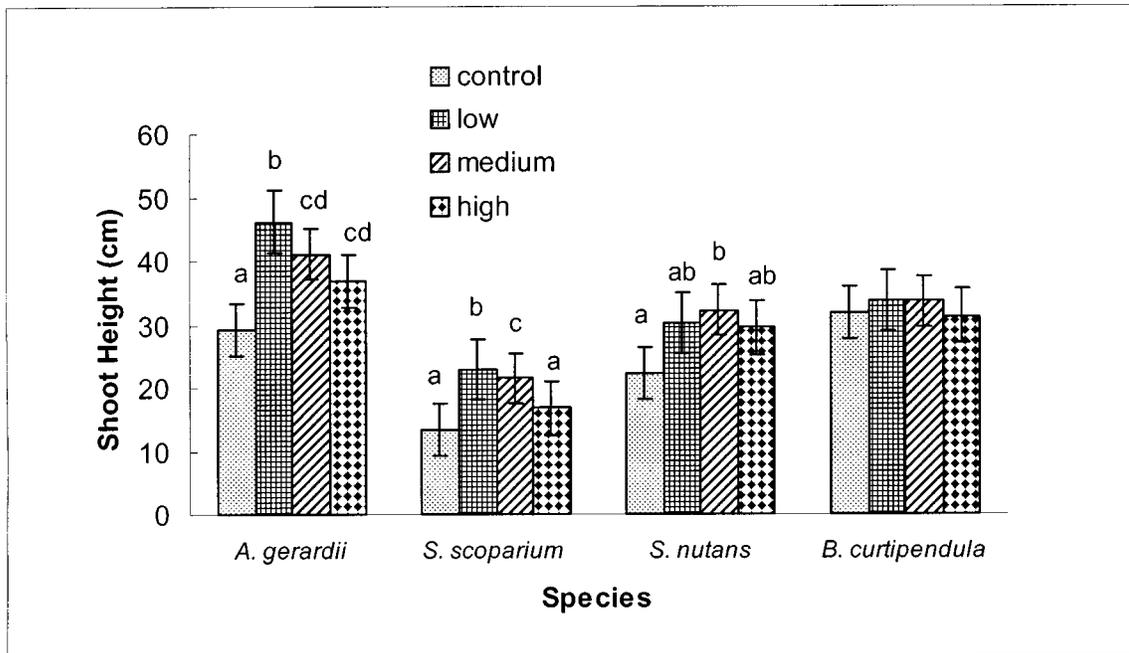


Figure 21. Repeated measures multivariate ANOVA results for mean shoot height averaged over the measurement period ( $\pm$  SE) for all four native grasses between treatments. Means with different letters are significantly different at  $p < 0.05$  as determined by LSD tests.

### End-of-Season Biomass

When data for aboveground dry biomass harvested at the end of the growing season were combined into three different plant functional types (i.e., native grasses, exotic bluestems, and broadleaf (dicot) species) and analyzed using univariate ANOVA (Table 6), there was no significant effect of herbicide treatment (Fig. 22). However, biomass differed significantly among plant functional types with the exotic bluestems showing more biomass production than either the native grasses or the dicots ( $p < 0.01$  for both, Fig. 23). There was also a significant treatment\*plant functional type interaction, indicating that the plant functional types responded differently to the herbicide treatments.

Multivariate ANOVA results (Table 7) indicated significant treatment effects on dicots and native grasses but not exotic grasses (Fig. 24). LSD analysis further revealed significantly more dicot biomass in controls versus low ( $p = 0.019$ ), medium ( $p < 0.01$ ), and high treatments ( $p < 0.01$ ). For native grasses significant differences were found between controls and low herbicide treatments ( $p = 0.014$ ), with greater biomass found in low plots. In general, native grasses and exotic bluestems tended to show positive biomass responses to herbicide treatment, whereas dicots showed negative responses to herbicide treatments.

Univariate ANOVA results for native grass biomass revealed differences in species biomass between *B. curtipendula* and *A. gerardii* ( $p < 0.01$ ) and between *B. curtipendula* and *S. scoparium* ( $p = 0.043$ ), with greater *B. curtipendula* biomass in both cases (Table 8, Fig. 25). Block effect was marginally significant, with greater native

grass biomass in the lowland site (block 1) as opposed to blocks 2 and 3 at higher elevations ( $p = 0.061$ ).

Multivariate ANOVA results (Table 9) indicated treatment differences for biomass of *S. nutans*, and marginally significant ( $p < 0.1$ ) differences in biomass for *A. gerardii* between treatments. *Sorghastrum nutans* showed greatest biomass in high treatments, and significant differences were between control and high treatments ( $p < 0.01$ ) and between medium and high treatments ( $p = 0.036$ ). *Andropogon gerardii* had greater biomass in low treatments than in controls ( $p = 0.021$ ). Although neither *S. scoparium* nor *B. curtipendula* showed significant differences between treatments (Fig. 26), data trends suggested greatest biomass in low imazapic treatments. Block effect was significant only for *S. nutans*, with greater biomass occurring in the lowland block versus the other two blocks at higher elevation ( $p = 0.019$ )

Table 6. Univariate ANOVA results for biomass data for three plant types (native grasses, exotic bluestems, and broadleaf species) between treatments. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F-statistic, p = level of significance.

<b>EFFECTS</b>	<b>D. F.</b>	<b>M. S.</b>	<b>F</b>	<b>p</b>
Treatment	3	73410.886	0.966	0.425
Plant Type	2	4104961	53.999	0.000
Treatment*Plant Type	6	241059.4	3.171	0.020
Error	24	76018.571		

