BIOLOGY, ECOLOGY AND MANAGEMENT OF NATALGRASS (*Melinis repens)*

By

COURTNEY ANN STOKES

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2010

To my family and friends

ACKNOWLEDGMENTS

I would like to thank my supervisory committee chair, Dr. Greg MacDonald, for allowing me this opportunity to further my education. Dr. MacDonald provided invaluable guidance as I worked toward the completion of my degree program. In addition to guiding my research, he offered me the chance to become involved in teaching, extension and international development work.

I would also like to thank my supervisory committee members, Dr. Ken Langeland, Dr. Carrie Reinhardt Adams and Dr. Debbie Miller, for their advice. Dr. Jason Ferrell and Dr. William Haller also provided me with a great deal of guidance throughout the course of my study. In addition, I thank Bob Querns for his help in the laboratory and the students in Weed Science for their assistance. Without the help of a number of my fellow students, it would have been a great deal more difficult to conduct my research.

I thank Danon Moxley, Tim King and the others at the Tenoroc Fish Management Area for providing me with a research site. Likewise, I thank Mike Green and the staff at Mitigation Resources, Inc. for providing me with a site at the Lake Louisa Mitigation Bank. The Florida Fish and Wildlife Conservation Commission and the UF/IFAS Center for Aquatic and Invasive Plants provided funding, which I greatly appreciate.

Finally, I thank my family and friends for their advice, pep talks and willingness to listen when I needed it most. Your encouragement helped me a great deal. I am grateful to each and every one of you for your love and support.

TABLE OF CONTENTS

page

LIST OF TABLES

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science

BIOLOGY, ECOLOGY AND MANAGEMENT OF NATALGRASS (*Melinis repens)*

By

Courtney Ann Stokes

December 2010

Chair: Gregory E. MacDonald
Major: Agronomy

Natalgrass (*Melinis repens* (Willd.) Zizka) is a species native to Africa. Introduced to the U.S. in the 1800s, natalgrass was grown as a hay crop in central Florida in the early 1900s. Although no longer cultivated, natalgrass is still common throughout much of the state. As the restoration of native plant communities becomes increasingly important, land managers are struggling to control this species. To develop an effective management plan, more information is needed about seed biology and ecology as well as the chemical management of natalgrass.

Natalgrass seeds were exposed to various light, temperature, pH and osmotic potential treatments to better characterize the conditions in which these seeds germinate. Natalgrass does not require light for germination. Maximum germination occurs at 20 C and greater and at pH levels ranging from 6 to 8. Germination did not occur at water potentials less than -0.2 MPa. Natalgrass seeds were buried at different depths to determine maximum depth of emergence. Natalgrass seeds emerged from a depth of 5 cm, the greatest depth tested in the study. Preliminary tests show that natalgrass likely requires an afterripening period after seed shed to reach maximum potential for germination.

Natalgrass seed longevity was studied under field conditions. Seed burial tubes were constructed, buried and exhumed after periods ranging from 0 to 15 mo. An initial decline in germination was observed after 3 mo, with no further decline. These results indicate the onset of dormancy in natalgrass seeds after burial. This finding will be useful to land managers who plan to utilize tillage for natalgrass control, a practice that buries seeds. Seed longevity was also studied on the ground surface, where dense layers of seeds form in infested areas. Exclusion frames were placed over seed deposits to prevent further seed rain and germination under the frames was monitored for 12 mo. After 1 mo, high levels of germination occurred, but levels declined to 0 seedlings/m^2 within several months. This finding indicates that surface seed deposits are quickly depleted if land managers can prevent further seed production. Natalgrass seeds were exposed to wind at varying speeds and the distance traveled was measured. Seeds traveled less than 2 m at the highest wind speed, 32 km/h.

A number of herbicides were tested in the greenhouse and in the field to determine potential for natalgrass control pre- and postemergence. Metsulfuron and fluazifop offered little or no control. Glyphosate provided excellent control, but the lack of residual activity resulted in immediate reinfestation. Pendimethalin and metolachlor offered good control preemergence, but were detrimental to native species. Hexazinone and sulfometuron provided good control pre- and postemergence, but were also detrimental to native species. Imazamox, imazapyr and imazapic offered less control but stunted growth and delayed flowering. These herbicides were also less harmful to native species. Many native plants are tolerant to imazapic and gained a competitive advantage when this herbicide was applied.

CHAPTER 1
INTRODUCTION

Natalgrass (*Melinis repens* (Willd.) Zizka) is a species native to Africa. This species was first described as *Saccharum repens* by Willdenow in Ghana in 1797 and in the last 100 years has also been recognized by the names *Tricholaena rosea* Nees, *Tricholaena repens* Nees, *Rhynchelytrum roseum* (Nees) Stapf & Hubb. and *Rhynchelytrum repens* (Willd.) C.E. Hubb. (Wunderlin and Hansen 2009).

Natalgrass is widespread in many tropical and subtropical regions of the world, including much of Africa, southeast Asia, Central and South America and parts of the United States (Haselwood and Motter 1966; Kleinschmidt and Johnson 1977; Häfliger and Scholz 1980). In the U.S., specimens have been collected from Florida, Georgia, Louisiana, Texas, New Mexico, Arizona, California, North Carolina, Maryland and Hawaii (USDA 2010). In Florida, vouchered specimens have been collected from 50 of 67 counties (Wunderlin and Hansen 2009; FLMNH 2010).

It is unknown when natalgrass was introduced to the U.S., but it was cultivated as an ornamental as early as 1866 (Tracy 1916). Tracy (1916) describes several examples of natalgrass spread from introductions in Florida and notes that this species was tested as a forage grass in the Department of Agriculture trial gardens as early as 1878. Between 1884 and 1894, seed sources of natalgrass grown for forage included Brazil, South Africa, Australia, India, Hawaii and Florida. In 1892, the Florida Agricultural Experiment Station released natalgrass as its first forage grass cultivar (Mislevy and Quesenberry 1999).

The U.S. Department of Agriculture (USDA) reported over 30,000 acres of natalgrass cultivated for hay in central Florida in 1915 (Tracy 1916). Scott (1913) also

reported that natalgrass was “grown abundantly” in central Florida. At that time, natalgrass was commonly grown as a warm-season crop in rotation with various winter crops. Natalgrass was also commonly cultivated as a hay crop in the row middles of citrus groves in Florida (Tracy 1916).

In addition to discussing the spread of natalgrass from points of introduction in the state of Florida, Tracy (1916) also notes the value of natalgrass as a smother crop: “When planted on a favorable soil Natal grass makes such a vigorous growth as to choke out most other grasses and weeds.” As an example, Tracy discusses the lack of sand spurs (*Cenchrus* spp.), a common pest in citrus groves, in areas where natalgrass was seeded. Finally, Tracy notes that if a field of natalgrass is established, it will continue to produce a crop for many years, particularly if cultivated occasionally.

Although natalgrass has not been cultivated in Florida in recent memory, this species is still widespread throughout the state (Wunderlin and Hansen 2009). The same qualities which made natalgrass a good forage crop in the early 1900s have also caused natalgrass to become a problematic weed. The Florida Exotic Pest Plant Council (FLEPPC) now lists natalgrass as a Category I invasive species in the state, indicating that research has shown that this species is considered to have caused significant ecological harm (FLEPPC 2009).

Biology

Natalgrass is alternately described as an annual, perennial or short-lived perennial species (Small 1933; Haselwood and Motter 1966; Kleinschmidt and Johnson 1977; Häfliger and Scholz 1980). In Florida, this species will perenniate if freezing temperatures do not occur but acts as an annual if freezing temperatures do occur (C. A. Stokes, unpublished data). In its native range, temperatures remain warm

throughout the year but periodic dry seasons occur (Klages 1947). In addition, heavy grazing pressure occurs seasonally in these areas, contributing to an annual growth habit.

Natalgrass grows erect to about 1 m in height and possesses slender culms that are often geniculate and root at the nodes. This species has fibrous roots and does not produce rhizomes. The leaf blades are flat and linear, usually reaching up to 20 cm in length and ranging from 3 to 10 mm wide (Hitchcock 1950; Häfliger and Scholz 1980). The ligule is a rosy fringe of hairs 1 to 2 mm in length. Pubescence may occur on the leaf sheaths and both surfaces of the leaf blades. The inflorescence of natalgrass is a panicle 10 to 15 cm long and 5 to 10 cm wide (Häfliger and Scholz 1980). The spikelets are 3 to 6 mm long and approximately 2 mm wide. The spikelets are pedicelled and covered with dense silky hairs that are initially rosy-pink in color but fade to white with age. Natalgrass plants sometimes accumulate anthocyanins in response to stress (Small 1933; Hitchcock 1950; Häfliger and Scholz 1980).

Natalgrass is a prolific seed producer and flowers nearly year-round in Florida if it is not killed by freezing temperatures. In areas infested with natalgrass, dense seed deposits up to 5 cm deep have been observed on the ground (C. A. Stokes, unpublished data). Tracy (1916) suggests that 45.5 kg (100 lb) of seeds per 0.4 ha (1 acre) could be collected from the initial growth of a stand of natalgrass.

Natalgrass is most commonly found growing in dry, sandy soils and does not tolerate wet conditions (Hitchcock 1950; Haselwood and Motter 1966). This species is most commonly found growing at low elevations but has also been observed at an elevation of approximately 1500 m (C. A. Stokes, unpublished data).

Management

There is little available information regarding natalgrass management. Tracy (1916) states that plants are controlled by tillage. However, it is noted that this act buries seeds and new growth will occur if another tillage operation uncovers the seeds. This was considered a desirable trait when natalgrass was used as a forage but suggests that natalgrass may be difficult to remove from a site when considered an undesired species.

Hernández-Quiroz (2010) found that natalgrass seedling emergence in Chihuahua, Mexico grasslands was unaffected by prescribed fire. Fire is often used as a management tool in Florida's many fire-adapted ecosystems to promote desired native species (Provencher et al. 2001). Based on the findings of Hernández-Quiroz, it does not appear that this management strategy is an effective choice for the control of natalgrass.

Natalgrass can be controlled by spot treatments of glyphosate or by imazapyr (MacDonald et al. 2008). Imazapic is also reported to offer some control of natalgrass (Kluson et. al 2000; Richardson et al. 2003). However, many of the other herbicides commonly used in natural areas have not been tested for natalgrass control.

Research Objectives

Some information is available regarding the cultivation of natalgrass as a forage, but little information is available regarding seed biology, ecology or management. The objectives of this research are therefore to better characterize the biology, ecology and management of natalgrass with the goal of contributing to a more comprehensive management plan for the control of this species.

CHAPTER 2
SEED GERMINATION CHARACTERISTICS OF NATALGRASS (*MELINIS REPENS)*

Introduction

Natalgrass (*Melinis repens* (Willd.) Zizka, formerly *Rhynchelytrum repens* (Willd.) C.E. Hubb.) is a grass native to Africa that has become a problematic weed in many tropical and subtropical regions around the world, including Florida, Mexico, the Caribbean, Central America, Brazil and many Pacific islands (Haselwood and Motter 1966; Kleinschmidt and Johnson 1977; Häfliger and Scholz 1980). In Florida, natalgrass can be found in many areas but is particularly widespread along the central Florida ridge in citrus groves and reclaimed phosphate mining areas (Kluson et al. 2000). The Florida Exotic Pest Plant Council (FLEPPC) considers natalgrass a Category I invasive in Florida, indicating that this species is considered to have caused significant ecological harm (FLEPPC 2009). For instance, research shows that natalgrass invades undisturbed ecosystems such as pine rocklands in Florida (Possley and Maschinski 2006).

Natalgrass is sometimes grown as an ornamental and was grown for this purpose in the United States as early as 1866 (Tracy 1916). Tracy (1916) also states that natalgrass was grown as a forage plant in the U.S. Department of Agriculture (USDA) trial gardens in 1878. Between 1891 and 1894, the USDA received natalgrass seeds from Natal, South Africa; Queensland, Australia; India and Hawaii. In 1892, natalgrass was the first forage grass cultivar released by the Florida Agricultural Experiment Station (Mislevy and Quesenberry 1999). Over 30,000 acres of cultivated natalgrass were reported in central Florida in 1915. Natalgrass was often grown between rows of

citrus trees, possibly explaining the species' current prevalence in citrus groves (Tracy 1916).

Natalgrass is an annual species that sometimes perenniates in warmer climates. Although its native range in south and east Africa has a warm climate, these regions experience dry conditions and heavy grazing pressure from migrating animals during certain times of the year, resulting in plant die-back (Klages 1949). In Florida, natalgrass will sometimes perenniate if temperatures do not reach freezing (C. A. Stokes, unpublished data).

Natalgrass forms tussocks that grow up to 1 m in height. While this species does not produce rhizomes, it is capable of rooting at the nodes and sometimes develops a sprawling appearance (Haselwood and Motter 1966). Natalgrass inflorescences are panicles up to 20 cm long; initially rosy pink, the inflorescences fade to silver with age. Natalgrass produces pedicelled spikelets that are covered with dense, silky hairs, giving the plant a feathery or fluffy appearance (Häfliger 1980).

Natalgrass is a prolific seed producer, and these seeds are windborne. Tracy (1916) suggests that 45.4 kg (100 lb) of seeds per 0.4 ha (1 acre) could be expected from the initial growth of a natalgrass crop. In areas where severe natalgrass infestations occur, dense layers of seeds up to 5 cm thick have been observed on the ground (C. A. Stokes, unpublished data). Natalgrass seeds appear to be key to the rapid spread of this species and extensive seed deposits are likely a reason for the persistance of natalgrass in a given area. Little research has been conducted concerning the biology of natalgrass and no published research is available that addresses seed biology. If effective management plans for this species are to be

developed, there is a need for a better understanding of the environmental factors that affect natalgrass seed germination. Therefore, the objectives of this research were to determine whether seed dormancy was present and to examine the effects of light, temperature, pH, water stress and depth of burial on natalgrass seed germination.

Materials and Methods

Seed Source

Natalgrass seeds were collected in November 2007 in Polk County, FL from both the duff layer on the ground and from the seedheads of mature plants. Duff layer seeds were likely deposited over the previous summer and fall seasons. Additional seeds were collected from the Lake Louisa Mitigation Bank in Lake County, FL in November 2008 from both the duff layer and the seedheads of mature plants and again in December 2009 from only the duff layer. Both groups of seeds collected in 2008 were used for preliminary germination tests, while seeds from the duff layer were used for the first run of all further experiments. Duff layer seeds collected in 2009 were used when each experiment was repeated. Unless otherwise stated, seeds were stored in a paper bag at room temperature.

General Germination Test Protocol

Unless otherwise stated, natalgrass seed germination was tested by placing thirty seeds with intact husks evenly in a 9 cm Petri dish[1] containing 1 piece of filter paper[2]. The filter paper was moistened with 4 mL of deionized water (pH = 6) or test solution. Each Petri dish was sealed with parafilm and placed in a growth chamber at 30 ± 1 C under constant light (200 µmol/m^2/s^1 photosynthetic flux density [PPFD]). Germination

[1] Fisherbrand Petri dishes, Fisher Scientific, 2000 Park Lane Drive, Pittsburgh, PA 15275.

[2] Fisherbrand P8 filter paper, Fisher Scientific, 2000 Park Lane Drive, Pittsburgh, PA 15275.

was visually determined after 14 d. Seeds were considered germinated when the radicle emerged from the seed coat. Any ungerminated seeds were tested for viability according to procedures described in the Handbook for Tetrazolium Testing (Moore 1985). In this procedure, seeds were removed from the husk and seed coat and placed in a 0.25% tetrazolium solution for 24 h in the dark. Seeds were examined under a dissecting microscope and were counted as viable if the entire embryo was stained red or pink. Percentage of seed germination was calculated by dividing the number of germinated seeds by the number of total viable seeds in each Petri dish, then multiplying by 100. Each Petri dish was considered a replication, each treatment was replicated 4 times and each experiment was conducted twice.

Preliminary Germination Test

Preliminary germination tests (data not shown) indicated that seeds collected from the duff layer had a much higher germination rate than seeds collected directly from seedheads, suggesting that natalgrass seeds require an afterripening period after the seeds are shed. To test this hypothesis, seeds were collected with a sweep net from mature seedheads at the Lake Louisa Mitigation Bank. A sample of these seeds was tested for germination immediately, and the remaining seeds were divided into 2 groups. The first group was stored in a paper bag at 4 C and the second group was stored in a paper bag at 25 C. Seeds from each group were tested for germination at intervals of 2, 4, 6, 8, 10 and 15 weeks. For dormancy tests, percent germination was calculated by dividing the number of germinated seeds by the total number of seeds tested. All environmental conditions were the same as described in the general germination protocol.

Light

To determine the effect of light on natalgrass seed germination, dry seeds were placed in Petri dishes containing water in a dark room with only green light present to ensure that all hydration occurred in the absence of light. The dishes were immediately wrapped in 2 layers of aluminum foil to prevent light penetration. Seed germination was then compared to control seeds exposed to continous light. All other environmental conditions were the same as described in the general germination protocol.

Temperature

The effects of temperature on natalgrass seed germination were determined by placing seeds in Petri dishes. Dishes were incubated at constant temperatures of 10, 20, 25, 30 or 35 C. All other environmental conditions were the same as described in the general germination protocol.

pH

To evaluate the effects of varying pH levels on natalgrass seed germination, seeds were placed in Petri dishes containing buffer solutions at pH values of 4, 6, 8 and 10. Seeds serving as the control were placed in Petri dishes containing deionized water. Buffer solutions were prepared at 25 µM and included potassium hydrogen phthalate, 2-(4-morpholino)ethanesulfonic acid (MES), N-2(2-hydroxyethyl)-piperazine-N´-2-ethanesulfonic acid (HEPES) and Tris(hydroxymethyl)-aminomethane (TRIS) for pH levels of 4, 6, 8 and 10, respectively. Buffer solutions were titrated with HCl or NaOH to achieve the desired pH. All other environmental conditions were the same as described in the general germination protocol.

Water Stress

To determine the effects of water stress on natalgrass seed germination, seeds were placed in Petri dishes with aqueous solutions of polyethylene glycol (PEG 600) with osmotic potentials of -0.2, -0.4, -0.6, -0.8 and -1.0 MPa. Seeds serving as the control were placed in Petri dishes with deionized water. A vapor pressure osmometer[3] calibrated with aqueous solutions of sodium chloride was used to confirm water potential. All other environmental conditions were the same as described in the general germination protocol.

Depth of Burial

To determine the effects of burial depth on natalgrass seedling emergence, seeds were planted in a wooden box containing field soil (Apopka sand: loamy, siliceous, subactive, hyperthermic Grossarenic Paleudults) collected from the Lake Louisa Mitigation Bank in Clermont, FL. Treatments were separated by wooden dividers. Ten seeds each were planted at depths of 0, 0.25, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0 or 5.0 cm. The box was placed in the greenhouse and received irrigation as needed to maintain adequate soil moisture. Seedlings were counted 21 d after planting. After the number of seedlings was counted, each seedling was exhumed to confirm that the soil did not shift and that the seed husk was present at the proper depth.

Statistical Analysis

Unless otherwise stated, all experiments were conducted twice using a completely randomized design with 4 replications of each treatment. Data were subjected to analysis of variance. There was no significant ($P > 0.05$) trial-by-treatment interaction

[3] Wescor vapor pressure osmometer, Model 5500, Wescor, Inc., 459 S. Main Street, Logan, UT 84321.

for each experiment; data were therefore pooled for analysis. Means were separated using 95% confidence intervals. Germination is reported as percent germination ± the 95% confidence interval. Regression analysis was used to determine the effects of temperature and depth of burial.

Results and Discussion

Preliminary Germination Test

Seed collected from the duff layer had an initial germination rate of 49% ± 3.8%, while seed collected directly from seedheads had a germination rate of 6% ± 5.1%. There was no difference ($P > 0.05$) between the germination rates of seed stored at 4 C and seed stored at 25 C, so data were pooled for analysis. Germination increased over time to 25% ± 4.6% after 15 weeks of storage (Figure 2-1). These results indicate that natalgrass may require an afterripening period after seed shed to reach maximum potential for germination. Afterripening is defined as the loss of a dormant state over a period of time through exposure of seeds to a set of environmental conditions after maturation and separation from the parent plant (Simpson 1990). Afterripening has been observed in a number of grass species and is well-documented in wild oat (*Avena fatua* L.) and red rice (*Oryza punctata* L.) (Quail and Carter 1969; Leopold et al. 1988; Foley 1994). Afterripening can be influenced by environmental conditions such as moisture status and temperature; the conditions that best facilitate afterripening vary with species (Foley 2001). While the results from this experiment suggest that afterripening does occur in natalgrass, further research is required to better characterize the afterripening mechanism. This could provide useful information to land managers attempting to control natalgrass infestations. Because dense seed deposits can form on the ground surface in areas where infestations occur, management should not end

when all plants have been eliminated. A better understanding of natalgrass afterripening could result in a prediction of how long germination should be expected from duff layer deposits after seed rain has ended.

Light

No difference ($P > 0.05$) was observed between the rate of natalgrass seed germination in the light and in the dark. The rate of germination was 90% ± 5.8% in light and 74% ± 17.3% in dark. These results suggest that light is not a requirement for natalgrass seed germination. Based on these results, experiments to determine the effects of varying light quality (phytochrome-based studies) were not performed.

Temperature

Natalgrass seed germination did not occur at a constant temperature of 10 C, and only 4% ± 5.4% germination occurred at 15 C (Figure 2-2). However, germination increased as temperature increased. The highest level of germination observed was 89% ± 10.2% at 30 C, although there was no significant difference among germination rates at 20 C or higher. This outcome was not surprising, because many tropical species have optimum germination rates above 20 C (Teuton et al. 2004; Wilder 2009). These results could explain why natalgrass has not become invasive in U.S. states other than Florida and Hawaii and why natalgrass has not spread to areas outside the southern U.S.

pH

Natalgrass seed did not germinate at pH 4 or 10. The rate of natalgrass seed germination at pH 6 was 96% ± 6.3% and at pH 8 was 91% ± 5.3%. Germination rates at pH 6 and 8 were not significantly different ($P > 0.05$). These results indicate that natalgrass seeds do not successfully germinate at acidic or basic pH levels. Natalgrass

is most often a problem in disturbed areas such as reclaimed phosphate mining areas and newly cultivated soils; however, populations appear to decline over time. This decline could possibly be a result of soils growing more acidic as they revert back to natural pH levels closer to 5 (Adjei and Rechcigl 2004).

Water Stress

Natalgrass seed germination was greatly affected by water stress. Germination was 85% ± 15.4% in deionized water, while seeds placed in the -0.2 MPa test solution had a germination rate of 98% ± 23.4%. At osmotic potentials less than -0.2 MPa no germination was observed. These results indicate that natalgrass seed germination is dependent on adequate soil moisture. Bradford (1990) describes seed germination as the process of initiating growth of a previously quiescent or dormant embryo, a process that usually begins with the imbibition of water. The rate of water imbibition and seed germination is generally very sensitive to changes in soil water potential. Evans and Etherington (1990) found that some species adapted to dry or well-drained habitats germinate well even in soil with osmotic potentials as low as -1.5 MPa. Other research has also shown that some species adapted to dry conditions, such as yankeeweed (*Eupatorium compositifolium* Walt.), germinate at low osmotic potentials (MacDonald et al. 1992). However, Evans and Etherington (1990) found that a number of species typically found in dry or well-drained areas did not germinate in dry soils. They suggested that this may be a response that confers an ecological advantage on a species in dry conditions. If seeds of these species germinate in very low water potentials, seedling establishment failures may occur if dry conditions continue. However, if the seeds do not germinate until higher levels of moisture are present in the soil, there is a greater chance that seedlings will survive. This response may allow

natalgrass to successfully germinate and reach maturity in the dry, sandy areas in which it is typically found. Because natalgrass germination is so dependent on available soil moisture, it may also be possible to predict, based on current rainfall patterns in an area, when large numbers of seeds will germinate in the field.

Depth of Burial

There was no significant difference among treatments; emergence was fairly uniform across all the depths tested. These results indicate that natalgrass can emerge from depths of up to 5 cm. Further testing is required to determine the depth at which natalgrass emergence is impeded.

Conclusions

Natalgrass seeds do not require light for germination. Although germination occurs at 15 C, high levels of germination occur at temperatures of 20 C and greater. Natalgrass germinates within a fairly neutral pH range of 6 to 8. Germination also appears to be dependent on soil moisture. Natalgrass seedlings can emerge from depths of at least 5 cm. Finally, natalgrass appears to require an afterripening period after seed shed to reach maximum germination potential. These results indicate that land managers should expect most natalgrass germination to occur as soil temperatures reach 20 C and above and rainfall becomes more consistent. A preemergence herbicide application at this time may inhibit seedling growth and effectively reduce natalgrass populations.

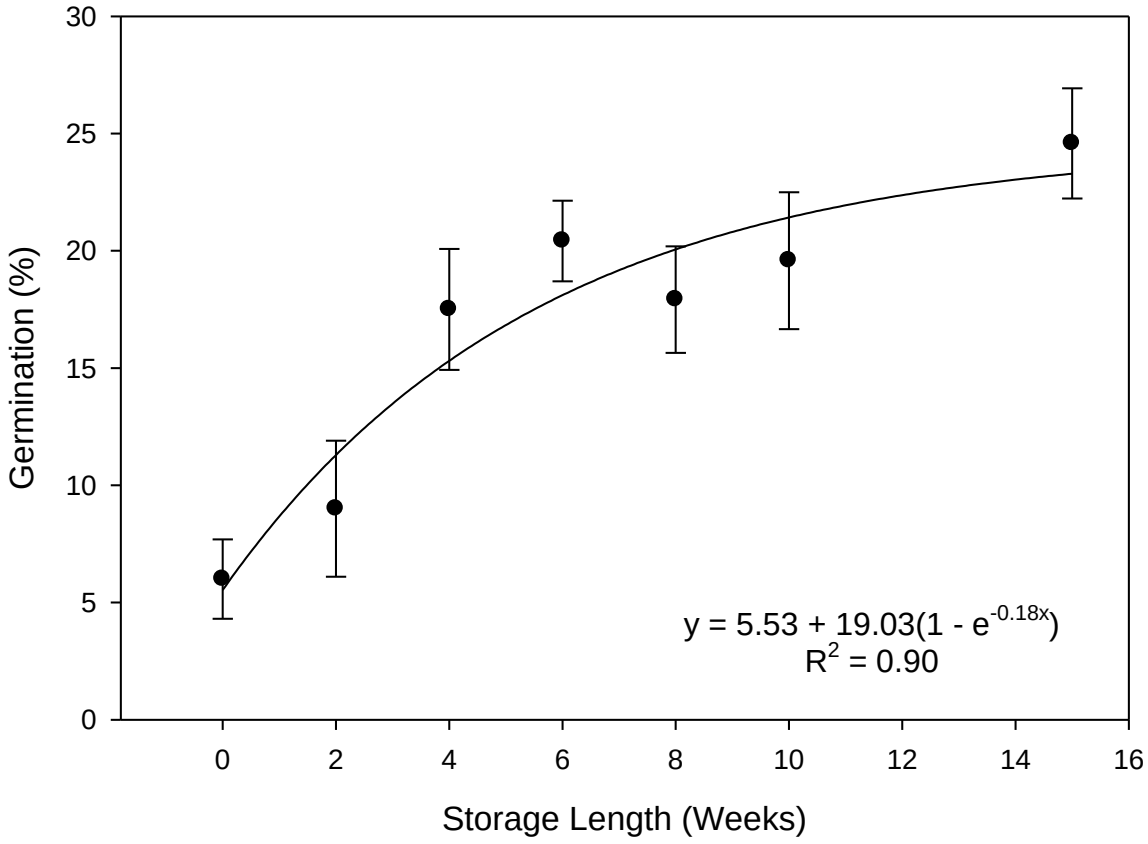

Figure 2-1. The effect of storage length on natalgrass germination. Values represent the mean of 8 replications with standard error.

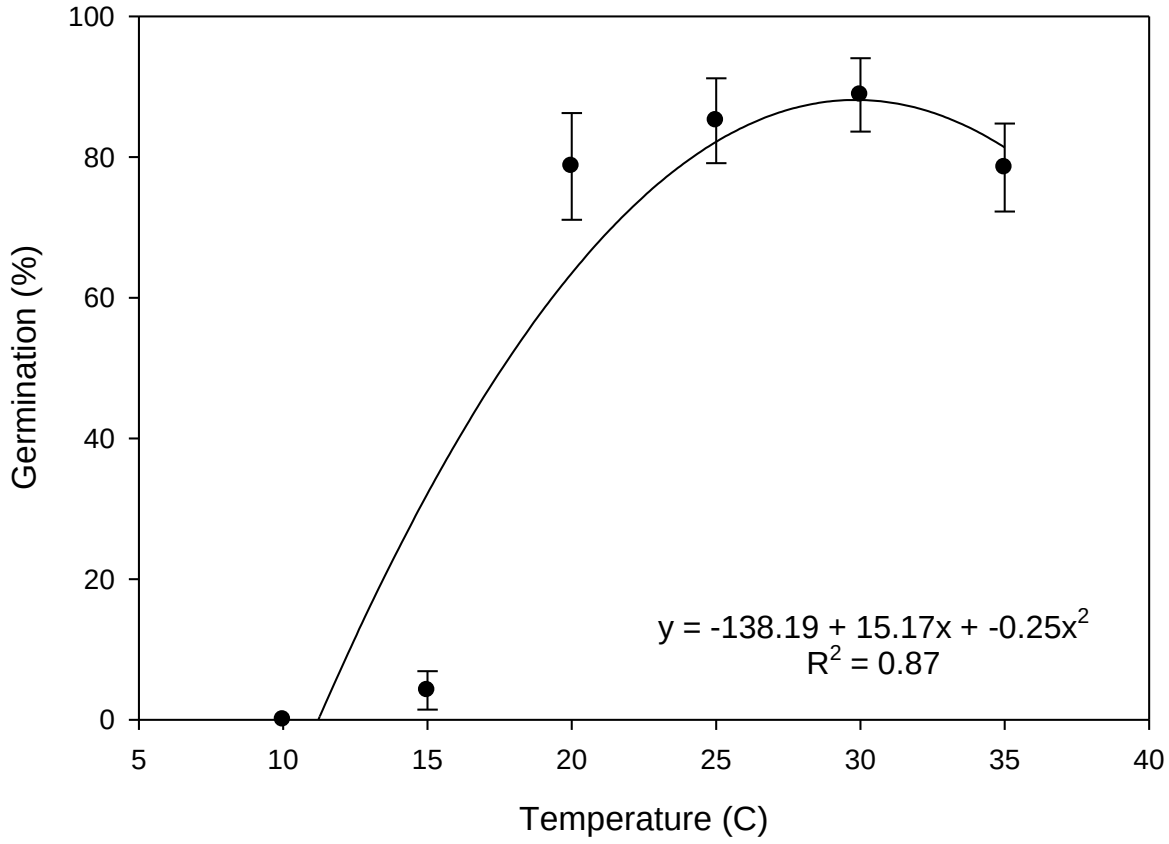

Figure 2-2. The effect of temperature on natalgrass germination. Values represent the mean of 8 replications with standard error.

CHAPTER 3

SEED ECOLOGY OF NATALGRASS (*MELINIS REPENS*)

Introduction

Natalgrass (*Melinis repens* (Willd.) Zizka) is a species native to the grasslands of south and east Africa. Natalgrass has become an increasing problem in many tropical and subtropical areas around the world, including Mexico, the Caribbean and numerous countries in Asia and Central and South America, along with Florida (Haselwood and Motter 1966; Kleinschmidt and Johnson 1977; Häfliger and Scholz 1980).

Natalgrass has been present in the U.S. since at least 1866. When natalgrass was observed growing well in Florida's sandy soils and spreading easily by seed, it was tested as a forage grass (Tracy 1916). Eventually, natalgrass was released as the Florida Agricultural Experiment Station's first forage grass cultivar in 1892 (Mislevy and Quesenberry 1999).

In Florida, natalgrass has been observed to quickly invade open, disturbed areas such as roadsides, citrus groves and phosphate mining areas (Kluson et al. 2000; Possley and Maschinski 2006). Natalgrass often becomes a problem after another invasive species such as cogongrass (*Imperata cylindrica* (L.) Beauv.) has been removed (G. E. MacDonald, personal communication). Natalgrass has also been shown to invade undisturbed ecosystems such as the pine rocklands of south Florida (Possley and Maschinski 2006).

Natalgrass produces large numbers of seeds which are dispersed readily by wind. Rapid dispersal of these seeds is presumed to be the method by which natalgrass quickly invades. A 37.6 ha (93 acre) site at the Lake Louisa Mitigation Bank in Lake County, FL offers a good example of natalgrass spread. According to the land

managers, the area was formerly bahiagrass (*Paspalum notatum* Flueggé). In preparation for native plant establishment, the bahiagrass was removed with glyphosate, resulting in nearly bare ground. Almost immediately, the land managers noticed natalgrass spreading from a small patch at the corner of the property. Within 6 mo, natalgrass had spread across the entire 37.6 ha (M. Green, personal communication). The spread occurred in the direction of prevailing winds; this conclusion was supported by the observation of older plants near the initial infestation, while younger plants were observed at a greater distance from this area.

Once a natalgrass infestation has occurred, dense duff layer seed deposits often form, particularly in the fall and early winter months. Little is known about how long these seeds persist on the soil surface. In addition, little is known about how long these seeds persist if buried. Natalgrass plants are easily controlled by mechanical cultivation, but this action buries seeds. More information is needed about natalgrass seed persistance under field conditions so that land managers can act in the most effective manner possible to control this species.

The objectives of this study were to determine the length of natalgrass seed persistence on the soil surface, to determine the length of natalgrass seed persistence when buried, and to better characterize the dispersal of natalgrass seeds by wind. This information will be important to land managers when developing a management plan for this species.

Materials and Methods

Seed Burial

Duff layer material, including large numbers of seeds, was collected from a single field site within the Lake Louisa Mitigation Bank in Lake County, FL in November 2008.

Field soil (Apopka sand: loamy, siliceous, subactive, hyperthermic Grossarenic Paleudults) was collected from the same site after the duff layer was completely removed. To determine if natalgrass seeds were present in the sample, the soil seed bank was assessed by placing trays of soil in the greenhouse and monitoring seedling emergence. The seed bank was determined to be negligible because of the complete lack of natalgrass seedlings and the low levels of seedling emergence for all other species (data not shown).

Material collected from the duff layer was comprised of seeds (approximately 50% of the total volume), soil (approximately 10% of the total volume) and other debris such as small twigs and stems (about 40% of the total volume). It proved to be difficult to separate the seeds from the other duff layer contents because of the fluffy hairs present on the husk, which clung to the other materials present. As a result, seeds for each replication of this study were not counted. Instead, duff layer material was mixed evenly and then divided by weight.

PVC pipe with a diameter of 4 in was cut into segments 30 cm in length and used to create seed burial tubes. Each 30 cm segment of pipe was cut in half lengthwise. Five 0.5 cm holes were drilled in each half, evenly spaced and running in a line lengthwise down the center of each half. Nylon mesh fabric was folded in half, forming a packet, and filled with a mixture of 10 g field soil and 1.2 g of the duff layer material. The 2 halves of the PVC pipe were filled with field soil and placed back together with the mesh packet centered between them. The 2 halves were secured together with duct tape[4]. Window screen[5] was placed over each end to prevent the field soil from

[4] All-Purpose Duct Tape, Shurtape Technologies, LLC, 1506 Highland Ave NE, Hickory, NC, 28601.

escaping the tube. The end product was a 4 in-diameter tube filled with field soil, with a mesh fabric packet containing both field soil and seeds suspended within the field soil in the center of the tube and stretching the 30 cm length of the tube (Figure 3-1). The holes drilled in the sides and the screen placed over the ends were present to allow the maximum moisture and gas exchange possible between the soil inside the tube and the outside environment. The contents of the tubes were kept dry at all times to prevent water imbibition and possible germination before the tubes were placed in the field.

One hundred tubes were buried in 10 groups of 10 tubes each within a 37.6 ha study area at the Lake Louisa Mitigation Bank in Lake County, FL in June 2009. The tubes were buried on end, with the top end level with the ground surface. Each location was marked with a flag and the GPS coordinates noted.

One tube from each group was exhumed at 0, 3, 6, 9, 12 and 15 mo after burial. The tubes were split in half lengthwise by removing the duct tape holding the halves together. The mesh packets were then opened without disturbing the contents. Each tube was then placed in the greenhouse and irrigated as needed to maintain adequate soil moisture. After 2 weeks, the number of natalgrass seedlings present was counted. The total number of seedlings was noted as well as the number of seedlings in each area of the tube corresponding to depths of 0 to 5, 5 to 10, 10 to 15, 15 to 20, 20 to 25 and 25 to 30 cm when the tubes were buried on end.

Seed Exclusion

Ten areas within the study site at the Lake Louisa Mitigation Bank were chosen based on 3 criteria: the presence of a duff layer natalgrass seed deposit, an area of at

[5] Fiberglass screen wire, PHIFER Inc., P.O. Box 1700, Tuscaloosa, AL, 35403.

least 1 m^2 and a lack of plants of any species growing within the area. In April 2009, each area was covered with a square wooden frame (1 m by 1 m) secured to the ground and covered with screen[6] to exclude any additional seeds from entering the plot (Figure 3-2). Hardware cloth[7] (3 squares/in) was placed over the screen to prevent damage from birds or other animals. The number of natalgrass seedlings growing in each plot was counted 1, 2, 3, 4, 5, 6, 8, 10 and 12 mo after the frames were put into place. After 6 mo, the soil and duff layer of half of the plots were disturbed to a depth of 3 cm. After each seedling count, a 1% solution of glyphosate was applied as needed to remove any plants growing in the plot.

Wind

Wind was generated using a seed blower and wind speed measured with a pocket wind meter[8]. Seeds were released into the airstream 46 cm from the floor and 50 cm from the air source. Air speeds included 4, 8, 16, 24 and 32 km/h. At each speed, 5 seeds were released; each seed was considered a replication. The study was repeated 4 times for a total of 5 trials.

Statistical Analysis

The seed burial study and seed exclusion study were conducted using a completely randomized design. These studies were each conducted once and included 10 replications. The wind study was conducted a total of 5 times and included 5 replications per treatment. Data were subjected to analysis of variance and means were separated using 95% confidence intervals.

[6] Fiberglass Screen Wire, PHIFER Inc., P.O. Box 1700, Tuscaloosa, AL, 35403.

[7] 3 Mesh Galvanized Hardware Cloth, TWP Inc., 2831 Tenth Street, Berkeley, CA, 94710.

[8] Kestrel 3000 Pocket Wind Meter, Nielsen-Kellerman, 21 Creek Circle, Boothwyn, PA 19061.

Results and Discussion

Seed Burial

There was no significant difference ($P > 0.05$) in the number of seedlings counted within the areas corresponding to different burial depths; therefore, only the total number of seedlings per burial tube is discussed. The control group (tubes buried for 0 mo) had a mean of 50 ± 8 seedlings per tube. There was no significant difference ($P > 0.05$) among the mean number of seedlings from tubes buried for 3, 6, 9, 12 and 15 mo; however, these values were significantly lower than the mean at 0 mo, indicating a decline in natalgrass germination after burial. The lowest mean number of seedlings observed was 13 ± 5 after 9 mo of burial. However, after the initial decline germination levels have remained relatively consistent, indicating possible dormancy.

There are a number of causes for increased dormancy during burial and decreased seed germination after burial. Several studies have shown that seeds can become light-sensitive after burial, even when germination of the same seeds was not previously light-dependent (Wesson and Wareing 1969, Mandoli and Briggs 1981). In addition, several studies have suggested that the increase in dormancy and decrease in overall germination observed after burial could be the result of toxic metabolites produced by anaerobic respiration occurring in hypoxic conditions (Holm 1972, Benvenuti and Macchia 1995). Finally, decreased seed germination can occur because of seed mortality. This mortality can be a result of predation, failed germination, aging or attack from pathogens (Baskin and Baskin 1998). Seed burial studies are often criticized for creating conditions that can result in accelerated seed mortality. Van Mourik et al. (2005) found that when high densities of seeds are buried in mesh bags during seed burial studies, attack from pathogenic fungi often causes an overestimation

of the rate of soil seed bank depletion. However, when lower densities of seeds were mixed with soil inside the mesh bags, mortality was significantly lower. Based on the findings of Van Mourik et al. (2005), the decision was made to mix field soil with natalgrass seed samples before burial to more closely mimic natural conditions. Because the study methods were designed in such a way as to limit artificial acceleration of seed mortality, decreased germination over the course of the study can more positively be attributed to an increase in dormancy.

Natalgrass plants are easily controlled by cultivation (Tracy 1916), but the effects of seed burial as a result of cultivation or other disturbance were unknown prior to this research study. The results from this study suggest that, if a subsequent cultivation or other disturbance brings natalgrass seeds back to the soil surface, these seeds have the potential to germinate at least 1 year after the initial burial. Land managers utilizing cultivation as a control method for natalgrass should expect germination to occur if they repeat tillage operations within this time period.

Seed Exclusion

The mean number of natalgrass seedlings per m^2 was 521 ± 354 after 1 mo of seed exclusion from the plots. This number decreased to 6 ± 7 seedlings after 2 mo and 0 after 4 mo of seed exclusion. No further germination was observed in any of the plots, even after disturbance. These results suggest that seeds deposited in the duff layer over the summer and fall months have largely concluded afterripening by April, when the study began. Afterripening is the loss of a dormant state over a period of time through exposure of seeds to a set of environmental conditions after maturation and separation from the parent plant (Simpson 1990). Afterripening commonly occurs in a number of grass species, and has been studied extensively in wild oat (*Avena fatua* L.)

and red rice (*Oryza punctata* L.) (Quail and Carter 1969; Leopold et al. 1988; Foley 1994).

With rainfall and warm temperatures during the month of April, most of the seeds present in the seed bank during this study germinated at once. These results are consistent with results from the seed biology studies that show that most natalgrass germination occurs at temperatures higher than 15 C and in conditions with adequate moisture available. These conditions existed at the study site in April 2009 (FAWN 2010). These results suggest that if land managers can prevent further seed deposition during the spring, active management of emerging seedlings for several months should result in a significant reduction of new natalgrass growth.

Wind

There was a large amount of variability in the distance traveled by natalgrass seeds at different wind speeds. At 4 km/h, the mean distance traveled by natalgrass seeds was 67 ± 33 cm. This distance was similar to that observed at 16 km/h (65 ± 26 cm). Both of these distances were significantly different from the 158 ± 40 cm the seeds traveled at 32 km/h. No other statistical differences were observed. Natalgrass seeds do not appear to travel great distances when exposed to wind in this manner. However, the methods used in this study may not be the most accurate method of characterizing wind dispersal of seeds. Further research utilizing alternate methods would be advisable.

Conclusions

Natalgrass seed does appear to enter a state of increased dormancy when buried. This is consistent with the observations of Tracy (1916), who instructed growers to plow under natalgrass fields in the winter and then cultivate again in the spring to induce new

growth. Land managers should be mindful of this potential for new growth if they utilize tillage in natural areas to control natalgrass or other species when natalgrass is present.

Although natalgrass can form dense seed deposits in infested areas, the seed bank appears to quickly become depleted when conditions are favorable for germination and further seed rain is prevented. If a land manager can prevent seed production through mechanical or chemical means while effectively controlling germinating seedlings for several months, natalgrass can be greatly reduced.

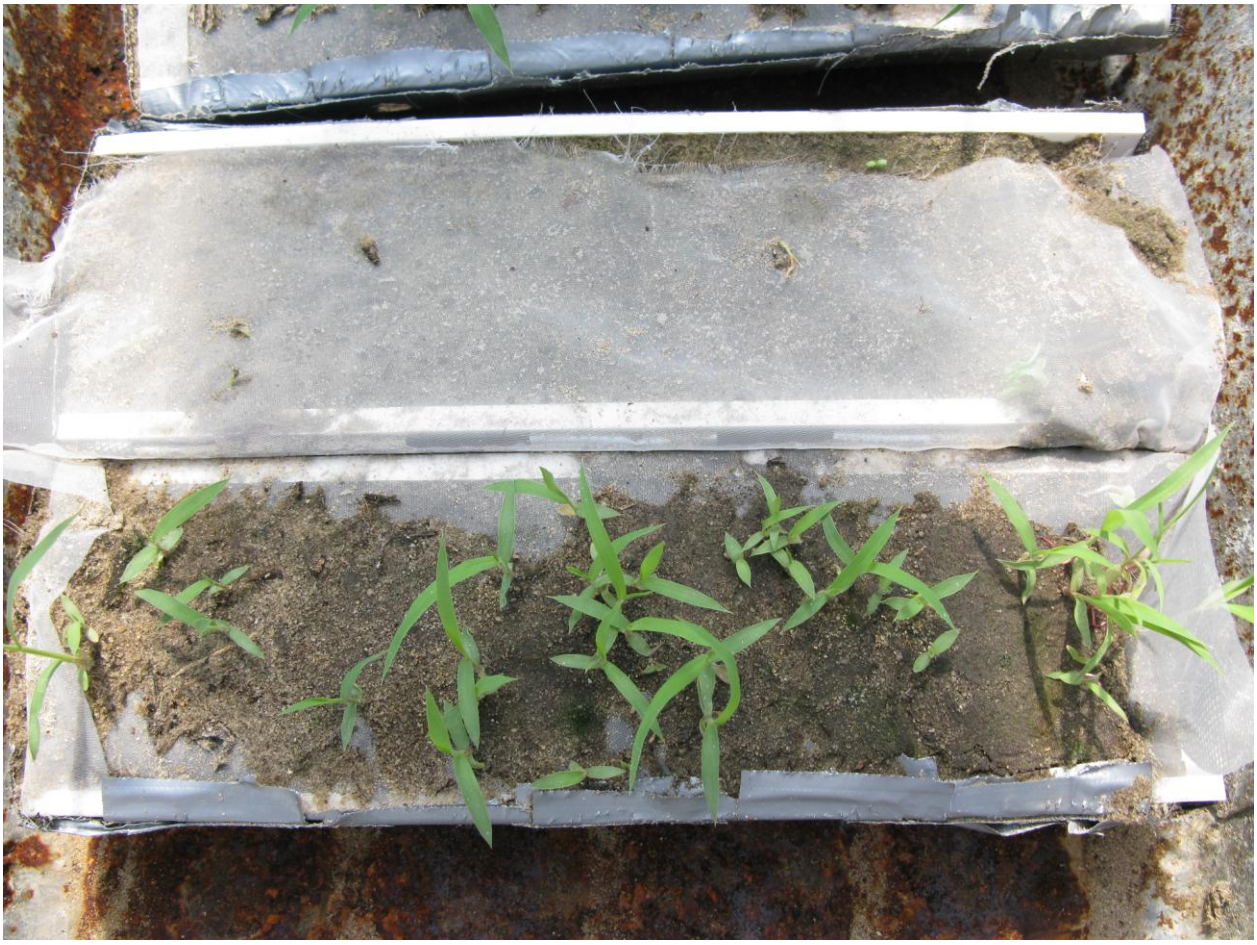

Figure 3-1. Seed burial tube opened and placed in the greenhouse.

Figure 3-2. Seed exclusion frame at the Lake Louisa Mitigation Bank.