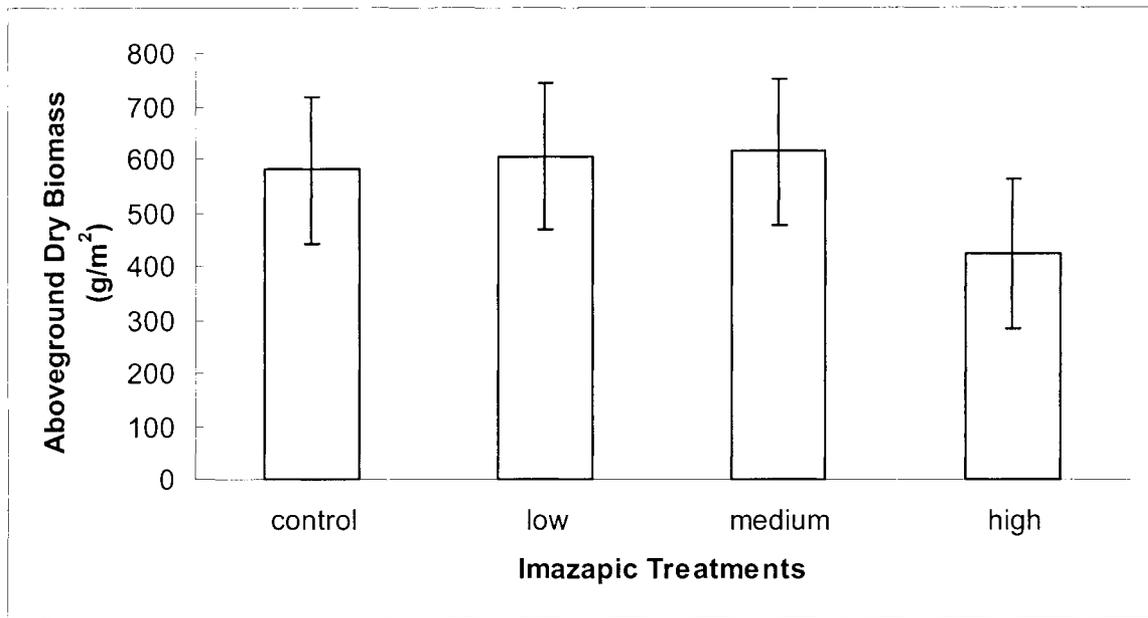


Figure 22. Univariate ANOVA results for total end-of season biomass ( $\pm$  SE) between treatments.

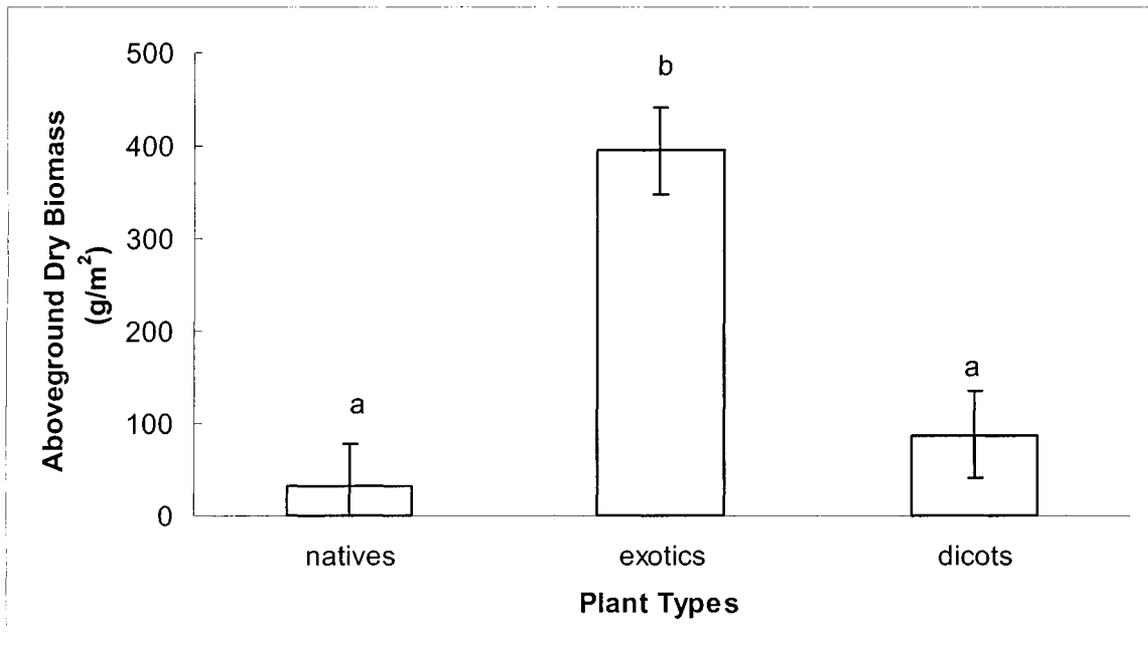


Figure 23. Univariate ANOVA results of end-of-season biomass ( $\pm$  SE) for three plant types (native grasses, exotic bluestems, and dicots). Plant types with different letters are significantly different at  $p < 0.01$  as determined by LSD analysis.

Table 7. Multivariate ANOVA results for biomass of three plant types (native grasses, exotic bluestems, and dicots) between treatments. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F-statistic, p = level of significance.

EFFECTS		D. F.	M. S.	F	p
Treatment for:	Natives	3	10124.776	3.493	0.07
	Exotics	3	155110.5	0.972	0.452
	Dicots	3	390294.5	5.958	0.02
Error for:	Natives	8	2898.886		
	Exotics	8	159646.6		
	Dicots	8	65510.262		

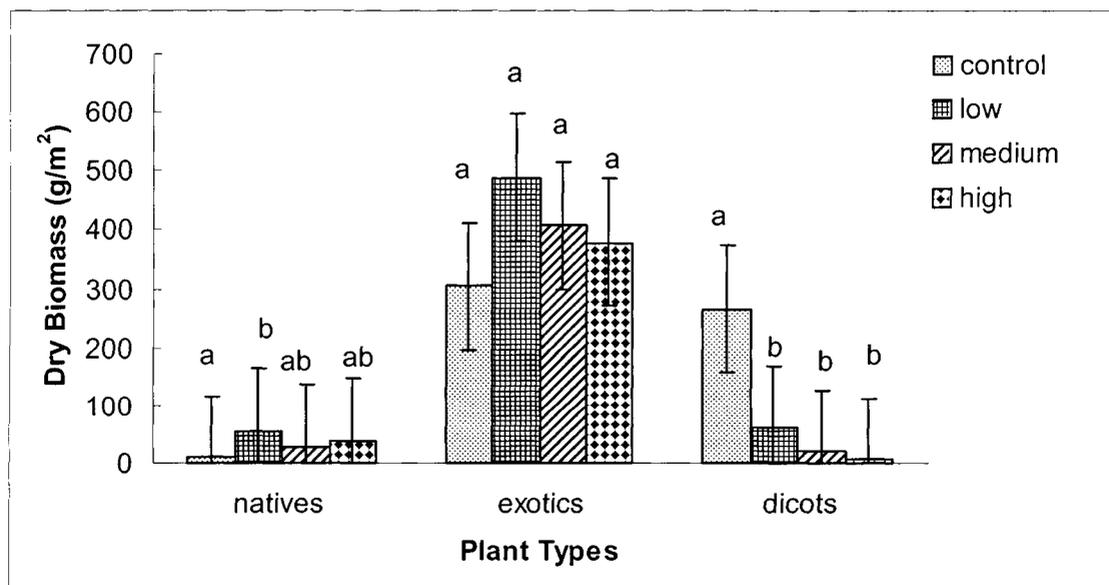


Figure 24. Multivariate ANOVA results for end-of-season biomass ( $\pm$  SE) for three plant types (native grasses, exotic bluestems, and dicots) between treatments. Within a group, bars with different letters indicate significant differences at  $p < 0.05$  as determined by LSD analysis.

Table 8. Univariate ANOVA results for native grass biomass. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F-statistic, p = level of significance.

EFFECTS	D. F.	M. S.	F	p
Treatment	3	2621.936	7.644	0.001
Block	2	1052.971	1.581	0.061
Species	3	1213.086	3.536	0.026
Treatment*Species	9	542.229	1.581	0.166
Error	30	343.020		

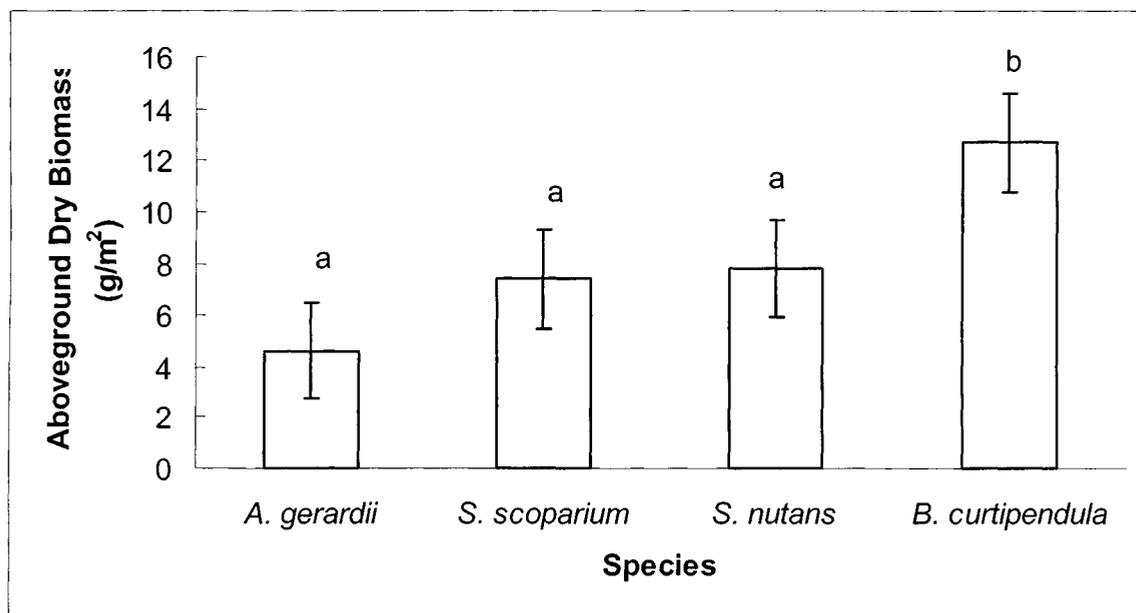


Figure 25. Univariate ANOVA results for mean end-of-season biomass ( $\pm$  SE) for each native grass species. Means with different letters show significant differences at  $p < 0.01$  as determined by LSD analysis.

Table 9. Multivariate ANOVA results of biomass data for all four native grass species between treatments. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F-statistic, p = level of significance.

EFFECTS		D. F.	M. S.	F	p
Treatment for:	A. gerardii	3	426.19	3.438	0.093
	S. scoparium	3	672.515	2.061	0.207
	S. nutans	3	859.262	5.595	0.036
	B. curtipendula	3	2290.657	2.799	0.131
Block for:	A. gerardii	2	49.240	0.397	0.689
	S. scoparium	2	397.719	1.219	0.359
	S. nutans	2	1262.943	8.224	0.019
	B. curtipendula	2	222.110	0.271	0.771
Error for:	A. gerardii	6	123.975		
	S. scoparium	6	326.226		
	S. nutans	6	153.567		
	B. curtipendula	6	818.319		

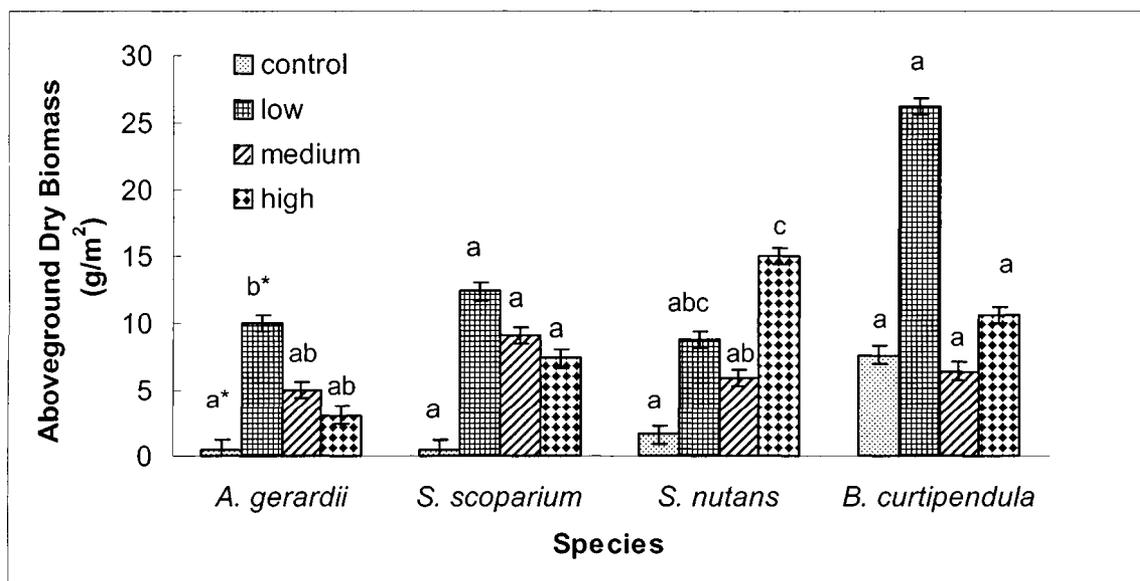


Figure 26. Multivariate ANOVA results for mean end-of-season biomass ( $\pm$  SE) for native grasses between treatments. Means with different letters show significant differences at  $p < 0.05$  as determined by LSD analysis. \*Indicates marginal differences at  $p < 0.1$ .

## Flowering Measurements

Univariate ANOVA results for percent flowering of native grass species at the end of the growing season showed a significant treatment effect when averaged across species (Table 10). Specifically, there were fewer plants flowering in controls compared to low imazapic treatments ( $p < 0.01$ ), medium treatments ( $p = 0.012$ ) and high imazapic treatments ( $p < 0.01$ ) when analyzed using LSD tests (Fig. 27). Native grasses also flowered more often in medium imazapic treatments versus low imazapic treatments ( $p = 0.017$ ) and control and high imazapic treatments ( $p < 0.01$  for both). Percent flowering between species was significantly different when averaged across treatments (Fig. 28). LSD results showed that *B. curtipendula* individuals flowered more than all three of the other species of native grasses ( $p < 0.01$  for all), but no other differences between species occurred.