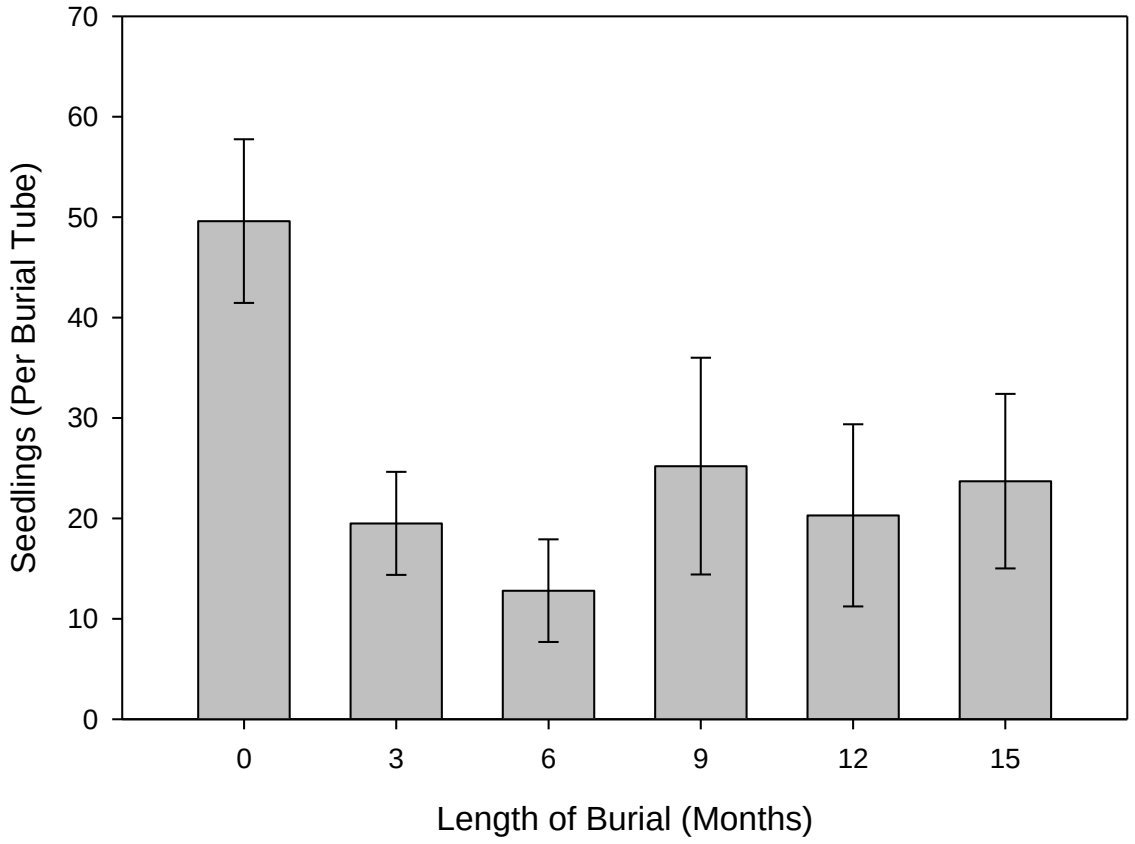

Figure 3-3. Effects of burial on natalgrass seedling emergence. Values reflect the mean of ten replications with 95% confidence intervals.

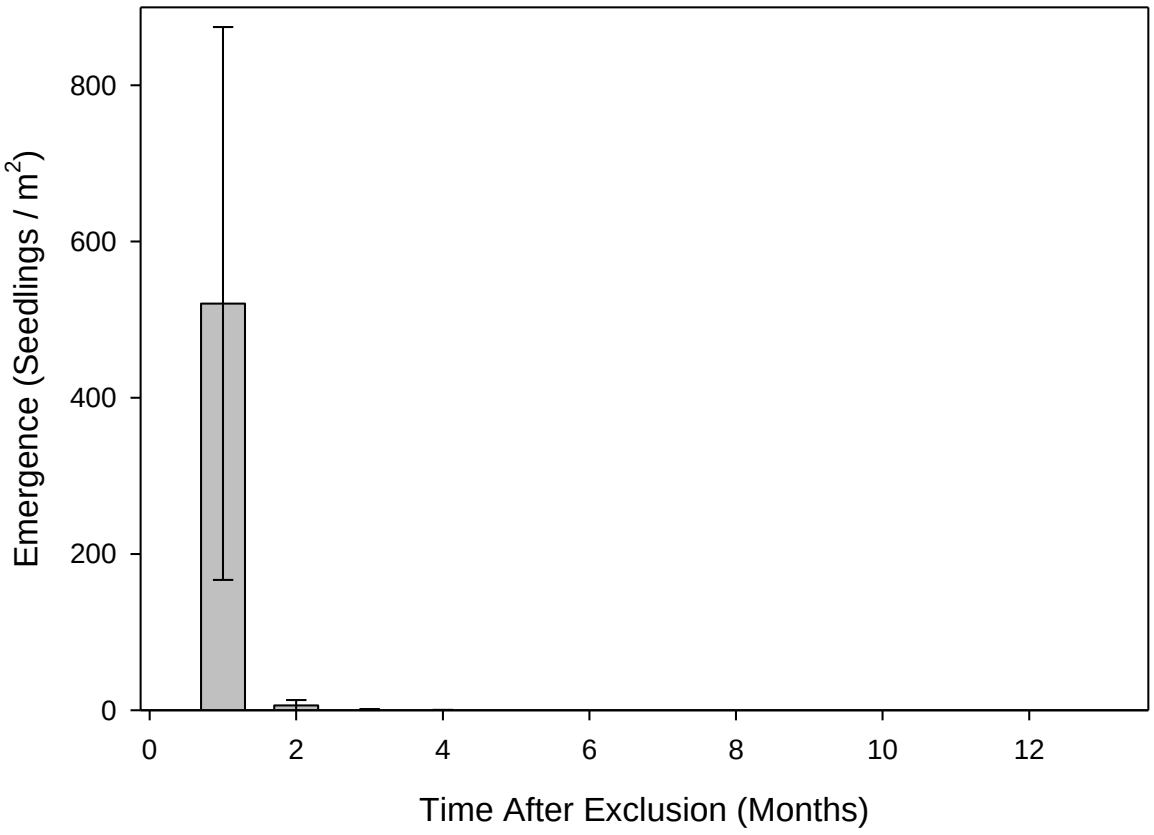

Figure 3-4. Effects of length of seed exclusion on the number of natalgrass seedlings per m^2. Values reflect the mean of 10 replications with 95% confidence intervals.

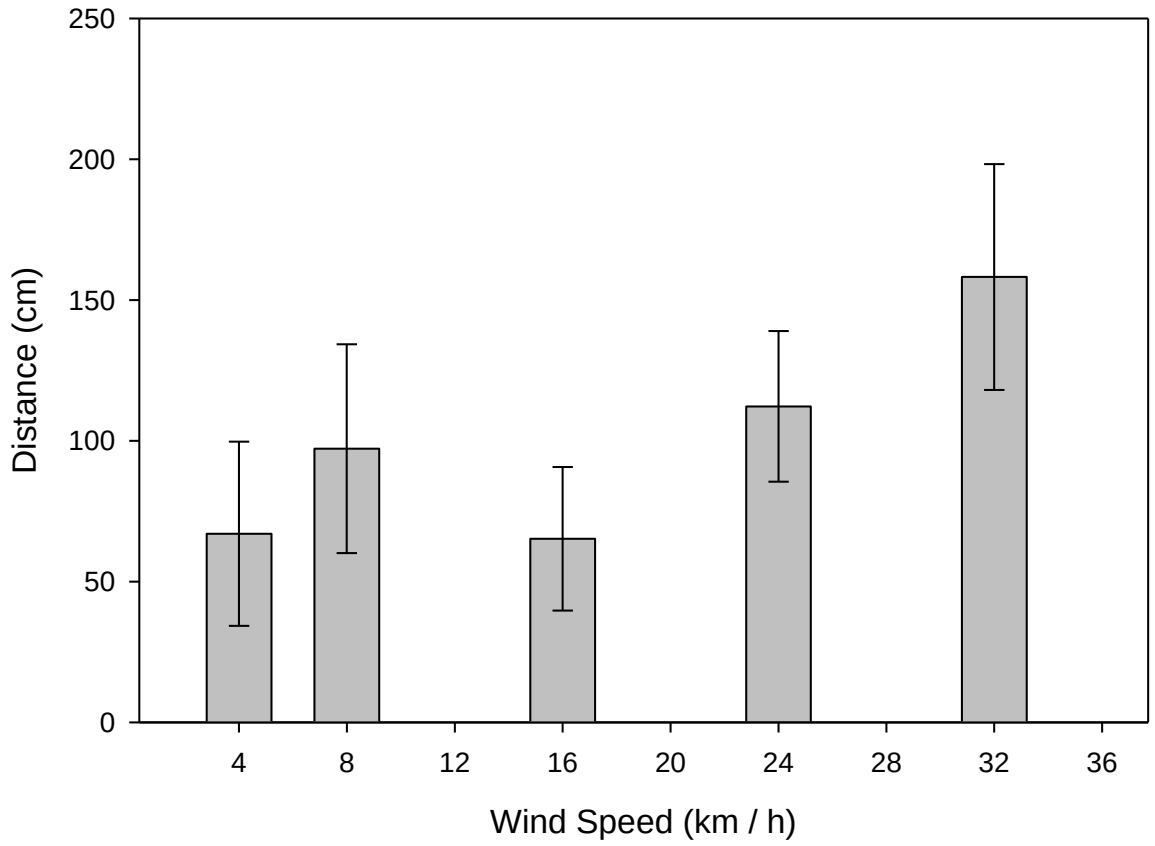

Figure 3-5. Effects of wind speed on distance traveled by natalgrass seeds. Values reflect the mean of 25 replications with 95% confidence intervals.

CHAPTER 4
CHEMICAL CONTROL OF NATALGRASS (*MELINIS REPENS*)

Introduction

Natalgrass (*Melinis repens* (Willd.) Zizka) is native to the savanna regions of south and east Africa. This species has become a weed problem in many tropical and subtropical areas around the world, including Central America and the Caribbean, Florida and Hawaii in the U.S., Brazil and areas in the Pacific (Haselwood and Motter 1966; Kleinschmidt and Johnson 1977; Häfliger and Scholz 1980).

In Florida, natalgrass has become a common problem in dry, sandy areas along the central ridge. This species is especially prevalent in citrus groves, abandoned fields and areas formerly mined for phosphates. The Florida Exotic Pest Plant Council (FLEPPC) considers natalgrass to be a Category I invasive species (FLEPPC 2009), meaning that research has shown that this species is capable of invading undisturbed ecosystems such as the pine rocklands of south Florida (Possley and Maschinski 2006).

Natalgrass was introduced to the U.S. in the 1800s and was grown as an ornamental as early as 1866. Natalgrass was also grown as a forage plant by the U.S. Department of Agriculture as well as the Florida Agricultural Experiment Station, which released natalgrass as its first forage grass cultivar in 1892 (Mislevy and Quesenberry 1999). Over 30,000 acres of natalgrass were grown for hay in central Florida in 1915 (Tracy 1916). Natalgrass is no longer cultivated, but remains widespread in Florida.

As restoration becomes an increasing priority for land managers, there is an increased need for natalgrass management. There is little literature available addressing chemical control strategies for this species. Recommendations usually include spot treatments of glyphosate (MacDonald et al. 2008), but the effects of

glyphosate for large-scale treatments are unknown. Several studies report that imazapic shows potential for natalgrass control (Kluson et al. 2000; Richardson et al. 2003), but imazapic control has not been compared to the other herbicides available for use in natural areas. The objective of this study was to thoroughly explore the potential of various herbicides for natalgrass control in natural areas in Florida.

Materials and Methods

Greenhouse Preemergence Study

A greenhouse study was initiated in May 2010 to determine the potential of various rates of 8 different herbicides applied preemergence for natalgrass control. The study was repeated. Natalgrass plants were grown in the greenhouse in 8.9-cm square pots[1] filled with 360.5 cm^3 of field soil (Apopka sand: loamy, siliceous, subactive, hyperthermic Grossarenic Paleudults) collected from the Lake Louisa Mitigation Bank in Lake County, FL. This soil was used to mimic field conditions as closely as possible. Seeds were collected from the same site in Lake County, FL in December 2009 and stored at room temperature until planting. Approximately 50 seeds were scattered on the soil surface and lightly pressed into the soil. Pots were irrigated daily in the greenhouse to maintain adequate soil moisture.

Herbicides were assigned a 1x rate based on label recommendations, personal observations of the authors and comments from land managers. These rates were estimated to be that which would provide adequate control of the treated plants. Herbicides were also applied at 0.0625, 0.125, 0.25, 0.5, 2 and 4x rates; these were calculated based on the chosen 1x rates. The herbicides used and the 1x rates chosen

[1] Traditional Square Pot, Kord U.S.A., Inc., 103 Lachicotte Rd, Lugoff, SC

included imazapic[2] [1.4 kilograms active ingredient/hectare (kg ai/ha)], imazapyr[3] (1.12 kg ai/ha), imazamox[4] (0.56 kg ai/ha), hexazinone[5] (0.56 kg ai/ha), sulfometuron[6] (0.22 kg ai/ha), metsulfuron[7] (1.12 kg ai/ha), pendimethalin[8] (1.12 kg ai/ha) and metolachlor[9] (1.12 kg ai/ha). Untreated plants served as the control. One pot was considered a replication and each treatment included 4 replications.

Treatments were applied within 24 h of seed sowing with a backpack sprayer calibrated to deliver 187 L/ha (20 gallons/acre) spray solution. Pots were then placed back in the greenhouse and received irrigation as necessary to maintain adequate soil moisture. Two weeks after treatment, seedling density in each pot was visually rated as a percentage of the untreated control. Ten weeks after treatment, the number of seedlings in each pot was determined and all above-ground biomass was harvested, dried at 60 C for 4 d, and weighed. The total dry weight of harvested material from each pot was converted to a percentage of the average biomass per pot for the untreated controls.

Data was analyzed using analysis of variance and means separated at the 0.05 probability level using Fisher's Protected Least Significant Difference (LSD) test. Nonlinear regression was used to describe the response of natalgrass to each herbicide

[2] Plateau herbicide, BASF Corporation, 26 Davis Dr, Research Triangle Park, NC 27709

[3] Habitat herbicide, BASF Corporation, 26 Davis Dr, Research Triangle Park, NC 27709

[4] Clearcast herbicide, BASF Corporation, 26 Davis Dr, Research Triangle Park, NC 27709

[5] Velpar L herbicide, I.E. duPont de Nemours and Company, 1007 Market St, Wilmington, DE 19898

[6] Oust XP herbicide, I.E. duPont de Nemours and Company, 1007 Market St, Wilmington, DE 19898

[7] Escort XP herbicide, I.E. duPont de Nemours and Company, 1007 Market St, Wilmington, DE 19898

[8] Prowl H2O herbicide, BASF Corporation, 26 Davis Dr, Research Triangle Park, NC 27709

[9] Dual Magnum herbicide, Syngenta Crop Protection, P.O. Box 18300, Greensboro, NC 27419

and I_{50} and I_{90} values were calculated to determine the herbicide rates necessary to reduce natalgrass biomass by 50 percent and 90 percent, respectively.

Greenhouse Postemergence Study

A greenhouse study was initiated in May 2010 to determine the potential of various rates of 8 different herbicides applied postemergence for natalgrass control. The study was repeated 2 mo after the initial study. Natalgrass plants were grown in the greenhouse in 8.9-cm square pots filled with 360.5 cm^3 of Fafard 4 potting mix[10]. Seeds were collected from Lake County, FL in 2008 and stored at 4 C until planting. Seeds were scattered on the soil surface and plants were thinned to 1 plant per pot after seedling emergence. Pots were irrigated daily in the greenhouse to maintain adequate soil moisture.

Herbicides were assigned a 1x rate based on label recommendations, personal observations of the authors and comments from land managers. These rates were estimated to be that which would provide adequate control of the treated plants. Herbicides were also applied at 0.0625, 0.125, 0.25, 0.5, 2 and 4x rates; these were calculated based on the chosen 1x rates. The herbicides used and the 1x rates chosen included imazapic (1.4 kg ai/ha), imazapyr (1.12 kg ai/ha), imazamox (0.56 kg ai/ha), glyphosate[11] (0.84 kg ai/ha), hexazinone (0.56 kg ai/ha), sulfometuron (0.22 kg ai/ha), metsulfuron (1.12 kg ai/ha) and fluazifop[12] (1.12 kg ai/ha). Treatments included non-ionic surfactant (NIS) at 0.25% v/v as required by the herbicide labels. An additional treatment consisting of water plus NIS was included and untreated plants served as the

[10] Conrad Fafard, Inc., 770 Silver St, Agawam, MA 01001

[11] Roundup WeatherMax herbicide, Monsanto Company, 800 N. Lindbergh Blvd, St. Louis, MO 63167

[12] Fusilade herbicide, Syngenta Crop Protection, P.O. Box 18300, Greensboro, NC 27419

control. One pot was considered a replication and each treatment included 4 replications.

Treatments were applied 8 to 10 weeks after planting with a backpack sprayer calibrated to deliver 187 L/ha (20 gallons/acre) spray solution. For the first trial, plants were approximately 35 cm tall. For the second trial, plants averaged 45 cm tall. Plants were placed back in the greenhouse and continued to receive irrigation as necessary. Two weeks after treatment, plants were visually rated for injury as a percent of the untreated control. Plants were then harvested at 3 cm above soil level, dried at 60 C for 4 d, and weighed. Plants were allowed to regrow for 8 additional weeks. At this time, plants were visually rated for percentage of regrowth compared to untreated controls and were again harvested, dried and weighed. The biomass harvested after regrowth was converted to a percentage of the biomass harvested from the regrowth of the untreated control plants.

Data was analyzed using analysis of variance and means separated at the 0.05 probability level using Fisher's Protected LSD test. Nonlinear regression was used to describe the response of natalgrass to each herbicide and I_{50} and I_{90} values were calculated to determine the herbicide rates necessary to reduce natalgrass biomass by 50 percent and 90 percent, respectively.

Field Preemergence Study

Field studies to evaluate the potential of several herbicides for preemergence natalgrass control in natural areas were initiated in April 2009 at the Lake Louisa Mitigation Bank in Lake County, FL and in June 2009 at the Tenoroc Fish Management Area in Polk County, FL. The Lake Louisa site was an Apopka sand (loamy, siliceous, subactive, hyperthermic Grossarenic Paleudults) and the Tenoroc site was a Neilhurst

sand (thermic, uncoated Typic Quartzipsamments). Plots were established in areas where natalgrass infestations had been present for at least 1 year to ensure the presence of seed deposits. Plots measured 3.1 m by 7.6 m (10 ft by 25 ft) and were arranged in a randomized complete block design with 4 replications; each plot was considered a replication. Treatments were applied with a CO_2-pressurized backpack sprayer delivering 187 L/ha (20 gallons/acre) spray solution. Treatments included imazapyr (0.14 and 0.28 kg ai/ha), imazapic (0.14 and 0.28 kg ai/ha), metsulfuron (0.042 and 0.126 kg ai/ha), sulfometuron (0.158 and 0.263 kg ai/ha), hexazinone (0.28 and 0.56 kg ai/ha), pendimethalin (1.12 and 2.24 kg ai/ai) and imazamox (0.14 and 0.28 kg ai/ha). All treatments also included glyphosate (3.08 kg ai/ha) to remove any existing plants within the plot area. Plots treated only with glyphosate served as controls.

Plots were visually rated for percentage of natalgrass cover using the following scale: 0 = no natalgrass cover; 100 = complete natalgrass cover. Plots at Lake Louisa were rated 1, 2, 4 and 6 mo after treatment (MAT). Plots at Tenoroc were rated 2, 3, 5 and 7 MAT. Data were analyzed using analysis of variance and means were separated using Fisher's Protected LSD test.

Field Postemergence Study

Field studies to evaluate the potential of several herbicides for natalgrass control in natural areas were initiated in July 2008 at the Tenoroc Fish Management Area and in July 2009 at the Lake Louisa Mitigation Bank. Plots were established in areas with heavy natalgrass pressure but also some native plants. Plots were arranged in a randomized complete block design with 4 replications and measured 7.3 m by 15.2 m (24 ft by 50 ft). Each plot served as a replication. Treatments were applied with an ATV

sprayer delivering 140 L/ha (15 gallons/acre) spray solution per acre. Treatments at both sites included glyphosate (1.12 and 3.36 kg ai/ha), fluazifop (0.28 kg ai/ha), imazapic (0.28 and 0.56 kg ai/ha), imazapyr (0.14 and 0.28 kg ai/ha) and hexazinone (0.56 and 1.12 kg ai/ha). Also included was a metsulfuron treatment (at Tenoroc, 0.28 kg ai/ha; at Lake Louisa, 0.11 kg ai/ha). All treatments included a non-ionic surfactant (NIS) at 0.25% v/v. Untreated plots served as controls.

Plots were visually rated for percentage of natalgrass cover using the following scale: 0 = no natalgrass cover; 100 = complete natalgrass cover. Plots at Tenoroc were rated 3, 9, 12 and 24 MAT. Plots at Lake Louisa were rated 3, 6 and 12 MAT. At Lake Louisa, significant damage from wild hogs was observed in some plots, so the percentage of each plot that had been disturbed was also rated 3, 6 and 12 MAT. Data were analyzed using analysis of variance and means were separated at the 0.05 probability level using Fisher's Protected LSD test.

Results and Discussion

Greenhouse Preemergence Study

There was no significant experiment-by-treatment interaction. Data were therefore pooled across experiments.

Metsulfuron (Figure 4-1) reduced natalgrass biomass by 31% at 0.07 kg ai/ha, but at 0.14 kg ai/ha biomass was higher than the untreated control. Biomass declined with each further rate increase, but was only reduced by 60% at the highest rate tested, 4.48 kg ai/ha. The I_{50} value generated from the regression curve was 2.1 kg ai/ha (Table 4-1), much higher than the maximum labeled use rate for metsulfuron in natural areas (0.168 kg ai/ha). No I_{90} value was generated because 90% control was never

observed. These results indicate that metsulfuron has limited potential for natalgrass control.

Hexazinone (Figure 4-2) showed the most inconsistent results of the compounds tested in this study. At 0.07 kg ai/ha, biomass was reduced by 70%; however, at 0.14 kg ai/ha, biomass was higher than the untreated controls. A 90% reduction in biomass was not observed in this experiment, but the I_{50} value generated from the regression curve was 0.315 kg ai/ha. This value is well within the maximum labeled rate. Hexazinone provided some control, but control was among the lowest of the herbicides tested.

Imazapyr (Figure 4-3) also provided somewhat inconsistent control of natalgrass seedlings in the greenhouse. A 41% reduction in biomass was observed at 0.07 kg ai/ha, but biomass reduction compared to the untreated control was only 7% at 0.14 kg ai/ha. However, all other rates of imazapyr reduced natalgrass biomass by at least 65%. The I_{50} value was 0.21 kg ai/ha, well below the maximum labeled use rate for this compound. No I_{90} value could be calculated using the regression curve generated. Although imazapyr treatment did not result in the largest reduction in biomass observed, this compound did appear to stunt the natalgrass seedlings that did emerge at higher rates.

Imazapic (Figure 4-4) application resulted in a 48% reduction of biomass at 0.0875 kg ai/ha, but only a 26% reduction at 0.175 kg ai/ha. The I_{50} value generated from the regression equation was 0.219 kg ai/ha, a rate slightly higher than the maximum labeled rate for natural areas. The I_{90} value was 0.92 kg ai/ha, significantly higher than the maximum labeled rate. Imazapic severely stunted natalgrass seedlings

at high rates, and these seedlings also appeared to be more susceptible to attack from fungal pathogens.

When imazamox (Figure 4-5) was applied at 0.035 kg ai/ha, only a slight (8%) reduction in natalgrass was observed. Between 0.07 and 0.28 kg ai/ha, biomass was reduced by 51% to 68%. At least a 90% reduction in biomass was observed for all rates higher than 0.28 kg ai/ha. The I_{50} value was 0.105 kg ai/ha, below the maximum labeled use rate. However, the I_{90} value was 1.04 kg ai/ha, higher than the maximum labeled rate. Imazamox also appeared to stunt natalgrass seedlings at high rates, although the high rates required may prevent effective use of this product in the field.

Sulfometuron (Figure 4-6) reduced natalgrass biomass more than 50% at even the lowest rates tested. At 0.0138 kg ai/ha, biomass was reduced by 52%. At 0.22 kg ai/ha, biomass was reduced by 85%. A 99% biomass reduction was observed at 0.44 kg ai/ha and a 98% reduction at 0.88 kg ai/ha. The I_{50} value was 0.02, well within the maximum labeled use rate, but the I_{90} value was much higher at 0.9 kg ai/ha, higher than the maximum labeled rate. These results indicate that low rates of sulfometuron may reduce natalgrass biomass, but sulfometuron may not provide desirable levels of control at the maximum labeled rate.

Metolachlor (Figure 4-7) reduced natalgrass biomass by approximately 31% at 0.07 kg ai/ha and 62% at 0.14 kg ai/ha. The I_{50} value was 0.11 kg ai/ha and the I_{90} value was 1.65 kg ai/ha, well within the labeled use rate for this compound. Metolachlor may be a good option for natalgrass control preemergence.

At the lowest rates tested (0.07 and 0.14 kg ai/ha), pendimethalin (Figure 4-8) did not provide control of natalgrass; at these rates, biomass was higher than the untreated

controls. However, at 0.28 kg ai/ha, pendimethalin resulted in a 28% reduction in biomass. At 0.56 kg ai/ha, an 85% reduction in biomass was observed, and at all other rates no biomass was measured. The I_{50} value was 0.48 kg ai/ha and the I_{90} was 1.07 kg ai/ha. Both rates are well within the labeled use rate for pendimethalin, suggesting that this compound may be a good option for natalgrass control applied preemergence.

Greenhouse Postemergence Study

There was a significant trial-by-treatment interaction, so data were analyzed separately. For many of the herbicides tested, greater control was observed in the first trial than in the second. This was probably a result of the smaller size of the plants in the first trial. At the time of the first harvest, the average dry weight harvested from 8 untreated plants from the first trial was 5.71 g. For the second trial, the average of 8 untreated plants at the time of the first harvest was 12.01 g, slightly more than double the weight of the plants from the first trial. The larger size of the plants used in the second trial is probably the reason for the slightly reduced control.

In the first trial, metsulfuron provided little control of natalgrass (Figure 4-9). At the lowest rate tested, 0.07 kg ai/ha, biomass was about the same as the control. Metsulfuron applied at 0.14 kg ai/ha resulted in an increase in biomass to 134% of the control. At the highest rate tested, 4.48 kg ai/ha, biomass was only reduced by 24%. I_{50} and I_{90} values were not generated (Table 4-2) because 50% and 90% reductions in biomass were not observed during this experiment, even though rates tested reached more than 25 times the maximum labeled use rate. The rate of metsulfuron required to reduce natalgrass biomass by 50% would be extremely high. In the second trial, biomass reduction compared to the control was never observed and metsulfuron

application at all rates resulted in higher biomass (Figure 4-10). At the highest rate tested biomass was still 137% of the control. I_{50} and I_{90} values were not calculated because no reduction in growth was observed during this trial (Table 4-3). In both trials, plants were flowering at the time the regrowth was harvested. Based on these results, metsulfuron appears to have little activity on natalgrass plants and can even increase growth, possibly by causing bud break and increased tillering. Metsulfuron should not be recommended for the control of natalgrass.

Sulfometuron provided fairly good control of natalgrass at high rates in the first trial, but did not provide as much control in the second trial. In the first trial, sulfometuron at 0.01375 kg ai/ha resulted in a 41% reduction in biomass (Figure 4-11). At 0.11 kg ai/ha, biomass was reduced by 57%. Biomass was reduced by 95% at 0.44 kg ai/ha and 98% at 0.88 kg ai/ha. The I_{50} value was 0.068 and the I_{90} was 0.30 kg ai/ha, both below the maximum labeled use rate. In the second trial, sulfometuron at low rates resulted in an increase in biomass compared to the control (Figure 4-12). At 0.0275 kg ai/ha, biomass was the highest at 129% of the control. Biomass was only reduced by 19% at the highest rate tested. No I_{50} or I_{90} values were generated because the regression curve does not reach these values. The maximum labeled rate for sulfometuron is 0.42 kg ai/ha. Sulfometuron may be an option for natalgrass control if plants are small, but based on these results, control is somewhat inconsistent and sulfometuron may not be the best option.

Hexazinone reduced biomass in the first trial by 38% at 0.035 kg ai/ha (Figure 4-13). At 0.28 kg ai/ha, biomass was reduced by 76%. At all higher rates, biomass was 0% of the untreated control and the plants were killed. The I_{50} value was 0.09 kg ai/ha

and the I_{90} value was 0.35 kg ai/ha. In the second trial, biomass was reduced by 71% at 0.035 kg ai/ha (Figure 4-14). At the highest rate biomass was 8% of the untreated. The I_{50} was 0.07 kg ai/ha, similar to that of the first trial, but the I_{90} value was more than double that of the first trial at 0.74 kg ai/ha. However, these rates are still within the maximum labeled rate, suggesting that hexazinone may be a good option for natalgrass control.

In the first trial, fluazifop at all but the lowest rates provided 100% reduction in biomass (Figure 4-15). At 0.07 kg ai/ha, biomass was 165% higher than the control. At 0.14 kg ai/ha and rates higher biomass was 0% of the untreated control. For the first trial, the I_{50} value was 0.14 kg ai/ha and the I_{90} value was 0.38 kg ai/ha. Both these rates are less than the maximum labeled rate. In the second trial, biomass was also higher than the control at 0.07 kg ai/ha (Figure 4-16). At 1.12 kg ai/ha biomass was reduced by 98% and was 0% of the untreated control at all higher rates. The I_{50} value for the second trial was 0.28 kg ai/ha and the I_{90} value was 0.73 kg ai/ha. The I_{50} value is less than the maximum labeled rate, but the I_{90} value is well over the maximum rate. This compound provided good control in the first trial, but less reliable control in the second trial. Fluazifop may provide some control of smaller plants, but is probably not a good option when plants are large.

In the first trial, imazamox at 0.035 kg ai/ha reduced natalgrass biomass by 16% (Figure 4-17). At all rates higher than 0.035, biomass was 0% of the untreated control or no more than 1%. The I_{50} value was 0.04 kg ai/ha, and the I_{90} was 0.12 kg ai/ha. In the second trial, biomass at the lowest rate (0.035 kg ai/ha) was reduced by 57% (Figure 4-18). Biomass at 2.24 kg ai/ha was 2% of the control. The I_{50} was

0.02 kg ai/ha and the I_{90} was 0.63 kg ai/ha, which exceeds the maximum labeled rate for imazamox (0.56 kg ai/ha). In both trials, none of the plants at rates higher than 0.035 kg ai/ha were killed, but all were severely stunted. Any regrowth that occurred at these rates was abnormal; clusters of small, twisted leaves sprouted at some of the nodes and the tissue was very brittle. These plants also appeared to be more susceptible to attack from fungal pathogens.

Natalgrass showed a similar response to imazapyr in both trials. In the first trial, imazapyr at 0.07 kg ai/ha reduced natalgrass biomass by 90% (Figure 4-19). At 0.14 kg ai/ha, biomass was less than 1% of the untreated control, and at all higher rates biomass was 0%. The I_{50} value was 0.02 kg ai/ha and the I_{90} was 0.07 kg ai/ha. In the second trial, biomass was reduced by 97% when imazapyr was applied at 0.07 kg ai/ha (Figure 4-20). The highest rate, 4.48 kg ai/ha, resulted in 0% biomass compared to the control. The I_{50} for the second trial was 0.017 kg ai/ha, and the I_{90} was 0.05 kg ai/ha. All I_{50} and I_{90} values are well below the maximum labeled use rate for imazapyr, which is higher than 1 kg ai/ha. No plants in the imazapyr study were killed, but plants were severely stunted. Except at the lowest 2 rates, all regrowth was similar to that observed in plants treated with imazamox; leaves were small and twisted and broke free from the plant easily.

Imazapic provided good control of natalgrass in both trials. In the first trial, biomass at 0.0875 kg ai/ha was reduced by 57% (Figure 4-21). At 0.175 kg ai/ha, biomass was less than 1% of the untreated control. All higher rates had a biomass of 0% of the control. The I_{50} was 0.06 kg ai/ha and the I_{90} was 0.19 kg ai/ha. In the second trial, biomass was reduced by 90% at 0.0875 kg ai/ha (Figure 4-22). Biomass

for all other rates was no more than 2% of the untreated control, although none were 0%. The I_{50} value was 0.03 kg ai/ha and the I_{90} was 0.08 kg ai/ha. The values from both trials are within the labeled use rates for imazapic in natural areas. None of the plants in either trial were killed, but plants at all but the lowest rates were severely stunted. Like imazamox and imazapyr, imazapic caused abnormal regrowth in plants at all but the lowest rates. These plants were not killed, but did not appear likely to recover from the treatments. The plants also appeared more susceptible to attack from fungal pathogens.

In both trials, glyphosate provided good control of natalgrass. In the first trial, biomass was reduced more at lower rates (Figure 4-23) than in the second trial (Figure 4-24). At 0.0525 kg ai/ha, biomass was reduced by 30%. Biomass was reduced by 95% at 0.42 kg ai/ha. All higher rates were reduced to 0% of the untreated controls, and these plants were all killed. The I_{50} value for the first trial was 0.17 kg ai/ha and the I_{90} was 0.56 kg ai/ha, both well below the maximum labeled rate. In the second trial, biomass increased at the lowest rate, but was reduced by 90% at 0.42 kg ai/ha. At all higher rates, biomass was 0% of the untreated control. The I_{50} value was 0.19 kg ai/ha and the I_{90} value was 0.52 kg ai/ha, very similar to the rates generated from regression in the first trial. These rates are all well within the maximum labeled rate, suggesting that glyphosate provides excellent control of natalgrass.

Field Preemergence Study

Data from the Tenoroc Fish Management Area and the Lake Louisa Mitigation Bank were analyzed separately. Overall, treatments at Tenoroc (Table 4-4) showed more control of natalgrass than treatments at Lake Louisa (Table 4-5). However,

results at Tenoroc were also more variable and, as a result, treatments were not as different statistically.

At both sites, a reduction in natalgrass was observed in the untreated controls over the course of the study. At Tenoroc, cover in the untreated plots declined from 100% 2 MAT to 72% 7 MAT. At Lake Louisa, cover decreased from 100% 1 MAT to 72% 6 MAT. Natalgrass cover also appeared to be declining in the area surrounding the study plots.

Metsulfuron provided very little control of natalgrass at either research site. The only exception was the 0.126 kg ai/ha treatment 1 MAT at the Lake Louisa site, where 40% control was observed. In many cases, natalgrass appeared to be more prevalent in plots treated with metsulfuron than in the untreated controls. In the greenhouse studies, metsulfuron application increased natalgrass biomass at some rates. In the field, metsulfuron may have had the same effect. In addition, metsulfuron may have controlled other species that were competing with natalgrass, allowing natalgrass to grow more prolifically in these plots. Metsulfuron appears to be a poor option for natalgrass control.

At Tenoroc, imazapyr at 0.28 kg ai/ha provided 62% control 2 MAT, while at 0.14 kg ai/ha 48% control was observed. All other imazapyr treatments were not statistically different from the control, with one exception. Imazapyr at 0.28 kg ai/ha 5 MAT provided 40% control. At the Lake Louisa site, the only statistical difference between imazapyr and the control was observed at 0.28 kg ai/ha 1 MAT, where imazapyr provided 24% control.

Imazapyr did not result in a large decrease in natalgrass cover in the field when applied preemergence. However, imazapyr did severely stunt natalgrass plants within the plots, delaying seed production and allowing many natives to more effectively compete with natalgrass. In addition, the rates tested in the field were fairly low. Based on results from the greenhouse studies, higher rates of imazapyr may provide acceptable levels of control in the field. Imazapyr may be a viable option for land managers, particularly because it is already commonly used in Florida's natural areas to treat cogongrass (*Imperata cylindrica*), a common invader in these areas (MacDonald 2004).

At Tenoroc, imazamox at 0.28 kg ai/ha provided 88% control, one of the better treatments, while 61% control was observed at 0.14 kg ai/ha 2 MAT. Three MAT, 60% control was observed at 0.28 kg ai/ha while no statistical difference was observed between the lower rate and the untreated control. Five MAT, control at 0.28 kg ai/ha was 66% while control at 0.14 kg ai/ha was 50%. Seven MAT, no statistical difference was observed between the imazamox plots and the control plots. The higher rate of imazamox ranked among the best treatments for natalgrass control throughout the course of the study, while the lower rate initially was among the middle treatments.

At Lake Louisa, control for both rates of imazamox 1 MAT was 43%. There was no statistical difference between imazamox plots and the untreated control for the latter 3 ratings. At this site, imazamox initially provided some measure of control, but this herbicide did not provide much control later in the study.

Imazamox showed inconsistent results in the field when applied as a preemergence herbicide. However, plants present in the imazamox plots did appear to

be stunted, an observation that is consistent with the effects of imazamox on natalgrass in the greenhouse. An increase in rate to the maximum labeled rate of 0.56 kg ai/ha would probably result in better control, based on the results of the greenhouse studies. Imazamox does appear to reduce natalgrass populations and perhaps delay seed production in plants that survive the application, although natalgrass will probably continue to require management in areas where imazamox is applied.

At Tenoroc, hexazinone at 0.56 kg ai/ha provided 98% control of natalgrass 2 MAT, one of the best treatments. Control declined at 5 MAT to 60% for 0.56 kg ai/ha and 50% for 0.28 kg ai/ha. Seven MAT, control was not statistically different from the control. At 3 and 5 MAT, values for hexazinone at Tenoroc were not statistically different from many of the other treatments; however, these treatments were among the more successful.

At Lake Louisa, hexazinone provided 70% control at 0.56 kg ai/ha and 75% control at 0.28 kg ai/ha 1 MAT, among the most successful treatments. Control declined to 43% for 0.56 kg ai/ha and 45% for 0.28 kg ai/ha 2 MAT. For the final 2 ratings at this site, hexazinone did not provide a measure of control that was statistically different from the control. Hexazinone initially offered some of the most natalgrass control of the treatments at Lake Louisa, but by the 6-mo rating, hexazinone ranked toward the bottom of the treatments.

At both sites, hexazinone offered at least some measure of natalgrass control. Hexazinone did not appear to be the most effective herbicide for natalgrass control of the compounds tested, but depending upon the desired species composition at a particular site this compound may be a good choice for land managers. A higher rate

would most likely prove more effective at controlling natalgrass, but could also be detrimental to native plant populations.

At Tenoroc, imazapic provided 100% control at 0.28 kg ai/ha and 95% control at 0.14 kg ai/ha 2 MAT. Three MAT, control was 94% for the higher rate and 88% for the lower rate. Control declined slightly 5 MAT to 89% for the higher rate and 84% for the lower. Finally, at 7 MAT, control was 80% for the higher rate and 74% for the lower. At this site, imazapic ranked among the best treatments for natalgrass control throughout the course of the study.

At Lake Louisa, imazapic provided 76% control at 0.26 kg ai/ha and 30% control at 0.14 kg ai/ha 1 MAT. Control was 35% for the higher rate 2 MAT, but no statistical difference was observed between the plots for the lower rate of imazapic and the control. No difference was observed between any of the imazapic plots and the control at 4 and 6 MAT at this site.

Although imazapic provided somewhat inconsistent results, it did severely stunt natalgrass plants present in the plots. Natalgrass plants in imazapic plots were not flowering. In addition, many native species in Florida are tolerant to imazapic (Kluson et al. 2000, Richardson et al. 2003). However, the maximum labeled rate for imazapic in natural areas is currently 0.21 kg ai/ha, lower than the higher rate tested in this study. Imazapic did not provide the most effective control of natalgrass, but it may be one of the best choices for land managers attempting to foster native plant communities.

At Tenoroc, pendimethalin provided 69% control at 2.24 kg ai/ha and 45% control at 1.12 kg ai/ha 2 MAT. Three MAT, 45% control was observed at the 2.24 kg ai/ha rate. No other pendimethalin treatments were statistically significant at this site.

At Lake Louisa, pendimethalin provided some of the best results observed in the study. One MAT, 91% control was observed at 2.24 kg ai/ha and 84% control at 1.12 kg ai/ha. At the higher rate, 91% control was also observed 2 MAT, while control declined to 69% at the lower rate. Four MAT, control was 84% at the higher rate and 86% at the lower. Finally, 6 MAT, control was 81% for the higher rate and 83% for the lower.

Pendimethalin provided somewhat inconsistent results, but did provide good control of natalgrass at the Lake Louisa site. The rates tested were also lower than the maximum labeled rate; an increased rate may provide better control. This herbicide may be a good option for land managers attempting to control natalgrass.

At Tenoroc, sulfometuron provided 95% control at 0.263 kg ai/ha and 99% control at 0.158 kg ai/ha 2 MAT. Control declined to 81% at the higher rate and 78% at the lower rate 3 MAT. Five MAT, control was 80% at the higher rate and 94% at the lower. Seven MAT, control for the higher rate was not statistically different from the control, but 76% control was observed at the lower rate.

At Lake Louisa, both 0.263 kg ai/ha and 0.158 kg ai/ha provided 91% control 1 MAT. Likewise, both rates provided 100% control 2 MAT. Four MAT, control was 89% for the higher rate and 91% for the lower. At 6 MAT, both rates provided 85% control.

Sulfometuron did appear to provide good control of natalgrass and may be a good option for land managers. However, the treatments appeared to be detrimental to many of the other plant species present in the study area, something that should be

considered before using this herbicide for natalgrass control. In areas where a seed bank exists for native plant species, another herbicide might be a better choice.

Field Postemergence Study

Data from Tenoroc and Lake Louisa were analyzed separately. At the Tenoroc site, there was no significant difference among any treatments at 12 or 24 MAT. Twelve MAT, natalgrass cover in all plots at Tenoroc averaged 17%, while cover declined to an average of 1% 24 MAT. At both sites, natalgrass cover in the untreated controls declined over time. At Tenoroc, natalgrass cover in the control plots declined from 100% 3 MAT to 70% 9 MAT. Twelve MAT, cover in the control plots was 19%, and 24 MAT was less than 1%. At Lake Louisa, cover declined from 85% at 3 MAT to 84% 6 MAT and finally 60% 12 MAT. An overall decline in natalgrass cover was also observed in the areas surrounding the research plots at both sites.

Plots treated with metsulfuron did not have natalgrass cover that was statistically different from the untreated control plots at either research location. These results are similar to the results observed in other studies. Metsulfuron appears to have little impact on natalgrass in the field and should not be used by land managers to control natalgrass.

Fluazifop did not provide any significant measure of control at either research location. These results were also similar to the results observed in other studies. Based on this information, fluazifop does not appear to be a viable option for land managers seeking to control natalgrass.

At Tenoroc, glyphosate application at 3.36 kg ai/ha resulted in 3% natalgrass cover in plots 3 MAT, while glyphosate at 1.12 kg ai/ha resulted in 20% cover. Nine MAT, the higher rate resulted in 25% cover while the lower rate resulted in 29% cover.

At Lake Louisa, cover in plots treated with glyphosate was not statistically different from the control plots at any of the rating times.

In glyphosate plots at both sites 3 MAT, dead plants were observed among younger plants that were already flowering. Results from the greenhouse studies indicate that glyphosate has very good activity on natalgrass; however, this compound does not provide residual activity. The application appeared to successfully control plants present in the plot at the time of treatment, but natalgrass grew back quickly from seed. In addition, other plants that were competing with natalgrass were also controlled by the glyphosate, and did not appear as prevalent in the months after treatment. Based on these results, glyphosate could be a good option if immediate control is required, but land managers should expect natalgrass populations to rebound quickly and perhaps be more dense than before because of the elimination of competing native plants.

At Tenoroc, imazapyr applied at 0.28 kg ai/ha resulted in 53% natalgrass cover, while 0.14 resulted in 56% cover 3 MAT. Plots treated with the higher rate had 26% cover and plots treated with the lower rate had 16% cover 9 MAT. At Lake Louisa, imazapyr resulted in 34% cover at 0.28 kg ai/ha and 44% cover at 0.14 kg ai/ha 3 MAT. Six MAT, natalgrass cover was not statistically different from cover in the untreated control plots. Twelve MAT, cover in plots treated with 0.28 kg ai/ha was 18%. Cover in plots treated with 0.14 kg ai/ha was not statistically different from the untreated control 12 MAT.

Imazapyr caused apparent stunting of natalgrass and a reduction in flowering, an observation suppported by results from the greenhouse studies. Imazapyr did seem to

provide some native plant species a competitive advantage by reducing natalgrass growth and seed production, but many native species are injured by this product. A higher rate of imazapyr might control natalgrass more effectively, but likewise would further injure native plant populations.

At Tenoroc, plots treated with hexazinone 1.12 kg ai/ha had 0% natalgrass cover 3 MAT, while plots treated with 0.56 kg ai/ha had 3% cover. Nine MAT, the 2 treatments again showed similar results. Plots treated with 1.12 kg ai/ha had 14% cover, while plots treated with 0.56 kg ai/ha had 13% cover.

At Lake Louisa, hexazinone at 1.12 kg ai/ha resulted in 4% cover in plots, while 0.56 kg ai/ha resulted in 9% cover 3 MAT. These treatments reduced natalgrass cover by the greatest amount 3 MAT. 6 MAT, hexazinone also reduced natalgrass cover by the greatest amount, resulting in 8% cover at the higher rate and 11% cover at the lower. 12 MAT, these plots still had some of the least natalgrass cover in the study area. Plots treated with 1.12 kg ai/ha had 14% cover, while plots treated with 0.56 kg ai/ha had 20% cover.

Hexazinone appeared to offer some of the longest-lasting control of natalgrass under field conditions. However, plots treated with hexazinone had very few other species present 3 MAT, and species composition was not very diverse 12 MAT. Although hexazinone offers good control of natalgrass, it may not be the best option if a land manager is attempting to restore native plants.

At Tenoroc, imazapic at 0.56 kg ai/ha resulted in 30% natalgrass cover 3 MAT, while 0.28 kg ai/ha resulted in 56% cover. Nine MAT, plots treated with the higher rate had 26% cover, while plots treated with the lower rate had 14% cover. At Lake Louisa,

results were less consistent. Three MAT, plots treated with 0.56 kg ai/ha had 45% cover, while plots treated with 0.28 kg ai/ha had 50% cover. Six and 12 MAT, cover in plots treated with imazapic was not statistically different from cover in the untreated control plots.