Multivariate ANOVA results revealed differences in percent flowering between treatments for *S. scoparium* and *S. nutans* (Table 11, Fig. 29). For *S. scoparium*, control plots showed significantly lower percent flowering than low ( $p = 0.015$ ), medium ( $p < 0.01$ ), and high (0.048) imazapic treatments, but there were no differences between any of the herbicide treated plots. Results also showed a significant block effect for *S. scoparium*, where percent flowering was significantly greater in the lowland site (block 1) than in the mid-slope site (block 2,  $p = 0.015$ ) and the upland site (block 3,  $p < 0.01$ ). For *S. nutans*, greater flowering occurred in medium imazapic treatments versus controls and low treatments ( $p < 0.01$ ). High treatments also showed significantly higher percent flowering than control plots ( $p < 0.01$ ). *Andropogon gerardii* also showed marginally

significant differences in percent flowering between controls and medium imazapic treatments, with greater flowering occurring in medium treatments ( $p = 0.018$ ).

Table 10. Univariate ANOVA results for flowering data of all four native grasses between treatments and species. D. F. = degrees of freedom, M. S. = mean square, F = calculated value for the F-statistic, p = level of significance.

<b>EFFECTS</b>	<b>D. F.</b>	<b>M. S.</b>	<b>F</b>	<b>p</b>
Treatment	3	0.575	9.845	< 0.01
Species	3	1.135	19.448	< 0.01
Treatment*Species	9	0.03414	0.585	0.800
Error	32	0.05838		

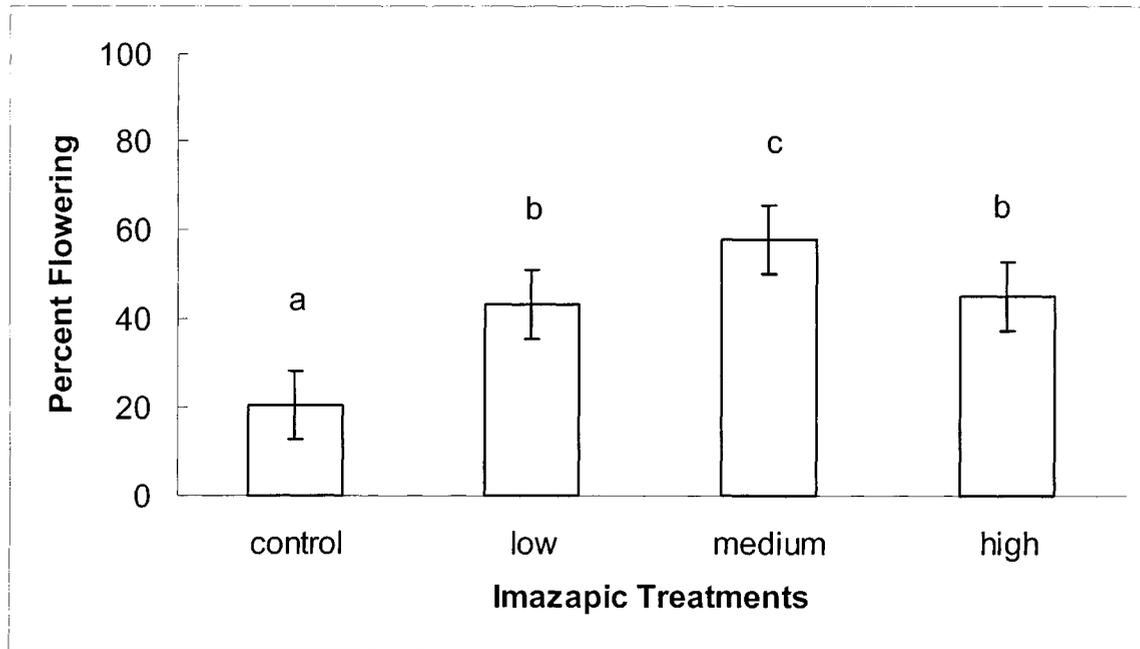


Figure 27. Univariate ANOVA results for percent flowering ( $\pm$  SE) for native grasses across imazapic treatments at the end of the growing season (Oct. 2001). Bars with different letters are significantly different at  $p < 0.01$  as determined by LSD tests.

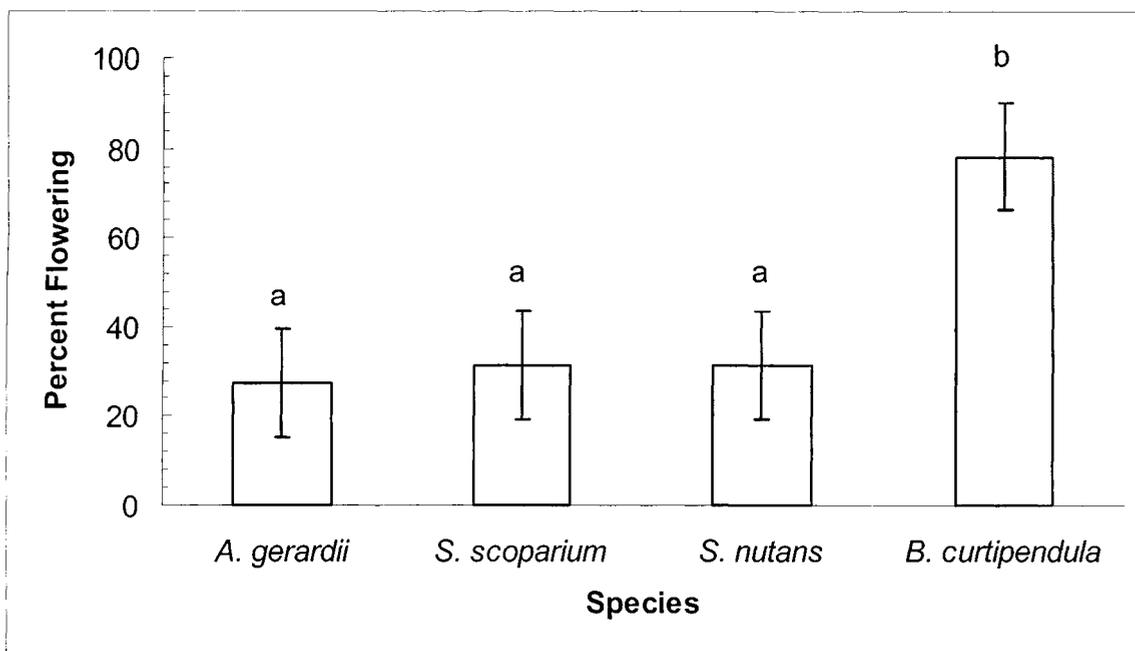


Figure 28. Univariate ANOVA results for percent flowering ( $\pm$  SE) at the end of the growing season (Oct. 2001) for all four native grass species. Bars with different letters indicate significant differences at  $p < 0.01$  as determined by LSD tests.