Although imazapic produced inconsistent results, visual observations indicate that imazapic may be a very good option for natalgrass control. The amount of natalgrass cover was not significantly different beyond 3 MAT at the Lake Louisa site, but natalgrass in all plots treated with imazapic at both sites appeared to be severely stunted. This observation is supported by results from the greenhouse studies, which show that imazapic does severely stunt natalgrass. Natalgrass was not flowering 3 MAT in imazapic plots, while all other mature natalgrass plants in the areas surrounding the study area were flowering. These plots also appeared to have some of the highest concentrations of native plants. Previous research has shown that many of Florida's native plants are tolerant to imazapic application, such as *Aristida beyrichiana*, *Andropogon* spp., *Eragrostis* spp., *Liatris* spp., *Pityopsis graminifolia* and *Solidago stricta* (Kluson et al. 2000, Richardson et al. 2003). *Andropogon* spp. and *Eragrostis* spp. were present in imazapic plots 3 MAT and were flowering. Although imazapic does not appear to kill larger natalgrass plants it does cause stunting, allowing native plants to gain a competitive advantage. As a result, natalgrass may be a very good option for land managers trying to control natalgrass and promote native plant communities.

Conclusions

In all field trials, a decrease in natalgrass cover over time was observed in the untreated control plots. In addition, natalgrass cover appeared to be declining throughout surrounding areas. This suggests that natalgrass may decline naturally as

plant communities grow more complex. Natalgrass did not persist as a monoculture at any of the study sites for more than 3 years after disturbance. However, many land managers cannot wait several years for natalgrass to decline, but must actively manage sites. In this case, one of several herbicides might be useful.

Metsulfuron and fluazifop do not appear to provide acceptable levels of natalgrass control in the field. Likewise, these compounds provided either no control in the greenhouse or control only at high rates. Neither of these compounds would be useful to land managers attempting to control natalgrass.

Glyphosate provides excellent control of natalgrass, but does not provide residual activity. As a result, natalgrass populations are quickly reestablished from seed, easily outcompeting native plants. Glyphosate provides immediate control, but other methods should be employed long-term. Glyphosate may be best utilized as a spot-treatment.

Pendimethalin and metolachlor both offer good control of natalgrass when applied preemergence. However, these herbicides were detrimental to many of the native species present at the research sites. These herbicides would be best utilized at a site with little to no seed bank for native species.

Hexazinone and sulfometuron both provided fairly good control of natalgrass pre- and postemergence. However, both compounds were also detrimental to native plants. These compounds would also be good options at sites with few native species present.

Imazamox, imazapyr and imazapic provided less control of natalgrass on average than hexazinone and sulfometuron, but were less harmful to native plant populations. Of the three herbicides, imazapic is the best choice when many native species are

present. Many native plants in Florida are tolerant to this compound and gain a competitive advantage when imazapic is used.

Table 4-1. I_{50} and I_{90} values for various herbicides applied preemergence to natalgrass in the greenhouse.

Herbicide Treatment	1x Rate (kg ai/ha)	I_{50}[1]	I_{90}[2]
Hexazinone	0.56	0.315	—[3]
Imazamox	0.56	0.105	1.04*[4]
Imazapic	1.40	0.219*	0.92*
Imazapyr	1.12	0.21	—
Metolachlor	1.12	0.11	1.65
Metsulfuron	1.12	2.10*	—
Pendimethalin	1.12	0.48	1.07
Sulfometuron	0.22	0.02	0.90*

[1] I_{50} = herbicide rate required to reduce biomass by 50% compared to the untreated control. [2] I_{90} = herbicide rate required to reduce biomass by 90% compared to the untreated control. [3] Missing values could not be calculated with the regression equations generated during statistical analysis. [4] Values marked with * indicate that the calculated rate is higher than the maximum labeled use rate for the compound.

Table 4-2. I_{50} and I_{90} values for various herbicides applied postemergence to natalgrass in the greenhouse (Trial 1).

Herbicide Treatment	1x Rate (kg ai/ha)	I_{50}[1]	I_{90}[2]
Fluazifop	1.12	0.14	0.38
Glyphosate	0.84	0.17	0.56
Hexazinone	0.56	0.09	0.35
Imazamox	0.56	0.04	0.12
Imazapic	1.40	0.06	0.19
Imazapyr	1.12	0.02	0.07
Metsulfuron	1.12	—[3]	—
Sulfometuron	0.22	0.068	0.30

[1] I_{50} = herbicide rate required to reduce biomass by 50% compared to the untreated control. [2] I_{90} = herbicide rate required to reduce biomass by 90% compared to the untreated control. [3] Missing values could not be calculated with the regression equations generated during statistical analysis.

Table 4-3. I_{50} and I_{90} values for various herbicides applied postemergence to natalgrass in the greenhouse (Trial 2).

Herbicide Treatment	1x Rate (kg ai/ha)	I_{50}[1]	I_{90}[2]
Fluazifop	1.12	0.28	0.73*[3]
Glyphosate	0.84	0.19	0.52
Hexazinone	0.56	0.07	0.74
Imazamox	0.56	0.02	0.63*
Imazapic	1.40	0.03	0.08
Imazapyr	1.12	0.017	0.05
Metsulfuron	1.12	—[4]	—
Sulfometuron	0.22	—	—

[1] I_{50} = herbicide rate required to reduce biomass by 50% compared to the untreated control. [2] I_{90} = herbicide rate required to reduce biomass by 90% compared to the untreated control. [3] Values marked with * indicate that the calculated rate is higher than the maximum labeled use rate for the compound. [4] Missing values could not be calculated with the regression equations generated during statistical analysis.

Table 4-4. Influence of herbicide treatments applied preemergence on natalgrass cover at the Tenoroc Fish Management Area in 2009.

Herbicide Treatment	Rate (kg ai/ha)	% Cover[1] 2 MAT[2]	3 MAT	5 MAT	7 MAT
Untreated		100f[3]	100g	97f	72b-d
Hexazinone	0.28	10abc	37a-e	50b-d	32ab
	0.56	2a	28a-d	40a-c	47a-c
Imazamox	0.14	39de	62c-g	50b-d	57a-c
	0.28	12a-d	40a-e	34a-c	52a-c
Imazapic	0.14	5ab	12a	16ab	26a
	0.28	0a	6a	11a	20a
Imazapyr	0.14	52e	72e-g	67c-f	60a-d
	0.28	38c-e	65d-g	60c-e	60a-d
Metsulfuron	0.042	100f	92fg	97f	85cd
	0.126	92f	100g	95ef	100d
Pendimethalin	1.12	55e	82fg	85d-f	77b-d
	2.24	31b-e	55b-f	67c-f	55a-c
Sulfometuron	0.158	1a	22a-c	6a	24a
	0.263	5ab	19ab	20ab	42ab

[1] Visual assessment of natalgrass cover based on the following scale: 0 = no cover; 100 = complete cover. [2] MAT = months after treatment. [3] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different at the 0.05 probability level according to Fisher's Least Significant Difference (LSD) test.

Table 4-5. Influence of herbicide treatments applied preemergence on natalgrass cover at the Lake Louisa Mitigation Bank in 2009.

Herbicide Treatment	Rate (kg ai/ha)	% Cover[1] 1 MAT[2]	2 MAT	4 MAT	6 MAT
Untreated		100d[3]	100f	90b	72b
Hexazinone	0.28	25a	55cd	75b	72b
	0.56	30a	57cd	90b	85b
Imazamox	0.14	57b	97f	97b	97b
	0.28	57b	95f	75b	77b
Imazapic	0.14	70bc	82d-f	76b	75b
	0.28	24a	65e	71b	72b
Imazapyr	0.14	82cd	95f	100b	100b
	0.28	76bc	90ef	97b	92b
Metsulfuron	0.042	81cd	100f	100b	100b
	0.126	60bc	100f	90b	95b
Pendimethalin	1.12	16a	31bc	14a	17a
	2.24	9a	9ab	16a	19a
Sulfometuron	0.158	9a	0a	9a	15a
	0.263	9a	0a	11a	15a

[1] Visual assessment of natalgrass cover based on the following scale: 0 = no cover; 100 = complete cover. [2] MAT = months after treatment. [3] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different at the 0.05 probability level according to Fisher's Least Significant Difference (LSD) test.

Table 4-6. Influence of herbicide treatments applied postemergence on natalgrass cover at the Tenoroc Fish Management Area in 2008.

Herbicide Treatment	Rate (kg ai/ha)	% Cover[1] 3 MAT[2]	% Cover[1] 9 MAT
Untreated		100a[3]	70a
Fluazifop	0.28	98a	43a-c
Glyphosate	1.12	20cd	29b-d
	3.36	3cd	25b-d
Hexazinone	0.56	3cd	13d
	1.12	0d	14cd
Imazapic	0.28	56b	14cd
	0.56	30bc	26b-d
Imazapyr	0.14	56b	16cd
	0.28	53b	26b-d
Metsulfuron	0.28	95a	50ab

[1] Visual assessment of natalgrass cover based on the following scale: 0 = no cover; 100 = complete cover. [2] MAT = months after treatment. [3] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different at the 0.05 probability level according to Fisher's Least Significant Difference (LSD) test.

Table 4-7. Influence of herbicide treatments applied postemergence on natalgrass cover at the Lake Louisa Mitigation Bank in 2009.

Herbicide Treatment	Rate (kg ai/ha)	% Cover[1] 3 MAT[2]	% Cover[1] 6 MAT	% Cover[1] 12 MAT
Untreated		85ab[3]	84ab	60ab
Fluazifop	0.28	63bc	71ab	55ab
Glyphosate	1.12	91a	90a	71a
	3.36	61bc	85a	71a
Hexazinone	0.56	9ef	11c	20c
	1.12	4f	8c	14c
Imazapic	0.28	50cd	75ab	39a-c
	0.56	45cd	80ab	30bc
Imazapyr	0.14	44cd	69ab	41a-c
	0.28	34de	53b	18c
Metsulfuron	0.11	80ab	78ab	55ab

[1] Visual assessment of natalgrass cover based on the following scale: 0 = no cover; 100 = complete cover. [2] MAT = months after treatment. [3] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different at the 0.05 probability level according to Fisher's Least Significant Difference (LSD) test.

Table 4-8. Disturbance to plots caused by wild hogs at the Lake Louisa Mitigation Bank in 2009.

Herbicide Treatment	Rate (kg ai/ha)	% Disturbance[1] 6 MAT[2]	% Disturbance[1] 12 MAT
Untreated		10c[3]	0b
Fluazifop	0.28	14bc	0b
Glyphosate	1.12	10c	0b
	3.36	14bc	14a
Hexazinone	0.56	0c	0b
	1.12	4c	0b
Imazapic	0.28	5c	0b
	0.56	0c	0b
Imazapyr	0.14	23bc	0b
	0.28	48ab	3b
Metsulfuron	0.11	58a	4b

[1] Visual assessment of disturbance to plots based on the following scale: 0 = no disturbance; 100 = complete disturbance. [2] MAT = months after treatment. [3] Values reflect the mean of 4 replications. Means within a column followed by different letters are significantly different at the 0.05 probability level according to Fisher's Least Significant Difference (LSD) test.

Table 4-9. Presence of species within treatment areas at the Tenoroc Fish Management Area.

Species	0 MAT[1]	3 MAT	6 MAT	9 MAT	12 MAT	24 MAT
Aeschynomene spp.	—[2]	—	—	—	—	X[3]
Andropogon spp.	X	X	X	X	X	X
Conyza canadensis	—	—	—	—	—	X
Eragrostis spp.	X	X	X	X	X	X
Eustachys petraea	X	X	—	X	X	X
Froelichia floridana	—	—	—	—	—	X
Heterotheca subaxillaris	X	X	X	X	X	X
Indigofera hirsuta	—	X	—	—	X	—
Melinis repens	X	X	X	X	X	X
Panicum repens	X	X	X	X	X	—
Panicum virgatum	—	—	—	X	X	X
Paspalum notatum	X	X	X	X	X	X
Passiflora incarnata	—	—	—	X	—	X
Scoparia dulcis	—	—	—	—	—	X
Sporobolus indicus	X	X	—	X	X	—

[1] MAT = months after treatment. [2] Indicates absence of species. [3] Indicates presence of species.

Table 4-10. Presence of species within treatment areas at the Lake Louisa Mitigation Bank.

Species	0 MAT[1]	3 MAT	6 MAT	9 MAT	12 MAT
Ambrosia artemisiifolia	X[2]	X	X	X	X
Aristida spp.	X	X	X	X	—
Conyza canadensis	—[3]	X	X	—	X
Cyperus rotundus	X	X	X	X	X
Eragrostis spp.	X	—	X	X	X
Eupatorium capillifolium	—	X	X	X	X
Froelichia floridana	—	X	—	—	X
Heterotheca subaxillaris	X	X	X	X	X
Indigofera hirsuta	—	—	—	X	—
Lantana spp.	—	X	X	—	X
Melinis repens	X	X	X	X	X
Nuttallanthus canadensis	—	—	—	X	—
Paspalum notatum	X	X	X	X	—
Richardia scabra	X	X	—	X	X
Rumex hastatulum	—	—	—	X	—
Urochloa maxima	X	X	X	—	X

[1] MAT = months after treatment. [2] Indicates presence of species. [3] Indicates absence of species.

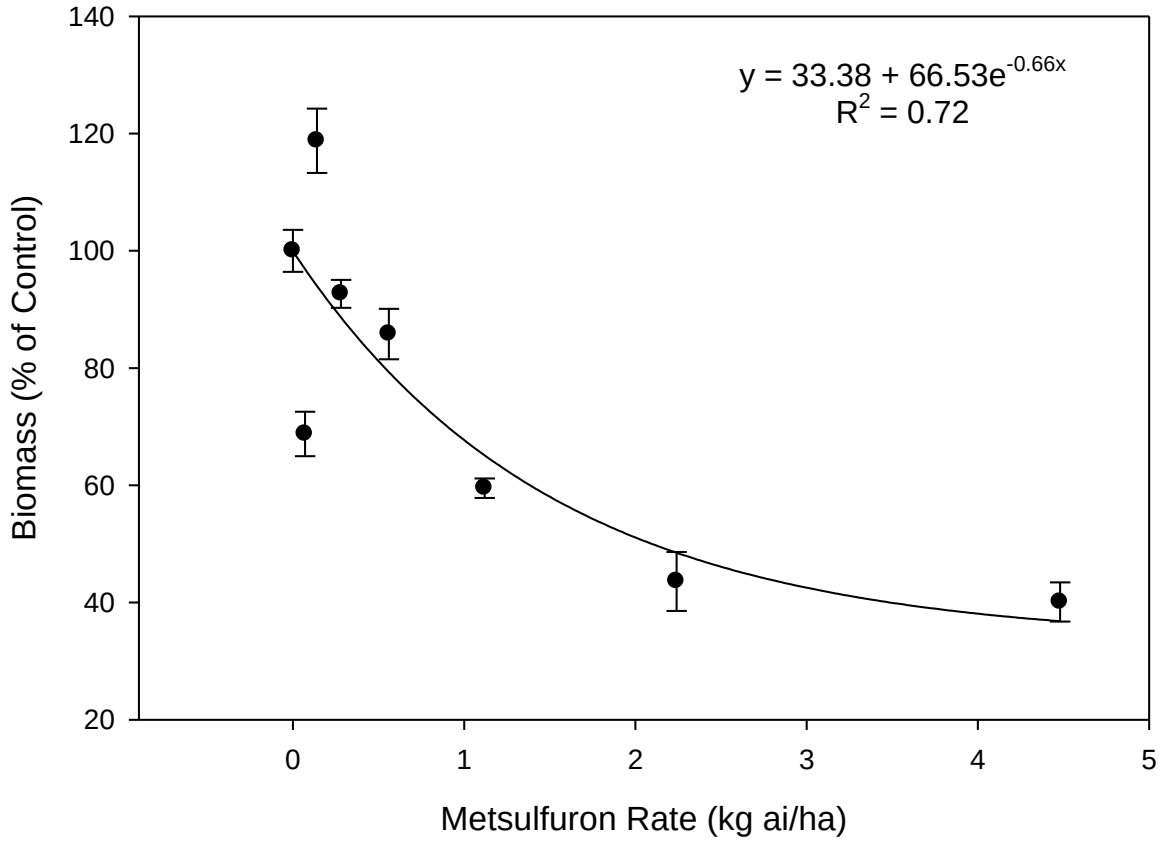

Figure 4-1. The effect of metsulfuron applied preemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Values represent the mean of 8 replications with standard error.

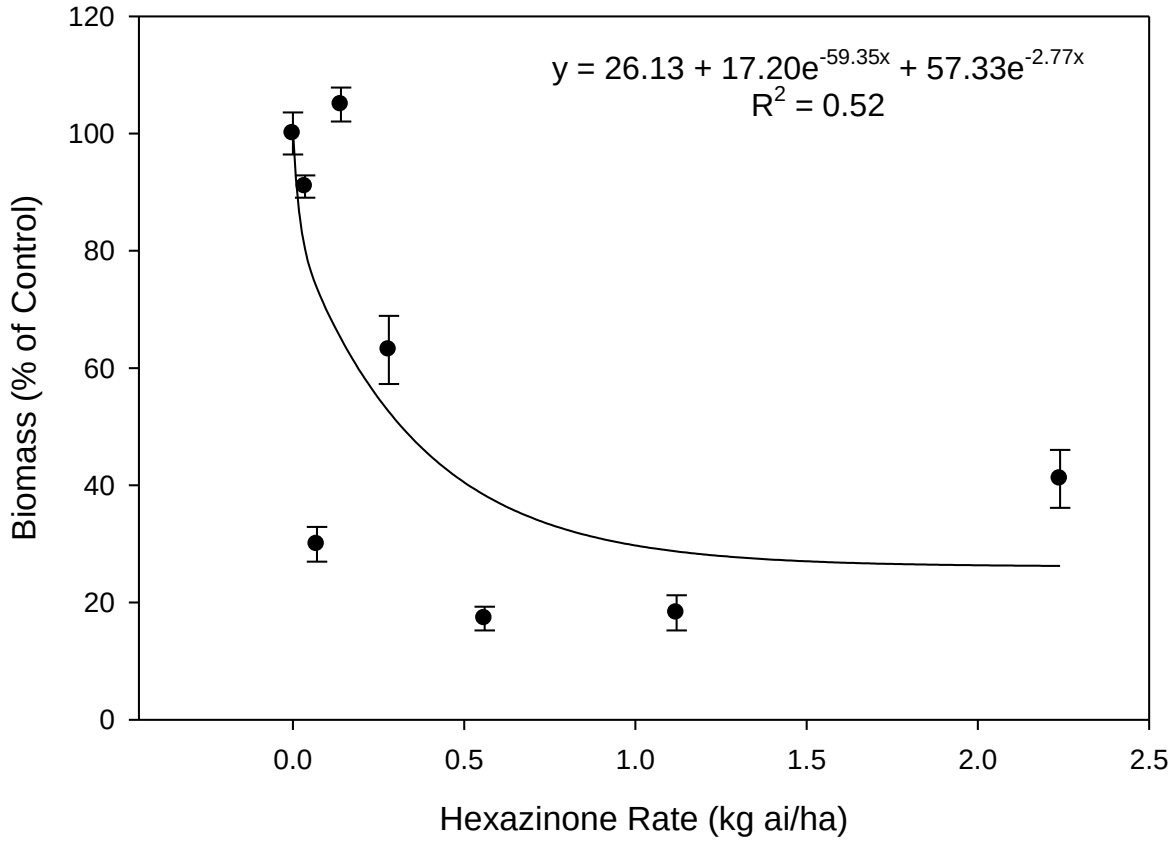

Figure 4-2. The effect of hexazinone applied preemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Values represent the mean of 8 replications with standard error.

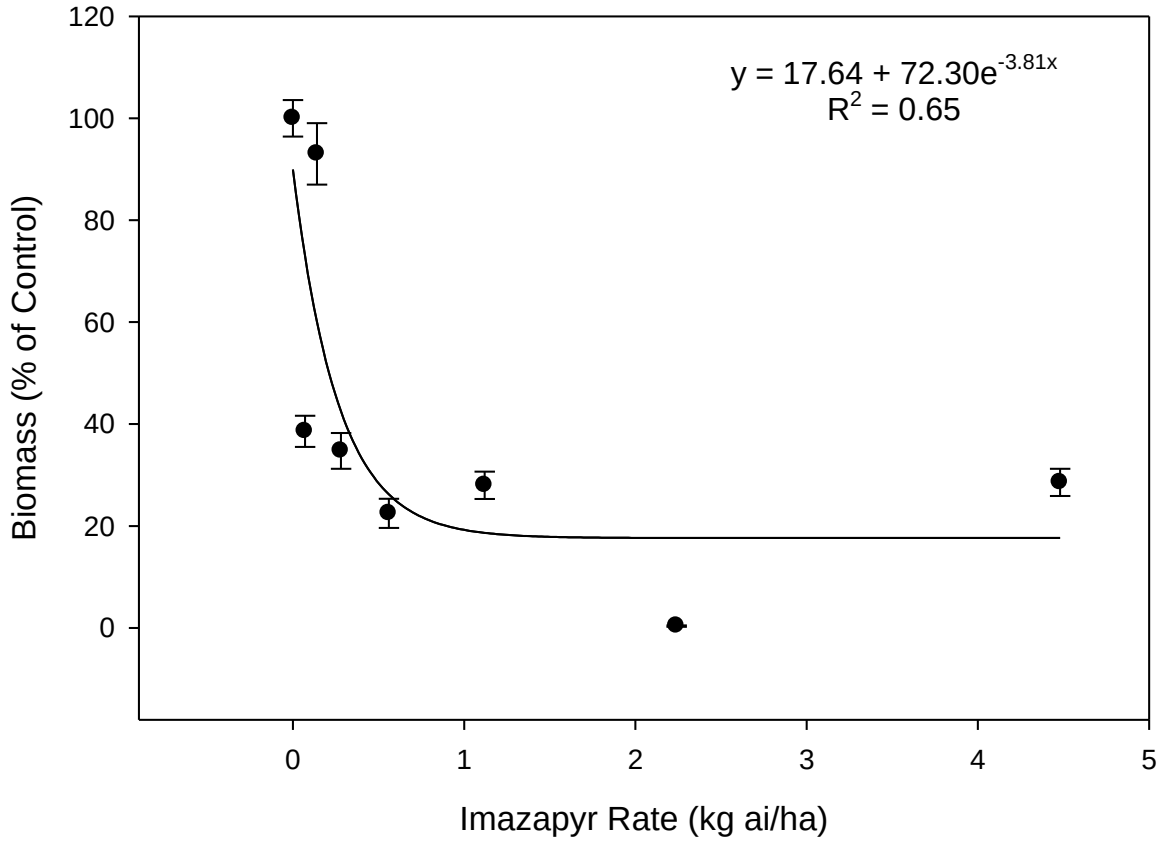

Figure 4-3. The effect of imazapyr applied preemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Values represent the mean of 8 replications with standard error.

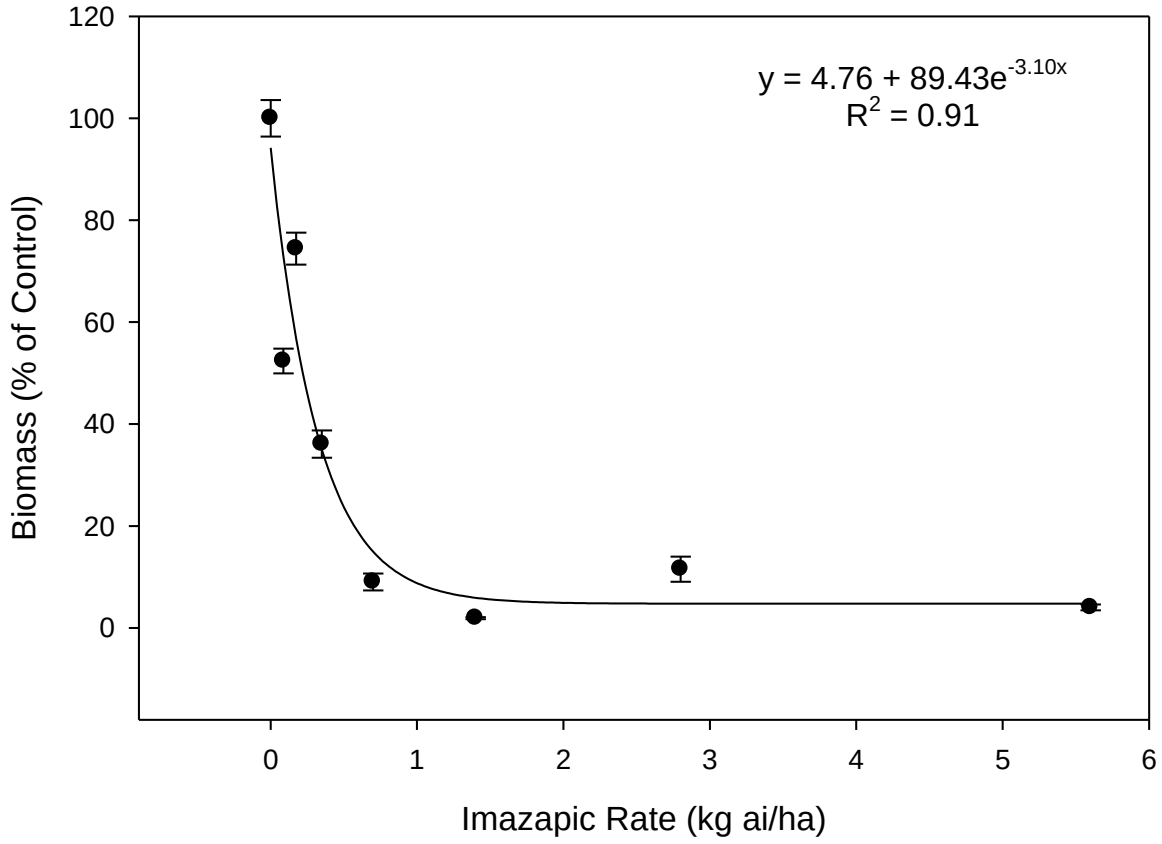

Figure 4-4. The effect of imazapic applied preemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Values represent the mean of 8 replications with standard error.

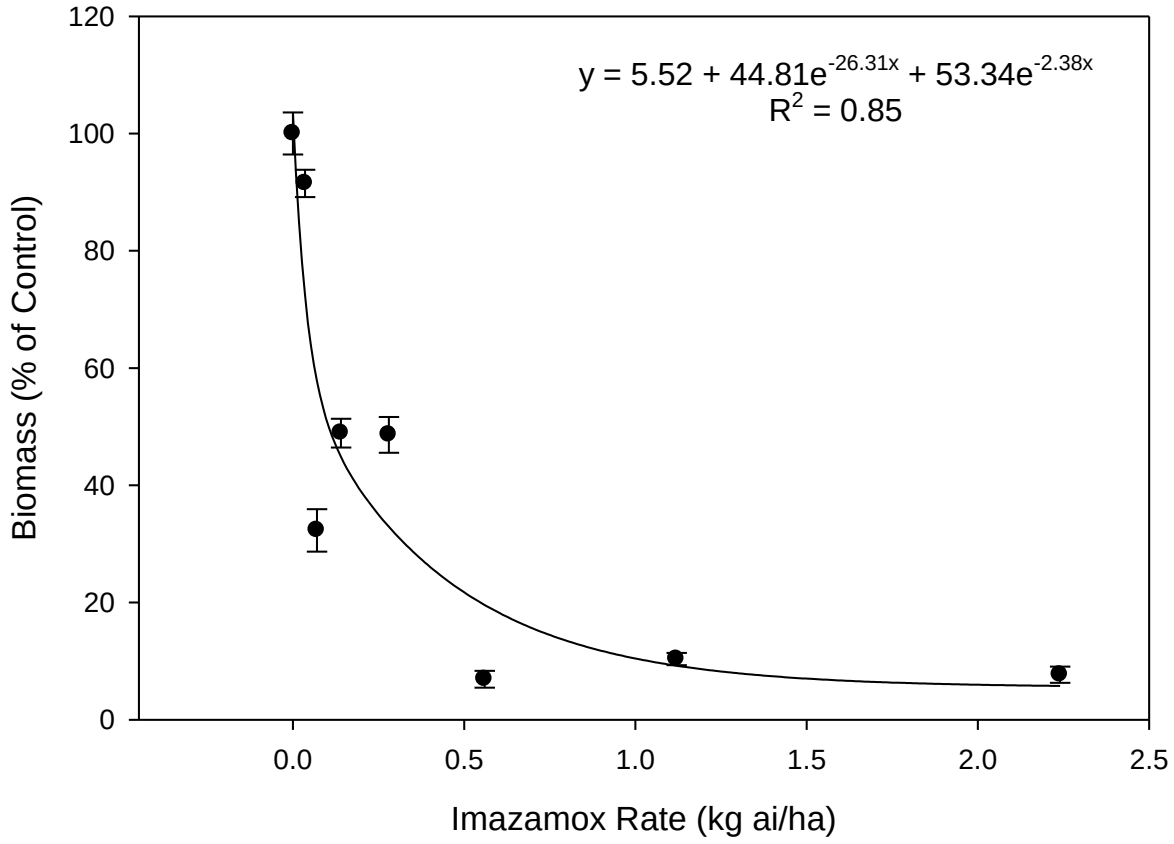

Figure 4-5. The effect of imazamox applied preemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Values represent the mean of 8 replications with standard error.

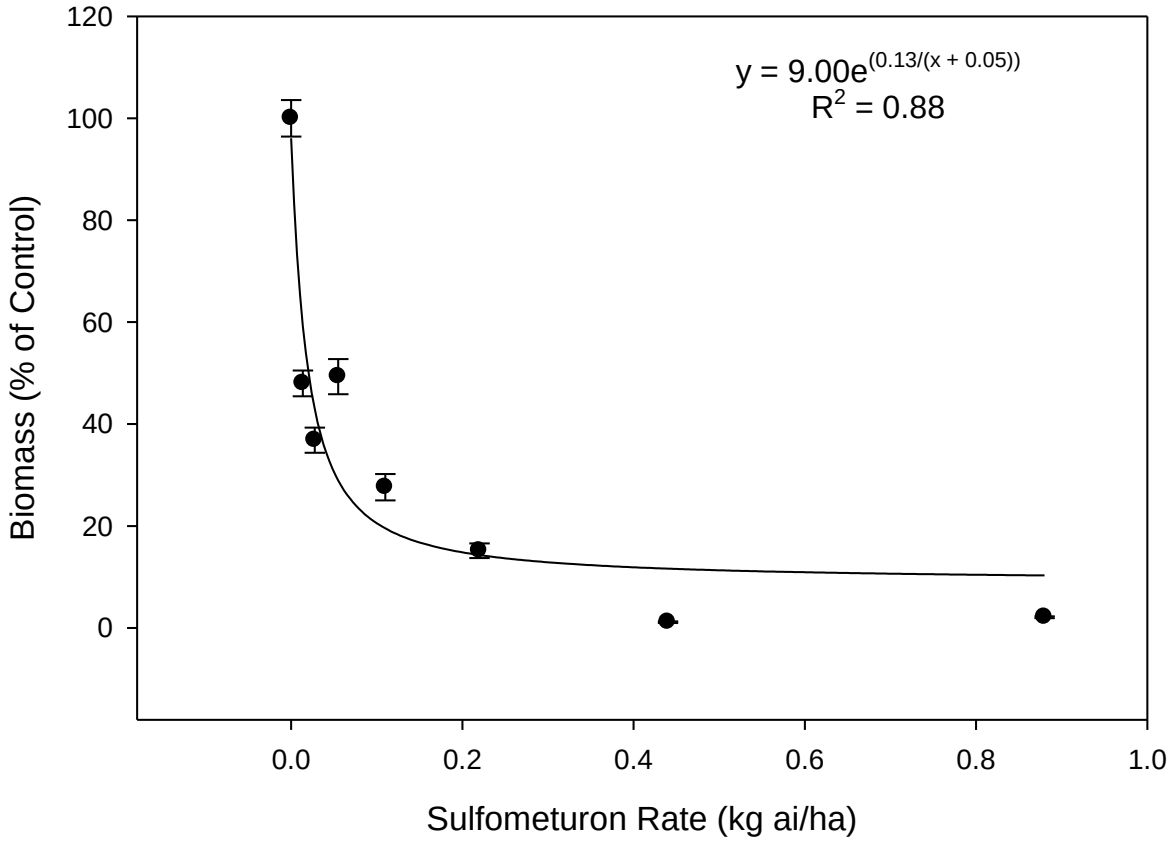

Figure 4-6. The effect of sulfometuron applied preemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Values represent the mean of 8 replications with standard error.

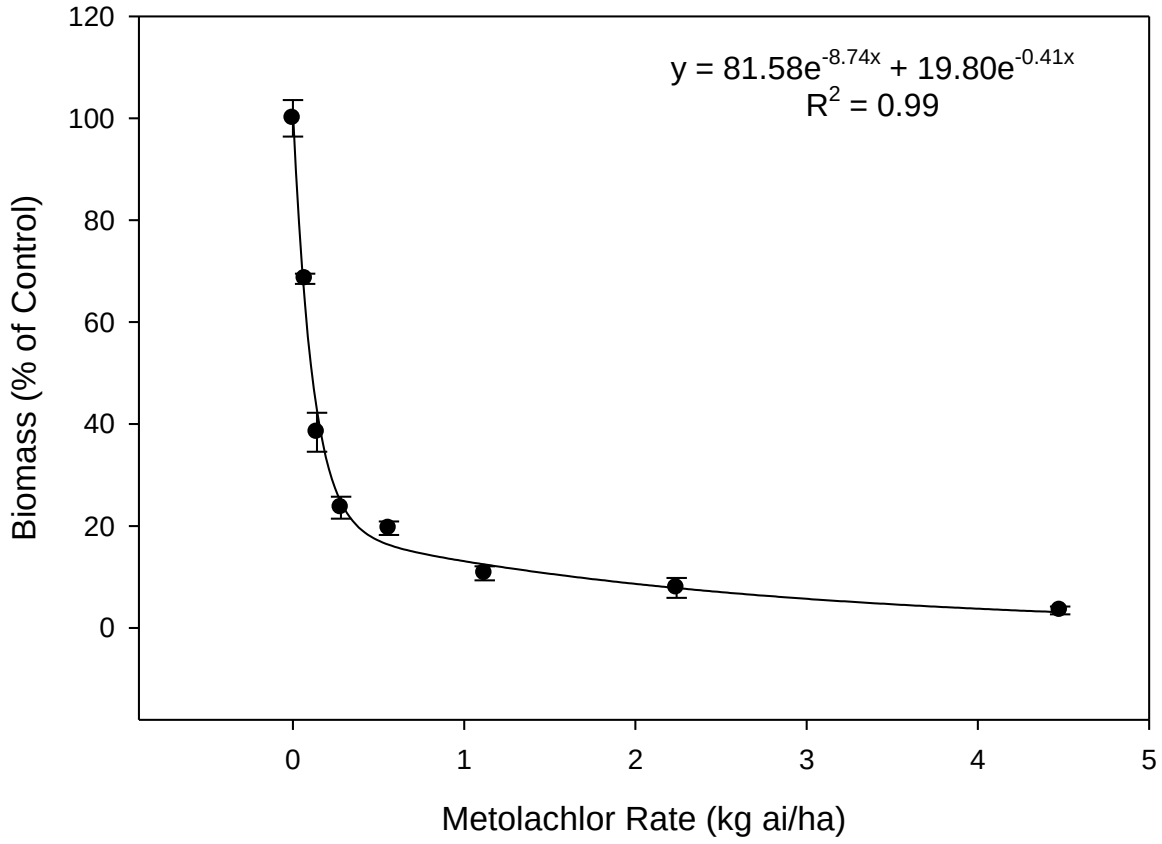

Figure 4-7. The effect of metolachlor applied preemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Values represent the mean of 8 replications with standard error.

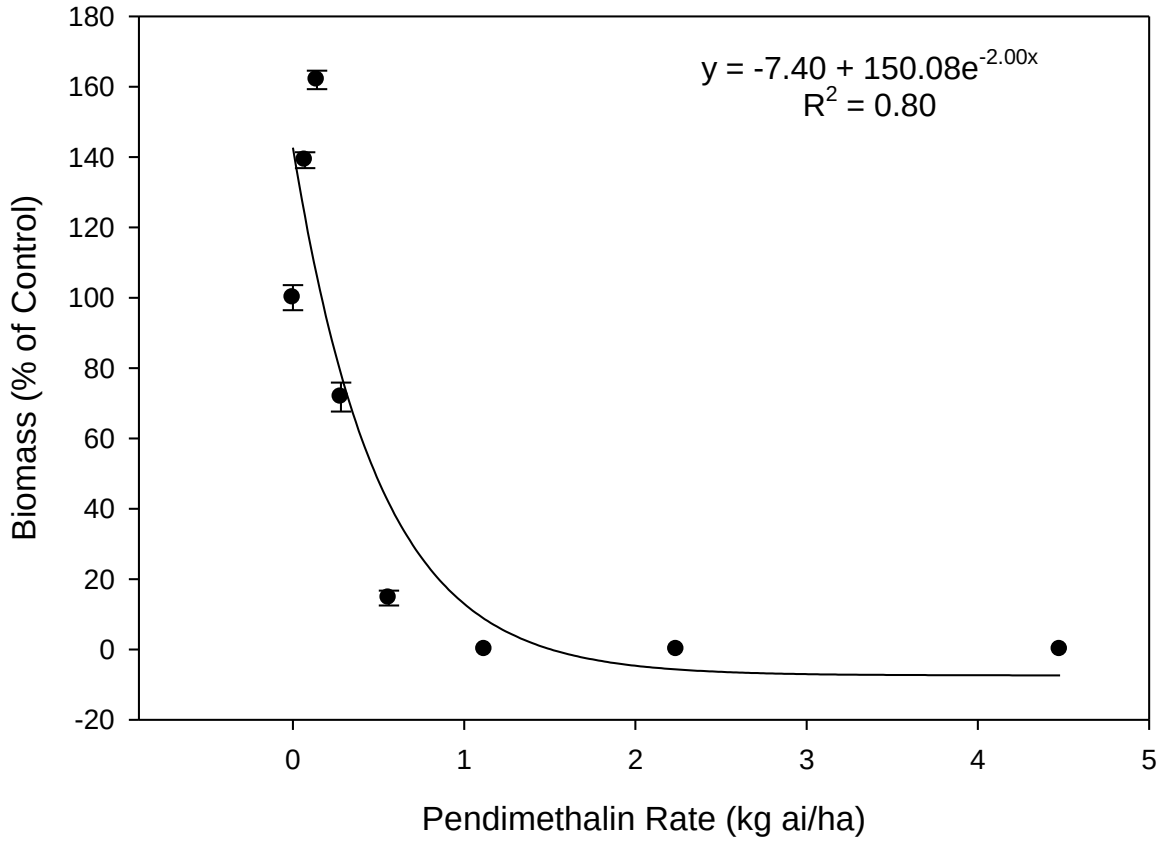

Figure 4-8. The effect of pendimethalin applied preemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Values represent the mean of 8 replications with standard error.

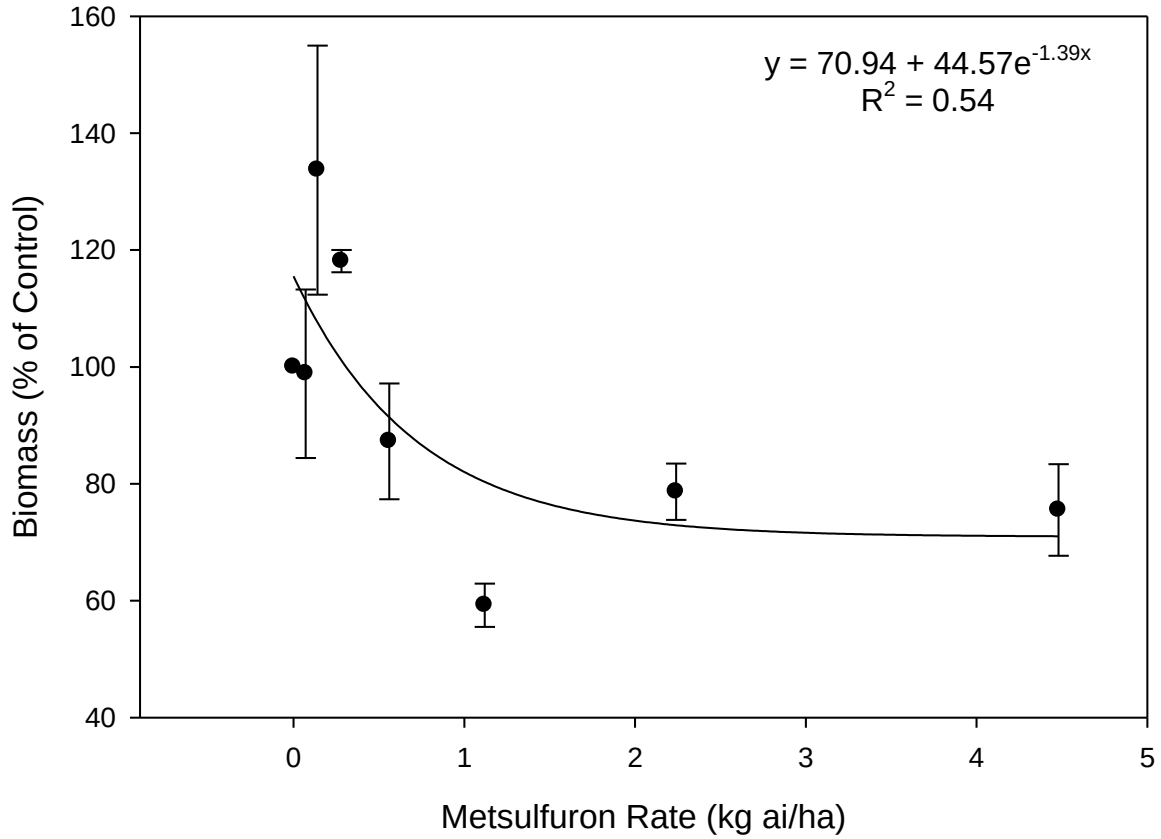

Figure 4-9. The effect of metsulfuron applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 1. Values represent the mean of 4 replications with standard error.

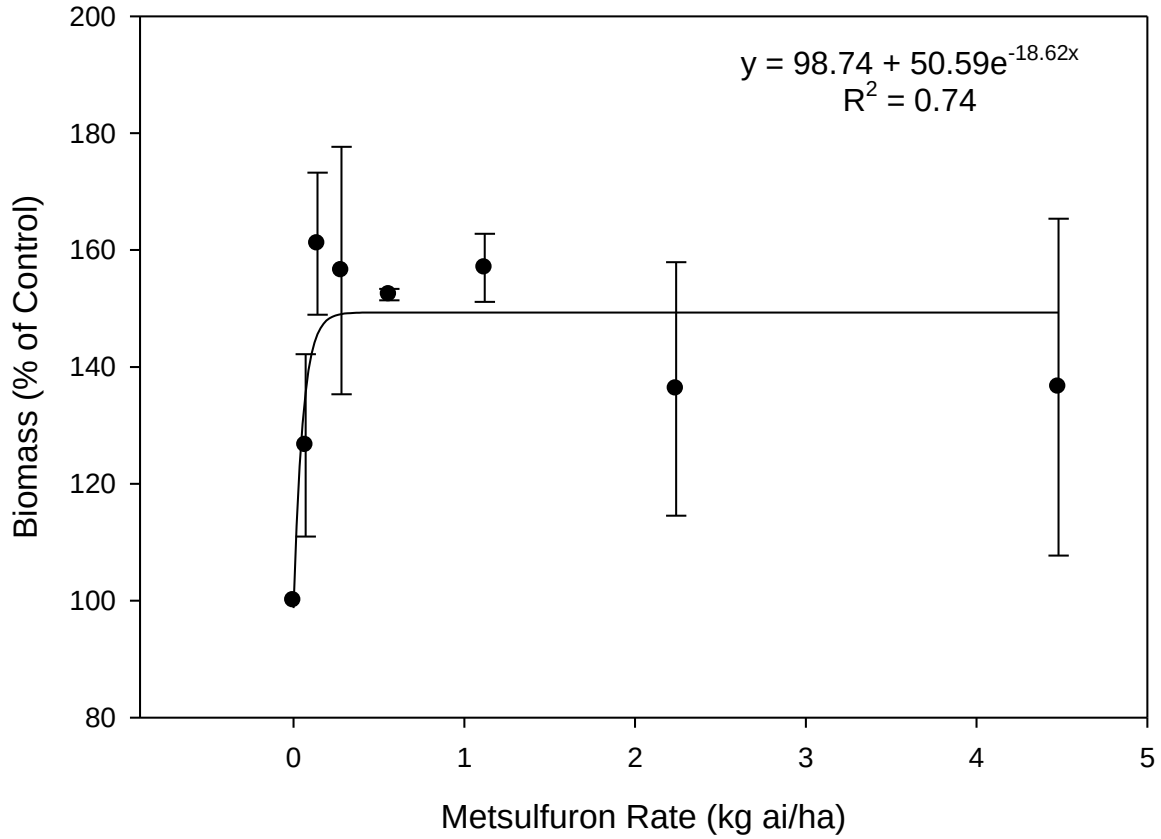

Figure 4-10. The effect of metsulfuron applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 2. Values represent the mean of 4 replications with standard error.

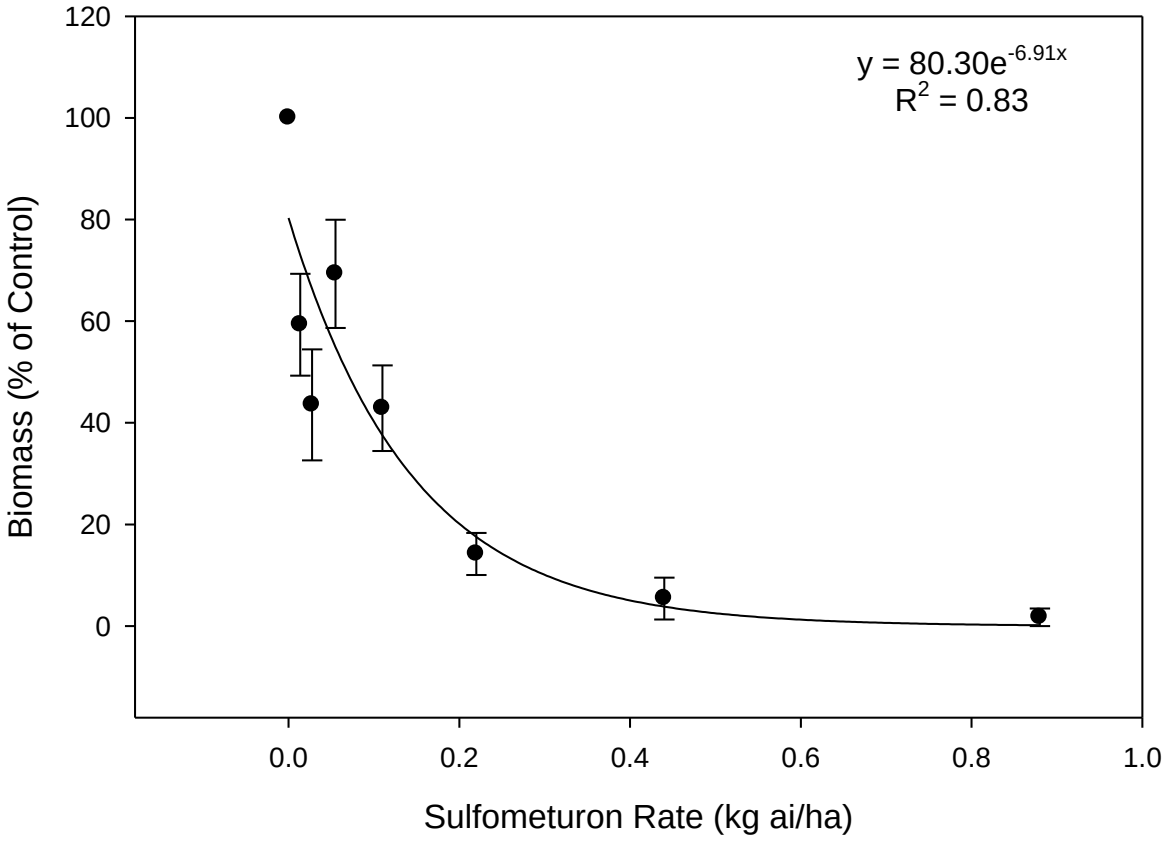

Figure 4-11. The effect of sulfometuron applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 1. Values represent the mean of 4 replications with standard error.