Table 11. Multivariate ANOVA results for flowering data for all four native grass species between treatments. D. F. = degrees of freedom, M. S. = mean square, F = the calculated value for the F-statistic, p = level of significance.

EFFECTS		D. F.	M. S.	F	p
Treatment for:	A. gerardii	3	0.09173	3.513	0.089
	S. scoparium	3	0.08255	6.132	0.029
	S. nutans	3	0.221	14.537	< 0.01
	B. curtipendula	3	0.307	2.767	0.133
Block for:	A. gerardii	2	0.01022	0.391	0.692
	S. scoparium	2	0.120	8.938	0.016
	S. nutans	2	0.03411	2.248	0.187
	B. curtipendula	2	0.03188	0.287	0.760
Error	A. gerardii	6	0.02612		
	S. scoparium	6	0.01346		
	S. nutans	6	0.01517		
	B. curtipendula	6	0.215		

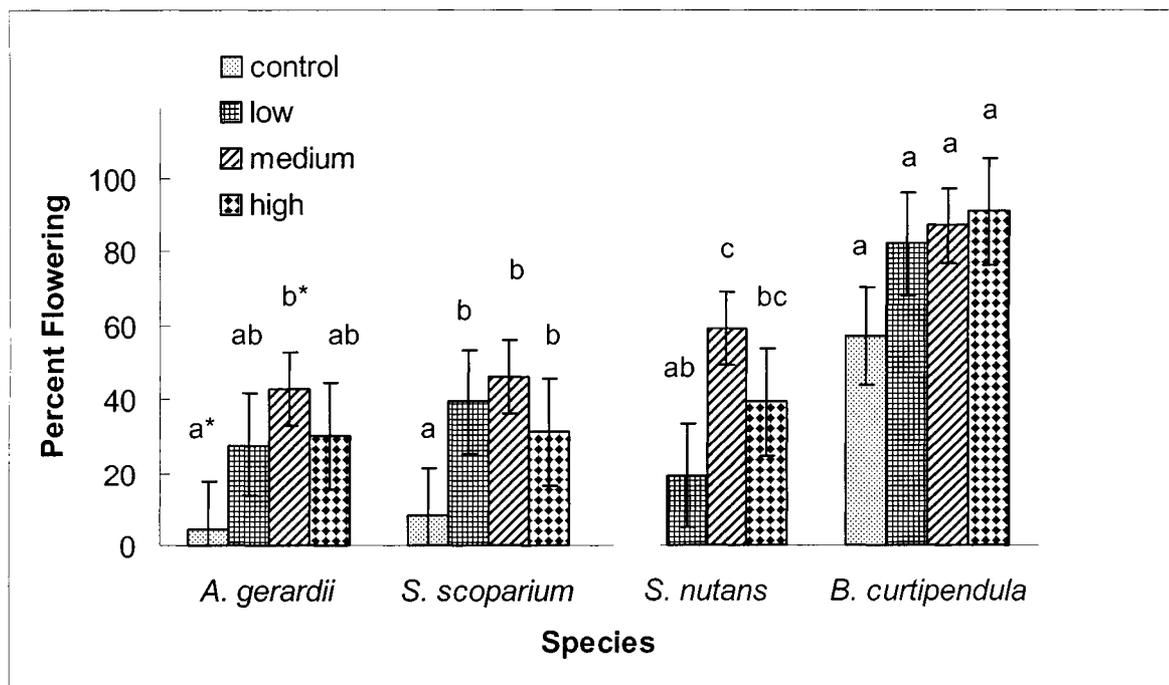


Figure 29. Multivariate ANOVA results for percent flowering ( $\pm$  SE) at the end of the growing season (Oct. 2001) for native grasses across treatments. Means with different letters indicate differences at  $p < 0.05$  as determined by LSD tests. \*Indicates marginally significant differences at  $p < 0.1$ . Lack of control bar for *S. nutans* represents a mean of zero.

## DISCUSSION

### Effects on Establishment

Control plots showed significantly lower seedling densities of native grasses than all three treatment plots when data were averaged over species, confirming my original hypothesis that imazapic treatments would positively influence the establishment of native grasses compared to plots without the imazapic herbicide. However, there were no differences in native grass seedling density among the three herbicide treatments. These results indicate that while there were beneficial effects of imazapic on the seedling establishment of native grasses, the effects did not increase with increasing herbicide levels. Therefore, medium to high herbicide concentrations may not be necessary in order to sufficiently reduce competition by dicots in favor of native warm season grasses.

When averaged across treatments, differences between species for seedling establishment were found for native grasses. In particular, *S. scoparium* showed significantly greater density than the other three remaining species, and there were a significantly greater number of *S. nutans* seedlings than those of *A. gerardii* and *B. curtipendula*. Therefore, establishment of *S. scoparium* and *S. nutans* was more successful at this site than that for *A. gerardii* or *B. curtipendula*. A significant block effect was also found, indicating that densities differed, possibly with changes in topography. Specifically, there was greater establishment in the lowland block, and this

could be related to higher moisture levels in lowlands than uplands. Block effects might also be related to different edaphic properties in the different blocks. Treatment\*block effect was significant for seedling density, suggesting that treatments in the lowland block had higher native grass establishment than treatments at higher elevations.

Recommended seeding rates vary depending on the intended use of the parcel of restored prairie in question. For optimal wildlife habitat, it is recommended that the seeding rate of native warm season grasses (NWSG) should be around 6.73 kg/ ha plus 0.28 kg forbs/ ha, but for prairie restoration these rates should be higher (Washburn et al. 1999). The seeding rate in the present study was 4.6 kg/ ha for grasses, which is lower than recommended seeding rates for restoration purposes. Consequently, overall establishment rates in this study were somewhat less than would be desired for successful Blackland Prairie restoration. In addition, low seedling establishment may have resulted from using the JThom 42 Wildseeder, which simply drops seed onto the ground instead of drilling them to the appropriate planting depth (Morgan 1997). This surficial sowing may have left seeds vulnerable not only to predation by birds, insects, and other wildlife, but may also have exposed the seeds to extreme desiccating conditions at these shallow depths. Nonetheless, despite low rates of seeding and establishment, imazapic treatments did contribute to significant improvements in seedling establishment relative to those of controls.