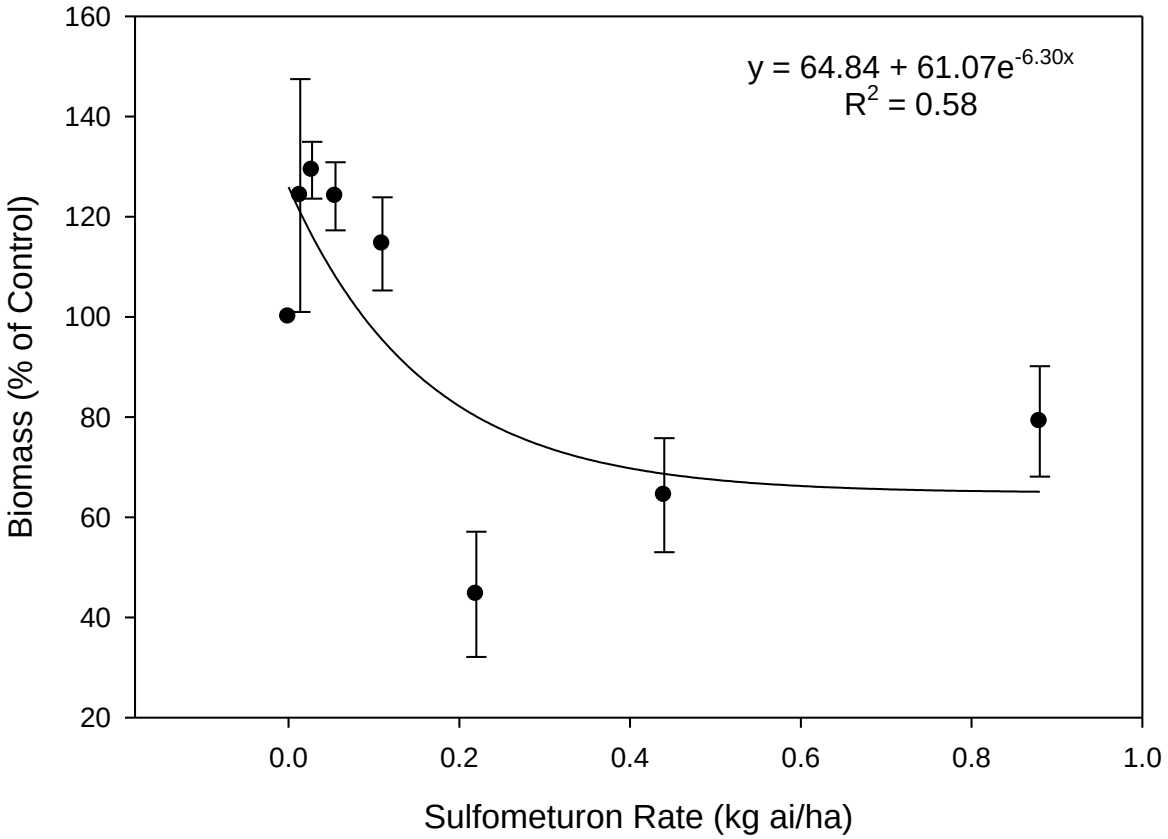

Figure 4-12. The effect of sulfometuron applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 2. Values represent the mean of 4 replications with standard error.

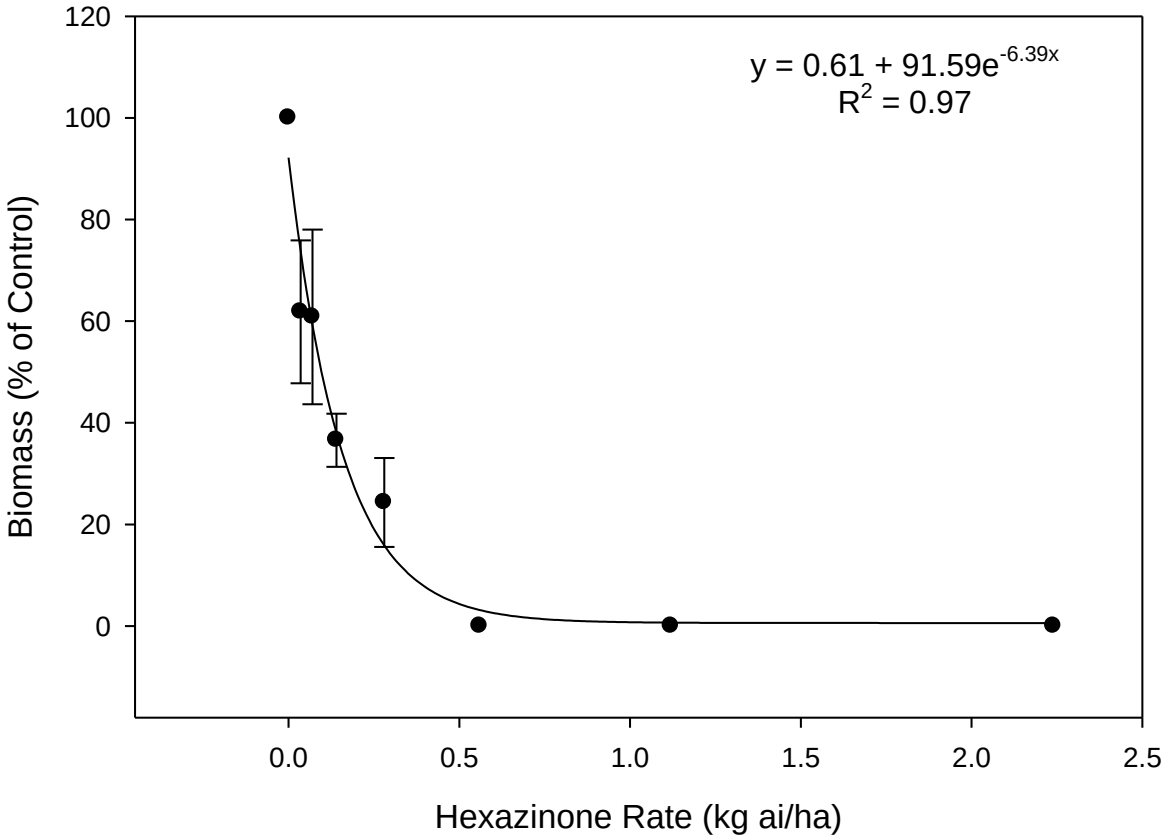

Figure 4-13. The effect of hexazinone applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 1. Values represent the mean of 4 replications with standard error.

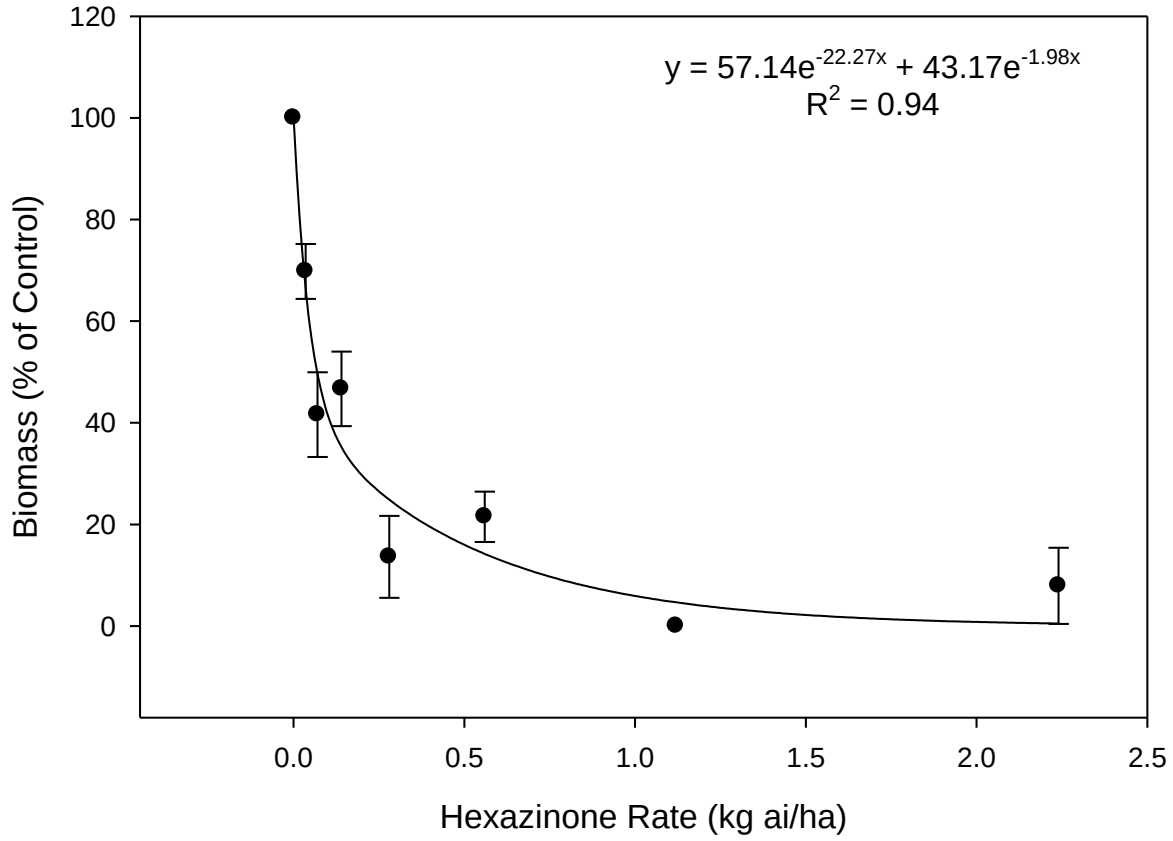

Figure 4-14. The effect of hexazinone applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 2. Values represent the mean of 4 replications with standard error.

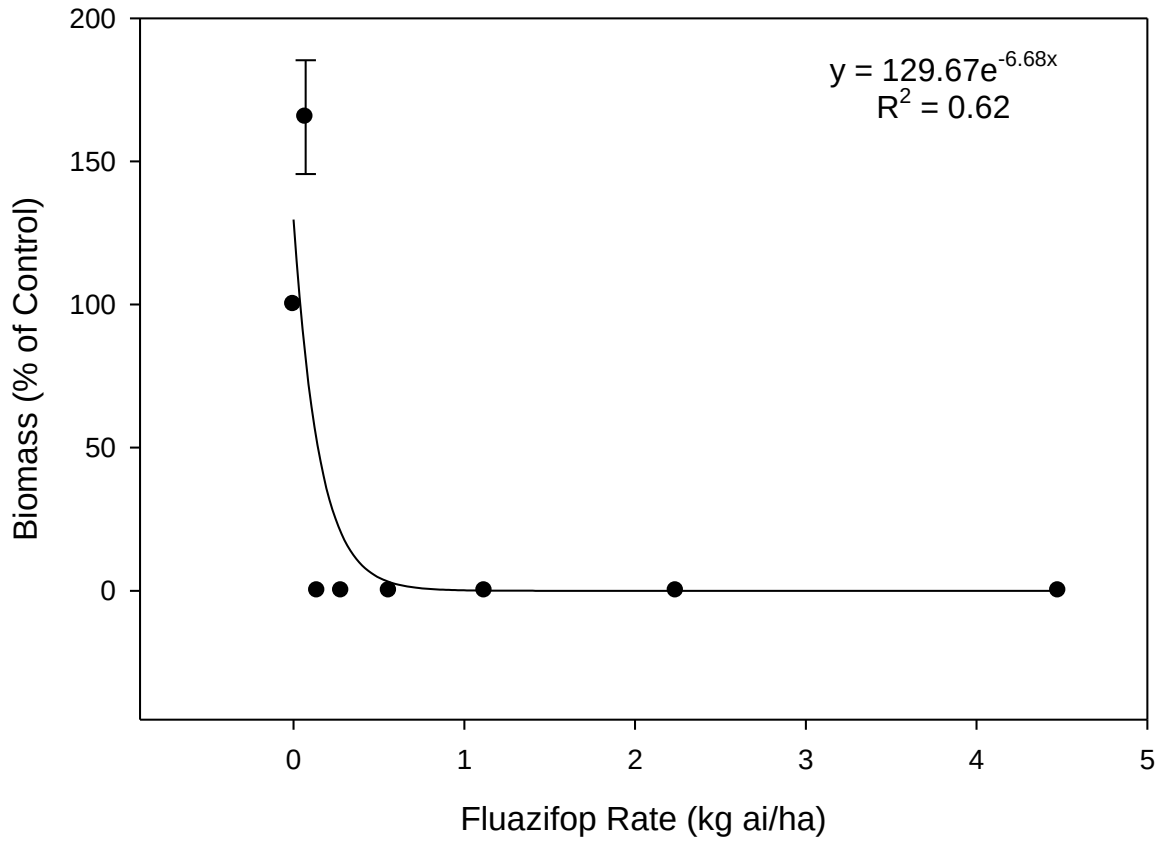

Figure 4-15. The effect of fluazifop applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 1. Values represent the mean of 4 replications with standard error.

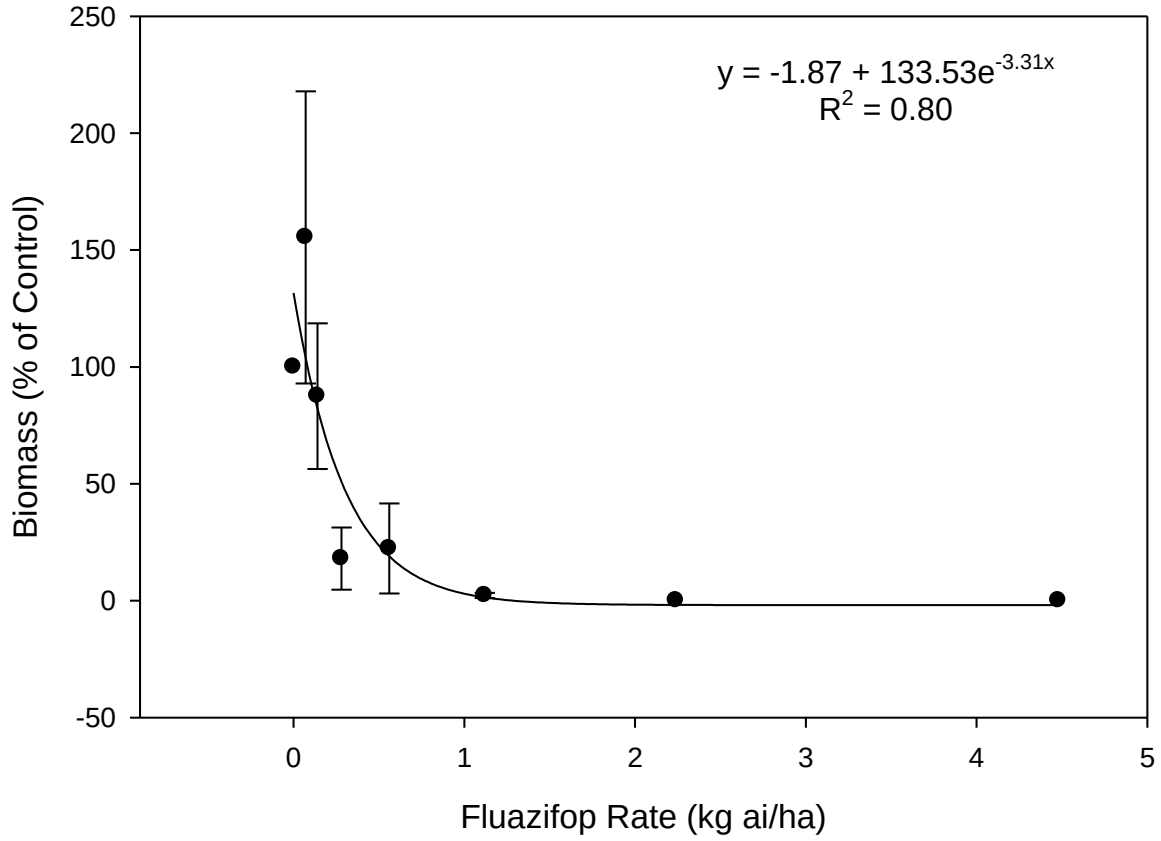

Figure 4-16. The effect of fluazifop applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 2. Values represent the mean of 4 replications with standard error.

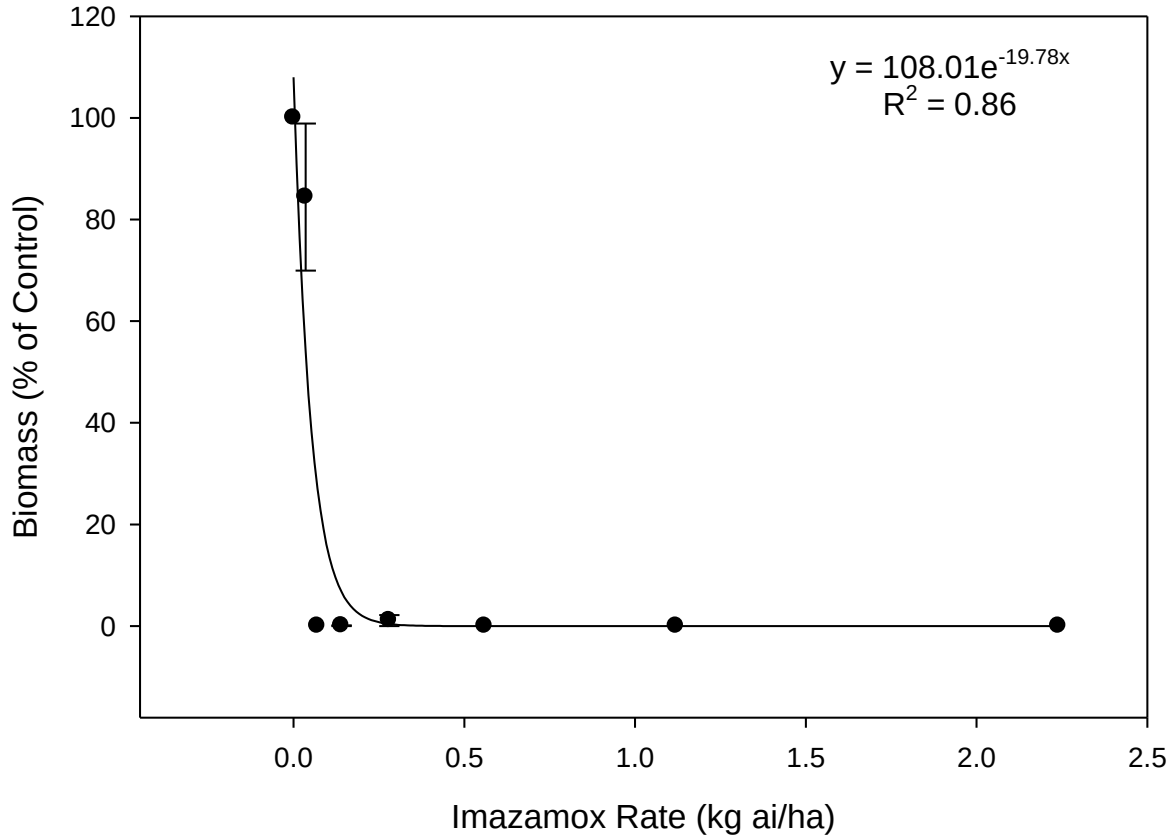

Figure 4-17. The effect of imazamox applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 1. Values represent the mean of 4 replications with standard error.

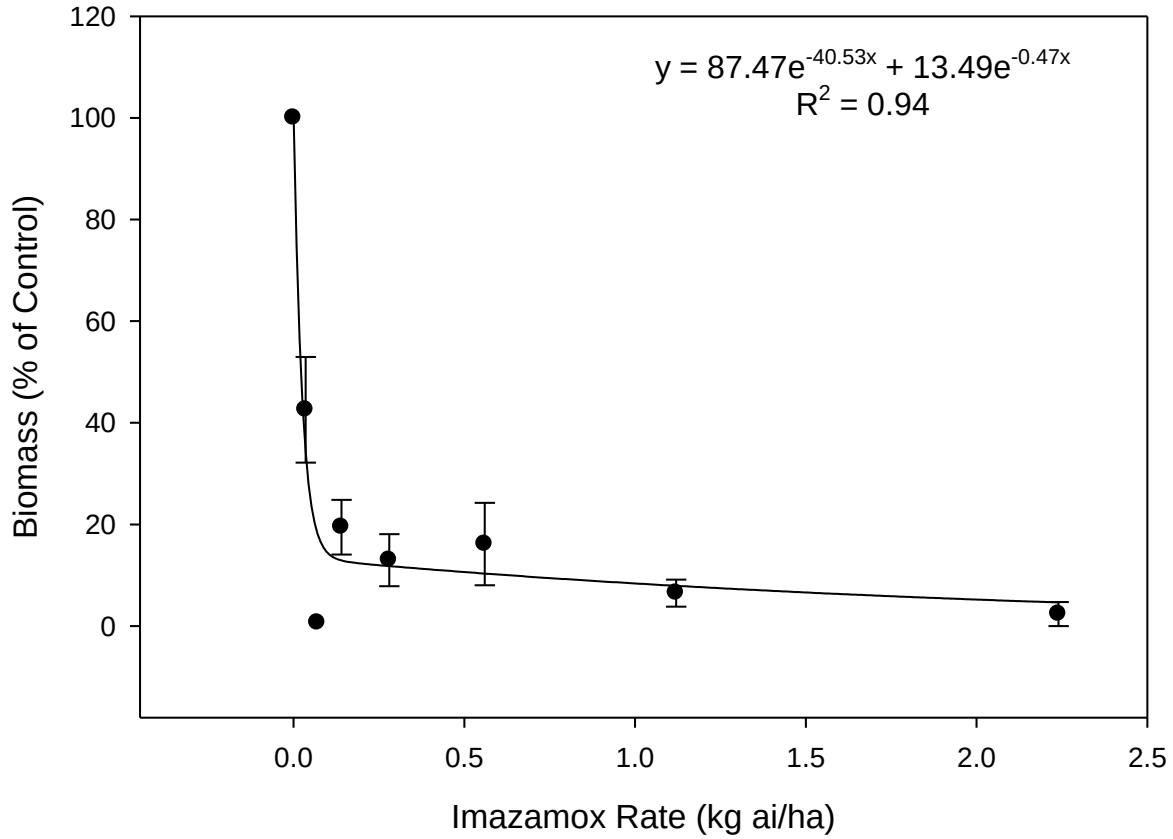

Figure 4-18. The effect of imazamox applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 2. Values represent the mean of 4 replications with standard error.