Successful seedling establishment of prairie species (i.e., native warm season grasses) is strongly influenced by soil moisture levels and reduced competitive effects from existing vegetation (Potvin 1993). The early dry spell experienced at the beginning of the growing season may have contributed to low seedling densities in the present

study. I also found significantly greater seedling densities in the lowland block than in upland sites suggesting that soil moisture influenced establishment. Potvin (1993) also found greatest establishment of seedlings in the Nebraska Sandhills on lowland sites, and lowest establishment on ridges when averaged across treatments and species. She went on to say that the primary cause of seedling mortality appeared to be desiccation, and that in untreated sites (no irrigation or disturbance) none of the seedlings survived on any of the sites. Desiccation of young seedlings is a potential problem on sites such as ours in south-central Texas where summer droughts are frequent. Indeed, Fowler (1986) found that microsites providing protection for seeds from desiccation were more successful than other microsites for *Bouteloua rigidseta*, a common C<sub>4</sub> grass of the Edwards Plateau in central Texas. Dry soils also form crusts that make it difficult for seedling shoots to emerge. In this regard, conditioning of arid soils to improve texture and moisture holding capacity has been shown to increase seedling establishment of native grasses by preventing soil crust formation, thus providing seeds with more favorable conditions for germination. For example, Rubio et al. (1990) showed significantly greater emergence of *B. curtipendula* with application of polyacrylamide, a chemical used as a soil conditioner, as opposed to untreated sites. However, polyacrylamide neither improved nor hindered emergence of the exotic bluestem, *Bothriochloa ischaemum*. Thus, conditioning of arid soils in this manner might yield greater establishment of native warm season grasses and potentially allow them to successfully compete with invasive old world bluestems.

Various types of disturbance can contribute to enhanced establishment of native plants by eliminating potential competitors. Omni-directional disking may be more successful at breaking up vegetative propagules to prevent regrowth in some plants. In

the Nebraska Sandhills, rototilling coupled with irrigation significantly improved emergence of native grass seedlings (Potvin 1993). Although my study site was disked in the fall and spring before planting, this disturbance may have been counter productive in that it likely stimulated germination and establishment of exotic bluestem grasses. It is known that *B. ischaemum* is an aggressive old world bluestem that responds positively to disturbance. Clones of this species are usually apomicts (Harlan 1963) and can therefore set seed without being fertilized. The intent of the disking was to break up rhizomes and stolons, and thereby prevent vegetative propagation. However, according to Stone and Davis ([www.texasprairie.org](http://www.texasprairie.org)), disking when *B. ischaemum* is present must not exceed two inches to avoid reseeding by dormant seeds in the seed bank. These investigators also recommend that any germinating seeds or vegetative regrowth must be killed as soon as they appear and that workers should expect at least two germination periods in the spring. Roundup® treatments or other glyphosates are recommended as one of the only effective treatments for elimination of *B. ischaemum*, thus preventing it from going to seed. Although the research site was treated with Roundup® herbicide following disking and prior to sowing, one application of this broad-spectrum herbicide appears to be insufficient for controlling or eliminating old world bluestems. An experiment by Wilson and Gerry (1995) showed 20 times greater establishment of native grass seedlings with supplemental nitrogen when glyphosate (the same chemical found in Roundup®) was applied to combat competition with Eurasian grass species. Future attempts at restoration on land where C<sub>4</sub> old world bluestems are currently dominant may require more than one season of broad-spectrum herbicide treatment, affording a “clean slate” from which reestablishment of native species can begin.

## Effects on Shoot Growth

I found that low imazapic treatments also resulted in greater shoot growth for native grasses than all other treatments when averaged across species, so both establishment and growth of seedlings is positively affected by some imazapic treatment. This increase in growth is most likely due to the herbicide's suppression of broadleaf species. Indeed, as the biomass data showed, dicots were significantly reduced in imazapic treated plots whereas native grass biomass increased, which suggests that when dicots are suppressed, native grasses benefit from the reduction of broadleaf competition. Conversely, controls showed significantly lower growth than all imazapic treatments across species.

When growth of native grass species was compared across treatments, *A. gerardii* was significantly greater than all other species, including *S. nutans*, another tallgrass species. However, growth of *B. curtipendula* did not differ from *S. nutans*, despite the fact that *B. curtipendula* is a midgrass species, indicating that height growth was not consistently greater for tallgrass species than midgrass species.

Multivariate analysis further revealed that different responses to imazapic treatment occurred within the native grass species. Both *A. gerardii* and *S. scoparium* showed positive growth responses to low imazapic treatments when compared to controls, whereas growth of *S. nutans* and *B. curtipendula* showed improvement but only in the medium imazapic treatments. These findings indicate that native grass species do vary in their sensitivity to imazapic concentrations. But since the biomass of the exotic grasses did not vary between the three imazapic treatments, the effects of competition on native grasses from exotics was likely similar between imazapic treatments. As for dicot

biomass, while there was significantly less biomass found in imazapic treated plots than in controls, there were no differences in dicot biomass between the different imazapic treatments. These findings suggest that differential responses of these grasses to imazapic treatments were likely due to inherent differences in species sensitivity to imazapic treatments, and not indirect effects on competition.

As was the case with seedling establishment, block effect on seedling height was significant for most species across treatment and species, indicating that topographic changes might also have affected shoot height for most species. However, changes in shoot height as a function of block differed between grass species. As with seedling establishment, moisture levels most likely affected growth of native grasses. Using shoot density as an indicator of growth success, results of a study in North Dakota showed that the densest plant stems were found in years when water and temperature were optimal, independent of planting date (Ries and Hofmann 1996). In the present study, *A. gerardii* showed greatest growth in the mid-slope position, whereas shoot height for *S. scoparium* was greatest in the lowland position. By comparison, *S. nutans* showed significantly greater shoot height in the upland position versus the mid-slope position. Because of these inconsistencies it is unlikely that local differences in higher soil moisture levels alone are responsible for differences in shoot height. These findings indicate that requirements of these plants after the seedling stage may differ from previous requirements as seedlings. Differences in light levels from competitive weeds and differences in soil aggregation may also have affected shoot growth. Empirical observation of the research site indicated that the number of rocks and hardness of soil

decreased from the upland block to the lowland block, which may contribute to changes in species performance with time.

There was also a significant treatment\*time interaction for shoot growth showing changes in treatment effects as a function of time, possibly due to residual effects incurred at the seedling level. Conversely, it is also possible that differences are due to decay of imazapic via microbial action later in the growing season and that growth is stimulated after any possible deleterious effects of the chemical are reduced. Half-life of imazapic ranges from 31 to 233 days, depending of moisture and soil characters (American Cyanamid 1997). In addition, treatment\*species\*time interaction was significant, indicating changes in shoot growth for different species as imazapic concentrations in the soil decrease over time. General trends suggest that shoot growth for different treatments diverged as a function of time and in all cases controls were the lowest in the divergence (Figs. 17-20). These results indicate that small beneficial effects of imazapic treatment on establishment early in the season may have significant consequences on growth later in the season.

### **Effects on Aboveground Biomass**

The finding that total aboveground biomass (i.e., native grasses + exotic grasses + dicots) did not differ between imazapic treatments indicated that overall community productivity was not impaired by this herbicide treatment. However, imazapic treatment did alter the species composition within these communities. In general, exotic bluestems composed far more of the total biomass than either native grasses or dicots and were the dominant species in all treatments. Although differences between treatments for exotic

grasses were not statistically significant, general trends in the data suggest higher biomass in treatments than controls, especially in the low treatment level. The primary effects of imazapic treatment were, however, to increase the relative abundance of the native grasses at the expense of the dicot species. Indeed, the majority of native grass biomass occurred in low imazapic treatments, whereas the biomass of dicots was greatest in the controls. Multivariate analysis of native grass biomass between species indicated that only *S. nutans* biomass differed significantly between treatments, with greatest biomass in high imazapic treatments. *Andropogon gerardii* showed marginally different biomass between controls and low imazapic treatments, with greater biomass in treatments. Despite lack of significance for the other two species, general trends suggest similar results for biomass as were found for seedling density and shoot growth. In general, biomass was greater in low imazapic treatments than in controls and higher herbicide treatments.

Along with treatment differences in biomass for native grasses as a group, results also revealed significant species effects when averaged across treatments. Specifically, *B. curtipendula* produced significantly more aboveground biomass than any of the other native grasses, possibly due to *B. curtipendula*'s ability to establish well on upland sites where water levels are typically lower. Block effect was also significant, showing that once again, changes in topography or edaphic characters likely affected plant production. In this case, biomass was greatest in the lowland block as opposed to the higher elevation sites. Biomass production as a function of topographic position in a study on the Konza Prairie revealed that significantly greater biomass was produced in lowland sites associated with higher moisture levels on native virgin prairie (Briggs and Knapp 1995).

The authors go on to say that more than one factor (i.e. soil moisture) is responsible for variation within their data, and that variable light levels, nutrient levels, and disturbance by fire contribute to results. A previous study on the Konza Prairie indicated that biomass was greatest in lowland areas in association with annual burns, and that in all treatments biomass was lowest during periods of drought (Abrams et al. 1986). The Konza Prairie is dominated by *Andropogon*, *Sorghastrum*, and *Panicum* species (Abrams et al. 1986), which are plant species that are commonly found in Blackland Prairie communities.

### **Effects on Flowering**

As hypothesized, results showed a significant positive effect of imazapic treatment on native grass flowering. When averaged across species, the plants in the medium imazapic treatment flowered more frequently than all other treatments. However, there was no significant block effect, indicating no differences in percent flowering for native grasses with changes in block. Within the native grasses, *B. curtipendula* showed higher percent flowering than the other grasses, which is consistent with the findings of greatest biomass production. During the growing season *B. curtipendula* began to flower before the other native grass species and continued throughout the season. This is not surprising since *B. curtipendula* typically begins to set seed in June and continues to do so through November, whereas the other grass species set seed from August/September to November/December (Gould 1978). Multivariate analyses revealed significant differences for percent flowering between treatments for *S. scoparium* and *S. nutans*, and in general, the controls for all four species indicated lower

flowering frequency. Imazapic positively affected flowering frequency in native grasses, possibly due to increased native grass performance with decreased competition with broadleaf weeds. Since growth of native grasses was also positively correlated with imazapic treatments, natives in these plots would be larger, more developed, and more prepared to produce reproductive structures than individuals in the controls.

### **Summary and Conclusions**

Findings from the present study indicate that treatment with the imazapic herbicide significantly increased native grass densities, shoot growth, biomass, and percent flowering, but effects were not always dose-dependent. Thus, in general, some imazapic treatment increased native grass performance, but beneficial effects did not always increase with increasing concentrations of this herbicide. Despite these positive effects in native grasses, exotic bluestems continue to dominate the research site, and imazapic appeared to have a minimal effect on the biomass of these species. Thus, in order to successfully restore Texas Blackland Prairie that is currently dominated by old world bluestems, measures must be taken to control these exotic bluestem grasses before native warm season grasses can dominate. Since these exotic species appear to respond favorably to disturbance, eradication may best be accomplished by chemical means. A broad-spectrum herbicide, such as Roundup® and other glyphosates can be used effectively, if applications are repeated when resprouts occur. Attempts at restoration may need to be delayed beyond one season to ensure that invasive warm season grasses are under control, giving workers a “clean slate” upon which to work. Spring planting of native warm season grasses can then proceed along with application of imazapic at the

time of planting. Although *S. nutans* often responded better to higher levels of imazapic, the rest of the native grasses showed best results with the lowest treatment concentration used (280 g/ha). Since imazapic is effective at controlling broadleaf species, establishment of prairie forbs might be more successful after initial establishment of dominant grasses is complete. It may be possible, however, to seed some legume species in with native grasses in the initial restoration/ imazapic application phase due to their potentially higher tolerance to imazapic than other dicot families.

### LITERATURE CITED

- Abrams, M. D., A. K. Knapp, and L. C. Hulbert. 1986. A ten-year record of aboveground biomass in a Kansas tallgrass prairie: effects of fire and topographic position. *American Journal of Botany* **73**:1509-1515.
- American Cyanamid. 1997. Plateau® herbicide for weed control and grass growth suppression on roadsides and other noncrop areas. American Cyanamid Company, Princeton, New Jersey, USA.
- Barnes, T. G., L. A. Madison, J. D. Sole, and M. J. Lacki. 1995. An assessment of habitat quality for northern bobwhite quail in tall fescue dominated fields. *Wildlife Society Bulletin* **23**:231-237.
- Bartlett, R. C. 1995. Saving the best of Texas. University of Texas Press. Austin, Texas, USA.
- Briggs, J. M. and A. K. Knapp. 1995. Interannual variability in primary production in tallgrass prairie: climate, soil moisture, topographic position, and fire as determinants of aboveground biomass. *American Journal of Botany* **82**:1024-1030.
- Celarié, R. P. and J. R. Harlan. 1959. The cytogeography of the *Bothriochloa ischaemum* complex. Graminae. I. Taxonomic and geographic distribution. *Botanical Journal of the Linnean Society* **55**:755-760.
- Cottam, G. and H. C. Wilson. 1966. Community dynamics on an artificial prairie. *Ecology* **47**:88-96
- Coyne, P. I. and J. A. Bradford. 1985. Some characteristics of four old world bluestems. *Journal of Range Management* **38**:27-33.
- Damude N. and K. Conrad Bender. 1999. Texas wildscapes: gardening for wildlife. Texas Parks and Wildlife Press. Austin, Texas, USA.
- Diamond, D. D., D. H. Riskind, and S. L. Orzell. 1987. A framework for plant community classification and conservation in Texas. *The Texas Journal of Science* **39**:203-221.

- Diamond, D. D. and F. E. Smeins. 1985. Composition, classification, and species response patterns of remnant tallgrass prairies in Texas. *The American Midland Naturalist* **113**:294-308.
- Diamond, D. D. and F. E. Smeins. 1993. The native plant communities of the Blackland Prairie. Pages 66-81 *in* R. Sharpless and J.C. Yelderemann, editors. *The Texas Blackland Prairie: land, history, and culture*. Baylor University Press. Waco, Texas, USA.
- Eck, H. V. and P. L. Sims. 1984. Grass species adaptability in the southern high plains – a 36-year assessment. *Journal of Range Management* **37**:211-217.
- Fowler, N. L. 1986. Microsite requirements for germination and establishment of three grass species. *The American Midland Naturalist* **115**:131-145.
- Gould, F. W. 1978. *Common Texas grasses: an illustrated guide*. Texas A & M University Press. College Station, Texas, USA.
- Hallmark, C. T. 1993. The nature and origin of the Blackland soils. Pages 41-47 *in* R. Sharpless and J.C. Yelderemann, editors. *The Texas Blackland Prairie: land, history, and culture*. Baylor University Press. Waco, Texas, USA.
- Harlan, J. R. 1963. Natural introgression between *Bothriochloa ishcaemum* and *B. intermedia* in West Pakistan. *Botanical Gazette* **124**:294-300.
- Harlan, J. R., R. P. Celarier, W. L. Richardson, M. Hoover Brooks, and K. L. Mehra. 1958. Studies on old world bluestems II. *Oklahoma Agricultural Extension Station Technical Bulletin No T-72*:1-23.
- Jastrow, J. D. 1987. Changes in soil aggregation associated with tallgrass prairie restoration. *American Journal of Botany* **74**:1656-1664.
- Jung, G. A., J. A. Shaffer, W. L. Stout, and M. T. Panciera. 1990. Warm-season grass diversity in yield, plant morphology, and nitrogen concentration and removal in northeastern USA. *Agronomy Journal* **82**:21-26.
- Kindscher, K. and L. L. Tieszen. 1995. Floristic and soil organic matter changes after five and thirty-five years of native tallgrass prairie restoration. *Restoration Ecology* **6**:181-196.
- Lemon, P. C. 1975. Prairie ecosystems are essential for environmental monitoring. Pages 343-348 *in* M.K. Wali, editor. *Prairie: a multiple view*. The University of North Dakota Press. Grand Forks, North Dakota, USA.

- McKenna, J. R., D. D. Wolf, and M. Lentner. 1991. No-till warm-season grass establishment as affected by atrazine and carbofuran. *Agronomy Journal* **83**:311-316.
- Meide, C. 1988. Aldo Leopold. University of Wisconsin Press. Madison, Wisconsin, USA.
- Mlot, C. 1990. Restoring the Prairie. *BioScience* **40**:804-809.
- Montgomery, J. A. 1993. The nature and origin of the Blackland Prairies of Texas. Pages 24-40 *in* R. Sharpless and J.C. Yeldermaun, editors. *The Texas Blackland Prairie: land, history, and culture*. Baylor University Press. Waco, Texas, USA.
- Morgan, J. P. 1997. Plowing and seeding. Pages 193-214 *in* S. Packard and C. F. Mutel, editors. *The tallgrass prairie restoration handbook for prairies, savannas, and woodlands*. Island Press. Washington D.C., Covelo, California, USA.
- Potvin, M. A. 1993. Establishment of native grass seedlings along a topographic/moisture gradient in the Nebraska Sandhills. *The American Midland Naturalist* **130**:248-261.
- Reis, R. E. and L. Hofmann. 1996. Perennial grass establishment in relationship to seeding dates in the northern great plains. *Journal of Range Management* **49**:504-508.
- Riskind, D. H. and O. B. Collins. 1975. Prairie management and restoration in the state parks of Texas. Pages 369-373 *in* M.K. Wali, editor. *Prairie: a multiple view*. University of North Dakota Press. Grand Forks, North Dakota, USA.
- Rosiere, R. E. Range types of North America.  
<http://www.tarleton.edu/~range/Grasslands/Introduced%20Forages/introducedforages.htm>. Accessed 20 October, 2002.
- Rubio, H. O., M. K. Wood, M. Cardenas, and B. A. Buchanan. 1990. Seedling emergence and root elongation of four grass species and evaporation from bare soil as affected by polyacrylamide. *Journal of Arid Environments* **18**:33-41.
- Sampson, F. and F. Knopf. 1996. *Prairie conservation: preserving North America's most endangered ecosystems*. Island Press. Washington D.C., USA.
- Sperry, T. M. 1994. The Curtis Prairie restoration: using the single-species planning method. *Natural Areas Journal* **14**:124-127.

- Stone, L. and A. Davis. Want to plant a prairie? Seed bed preparation: the Johnsongrass wars, or, bedding down with the enemy.  
[http://www.texasprairie.org/resource\\_howtoremove.htm](http://www.texasprairie.org/resource_howtoremove.htm). Accessed 20 October, 2002.
- Washburn, B. E., T. G. Barnes, and J. D. Sole. 1999. No-till establishment of native warm-season grasses in tall fescue fields. *Ecological Restoration* **17**:144-149.
- Washburn, B. E. and T. G. Barnes. 2000. Native warm-season grass and forb tolerance to imazapic and 2, 4-D. *Native Plant Journal* **1**:61-68
- Wilson, S. D. and A. K. Gerry. 1995. Strategies for mixed-grass prairie restoration: herbicide, tilling, and nitrogen manipulation. *Restoration Ecology* **3**:290-298.
- Zar, J. H. 1984. *Biostatistical analysis* 2<sup>nd</sup> edition. Prentice-Hall, Inc. Engelwood Cliffs, New Jersey, USA

## VITA

Jennifer Mittelhauser was born on 22 January, 1971 in Lubbock, Texas. She lived in Texas, Louisiana, and Missouri, as a child and moved back to Lubbock in 1987, where she graduated from Monterey High School in 1989. Jennifer attended Texas Tech University, Austin Community College, and San Antonio College before settling into a serious academic career at Southwest Texas State University in 1996. She earned her B.S. in Botany with a minor in Biochemistry before moving on to graduate studies in plant ecology at the university. While at SWT Jennifer served as Tri-Beta Biological Honor Society president, worked in the herbarium, taught six different labs, and assisted with the SWT wetland restoration project. She endeavors to attend the University of Kentucky in Lexington, Kentucky, in order to receive a Ph.D. while working on a coastal prairie restoration project at the Welder Wildlife Refuge in Sinton, Texas. She is currently living in San Marcos with her roommate and best friend, Diana (and cat, Jimmie), as well as her dog Penny, her cats Linus and Ranger, her salamander Amby, and a slough of Madagascar hissing cockroaches.