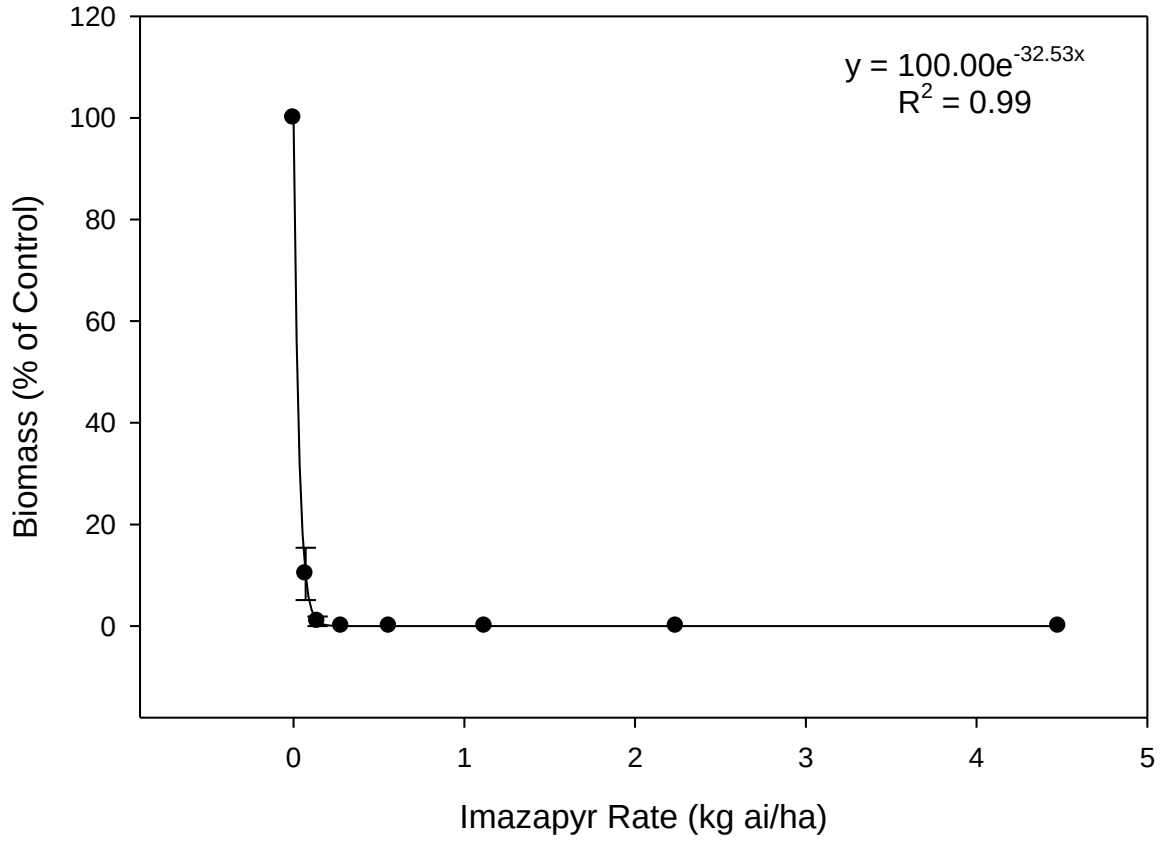

Figure 4-19. The effect of imazapyr applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 1. Values represent the mean of 4 replications with standard error.

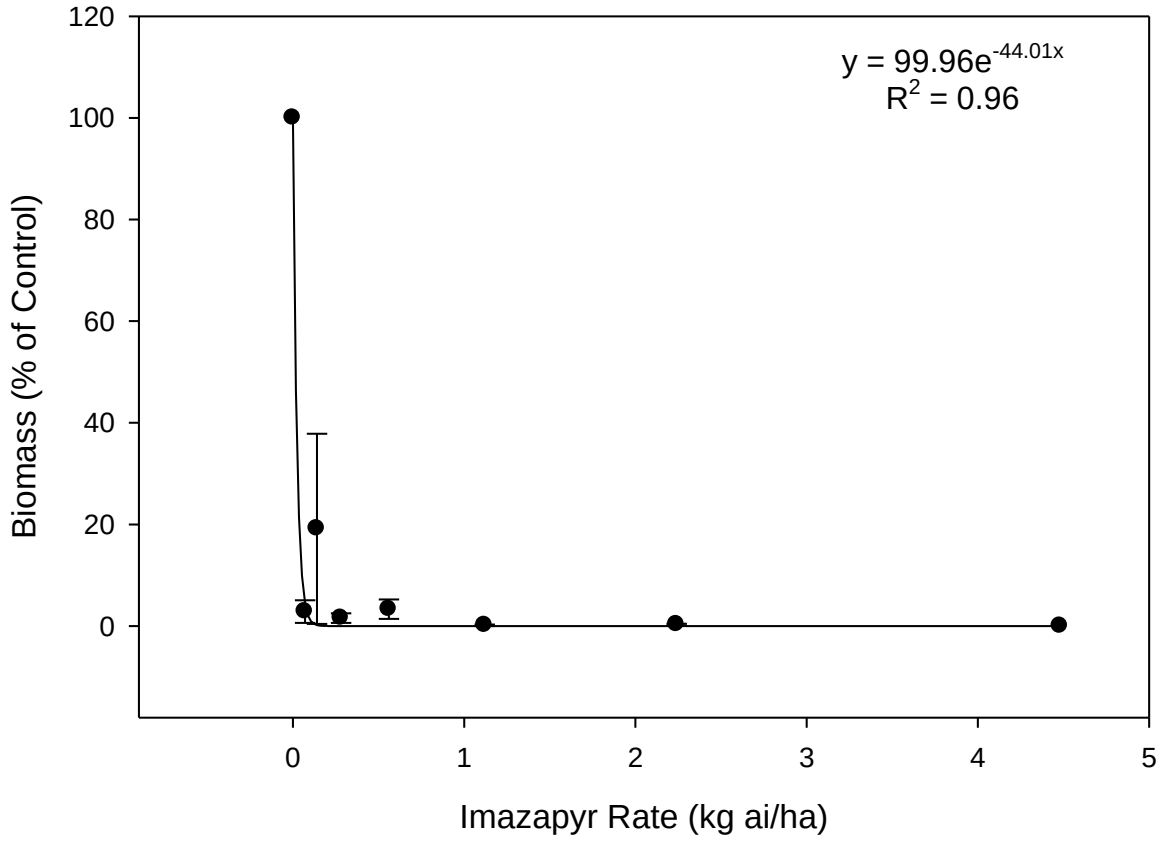

Figure 4-20. The effect of imazapyr applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 2. Values represent the mean of 4 replications with standard error.

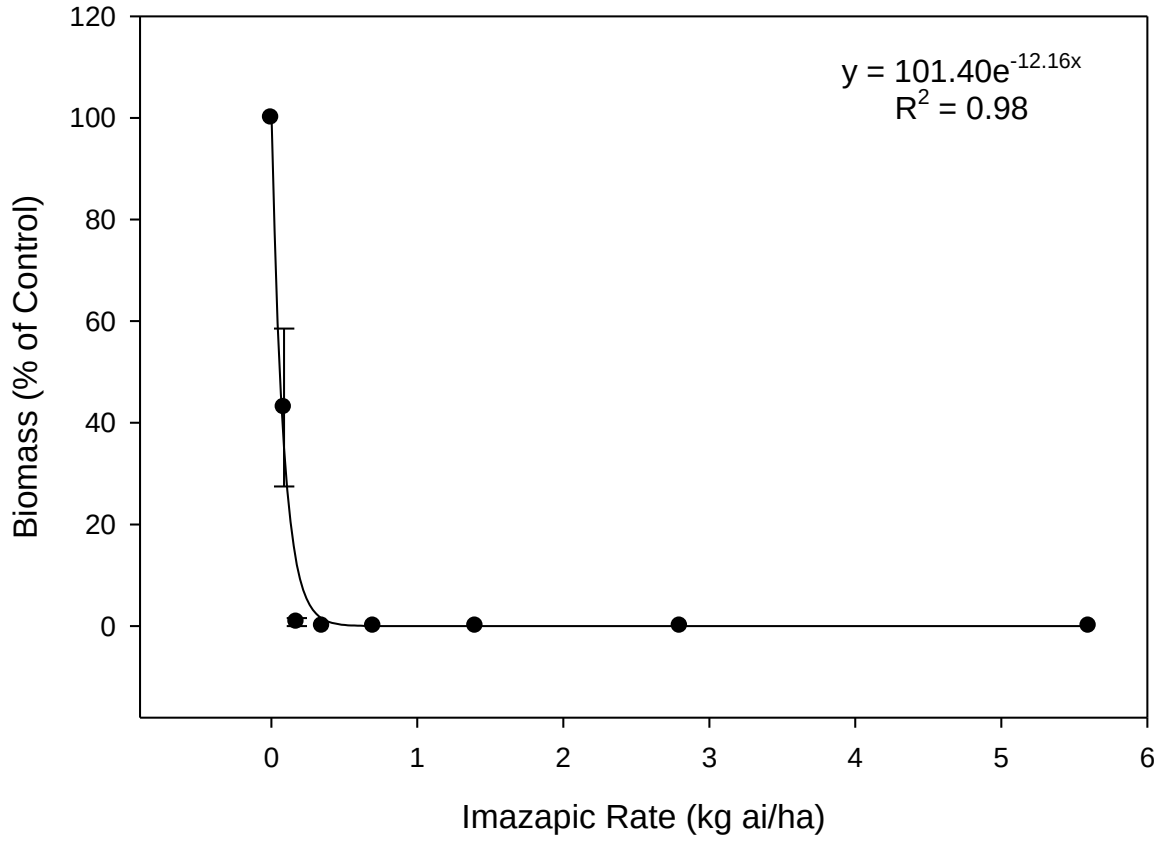

Figure 4-21. The effect of imazapic applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 1. Values represent the mean of 4 replications with standard error.

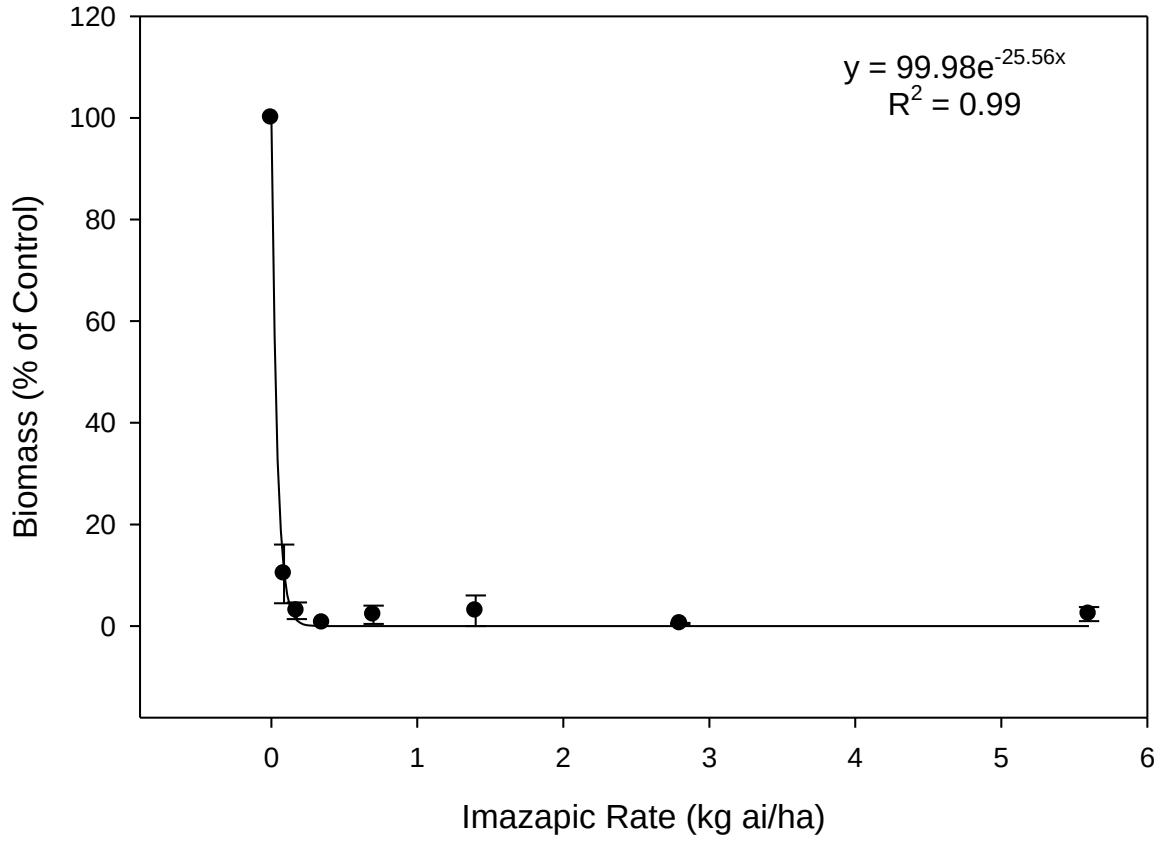

Figure 4-22. The effect of imazapic applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 2. Values represent the mean of 4 replications with standard error.

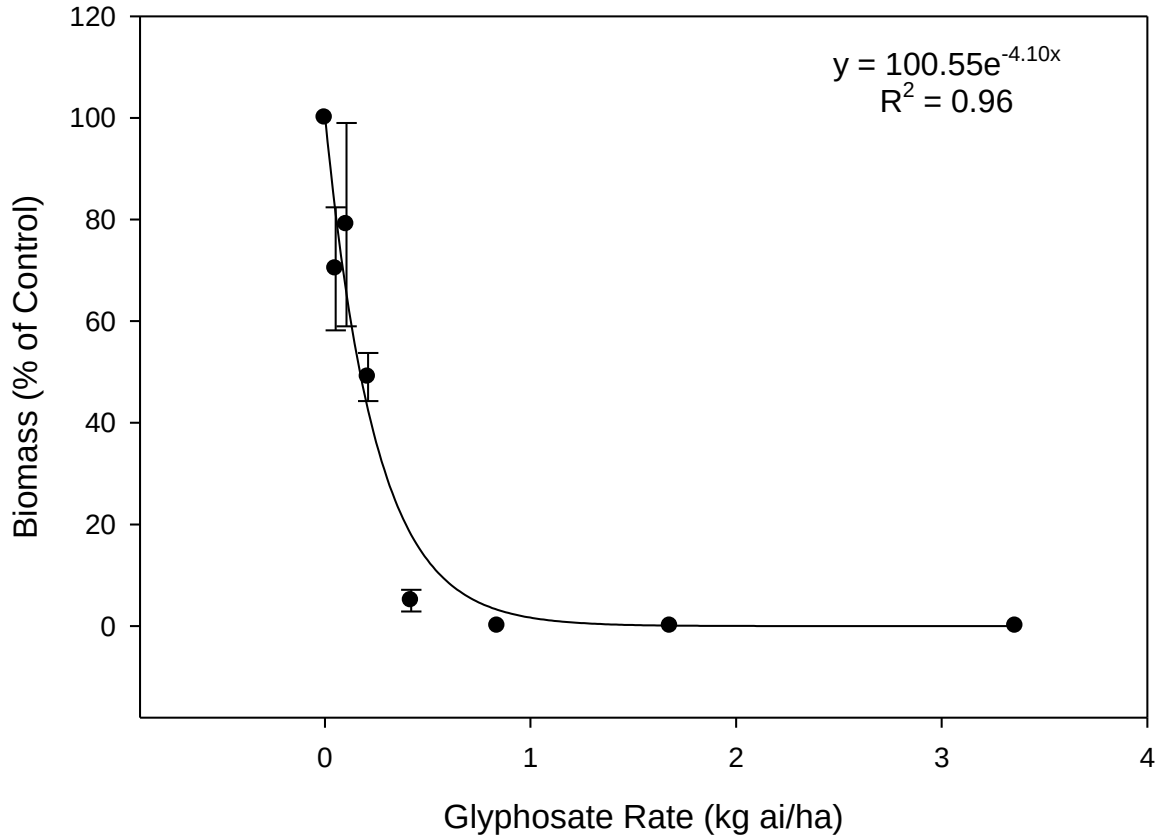

Figure 4-23. The effect of glyphosate applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 1. Values represent the mean of 4 replications with standard error.

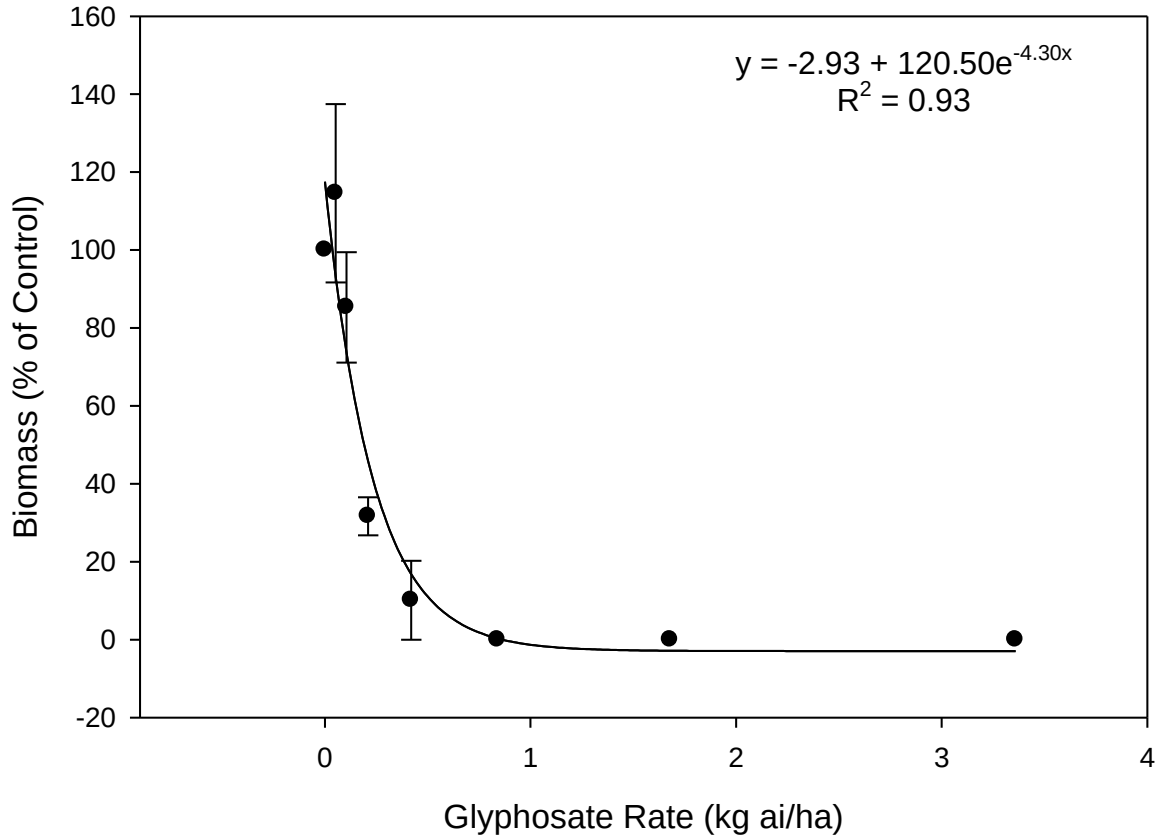

Figure 4-24. The effect of glyphosate applied postemergence on natalgrass biomass (expressed as a percentage of the dry weight of the untreated control). Trial 2. Values represent the mean of 4 replications with standard error.

CHAPTER 5
CONCLUSIONS

Natalgrass seeds do not require light for germination. Some germination occurs at 15 C, but most germination occurs at temperatures of 20 C and greater. Natalgrass germinates at pH levels of 6 and 8. Germination was highly dependent on available moisture, only occurring at osmotic potentials of -0.2 MPa and greater. Natalgrass seedlings are capable of emerging from depths of at least 5 cm. Natalgrass also appears to require an afterripening period after seed shed to reach maximum germination potential. Land managers should expect most natalgrass germination to occur as temperatures in the field reach 20 C and rainfall becomes regular. A preemergence herbicide application prior to this time may result in successful reduction of natalgrass at the site.

When buried, natalgrass seed appears to develop increased dormancy. Land managers can successfully utilize tillage to control natalgrass plants, but should be aware that this act will most likely result in seed burial and, therefore, seed dormancy. If tillage is utilized a second time and seeds are returned to the soil surface, managers should be prepared for germination of these seeds to occur.

Natalgrass forms dense seed deposits in infested areas, but these seed deposits appear to become quickly exhausted when conditions are favorable for germination. If land managers can control germinating seedlings for several months with a preemergence herbicide while preventing further seed rain at the site, a reduction in natalgrass will likely be achieved.

During monitoring of study sites, an overall decrease in natalgrass was observed in untreated plots as well as surrounding areas. This may indicate that natalgrass populations decline naturally as plant communities gain more structure. Natalgrass appears able to quickly invade disturbed areas, but did not persist as a monoculture for more than several years after disturbance at any of the research sites.

Metsulfuron and fluazifop offer little to no control of natalgrass at labeled use rates. The rates required to significantly reduce natalgrass populations are above the maximum labeled use rates. These herbicides offer little utility to land managers attempting to control natalgrass.

Glyphosate provides excellent control of natalgrass at fairly low rates. However, glyphosate does not have residual activity. As a result, natalgrass populations quickly became reestablished from seed. Glyphosate may offer good control short-term, but may cause an overall increase in natalgrass density long-term by eliminating competing plants.

Pendimethalin and metolachlor both offer good control of natalgrass when applied preemergence. However, both compounds were detrimental to native plant populations. These herbicides would be best utilized at a site with little to no seed bank present for native species.

Hexazinone and sulfometuron provided good control of natalgrass both pre- and postemergence. These herbicides were also harmful to most native plants present at the study sites. As a result, these herbicides would also be best utilized when few native plant species are present.

Imazamox, imazapyr and imazapic provided less control of natalgrass on average than hexazinone and sulfometuron, but were less harmful to native plant populations. These compounds did not result in a large decrease in natalgrass cover, but did result in severe stunting of natalgrass and delay of flowering and seed set. Of the three herbicides, imazapic appears to be the best choice when many native species are present. Many native plants in Florida are tolerant to this compound and gain a competitive advantage when imazapic is used.

APPENDIX
AFTERRIPENING STUDY

Introduction

Afterripening is the loss of a dormant state over a period of time through exposure of the seeds to a set of environmental conditions after maturation and separation from the parent plant (Simpson 1990). Common in many grass species such as wild oat (*Avena fatua* L.) and red rice (*Oryza punctata* L.) (Quail and Carter 1969; Leopold et al. 1988; Foley 1994), afterripening is influenced by environmental conditions such as temperature and moisture status (Foley 2001). The results of the experiment discussed in Chapter 2 examining natalgrass germination over time suggest that natalgrass likely undergoes an afterripening period after seeds are shed from the parent plant. Based on this conclusion, an experiment was designed to investigate the effects of seed moisture status over time on the afterripening process of natalgrass seeds.

Materials and Methods

Natalgrass seeds were collected from the Lake Louisa Mitigation Bank in Lake County, FL in December 2009. Seeds were collected with a sweep net directly from mature seedheads. Seeds were left in the husk to mimic natural conditions as closely as possible. The same day, seeds were sterilized by immersion in a 1% bleach solution with a non-ionic surfactant (0.25% v/v) to ensure that the bleach solution came in contact with the entire surface. Seeds were air dried under a sterile hood.

Seeds were placed into 6 sealed containers[21] each containing a different saturated salt solution. Salt solutions were placed in open Petri dishes in the bottom of the

[21] Thermo Scientific Nalgene Autoclavable Plastic Dessicators, Nalge Nunc International, 75 Panorama Creek Drive, Rochester, NY 14625

containers; seeds were placed in open Petri dishes on a metal rack in the upper portion of the chamber. Salts used and the corresponding relative humidity levels at 25 C can be found in Table A-1 (Winston and Bates 1960; Rockland 1960). The containers were placed in a growth chamber under constant light and a constant temperature of 25 C to maintain the desired relative humidity levels.

At 3, 6, 9, 12, 15 and 18 weeks after the beginning of the experiment, each container was opened and approximately 150 seeds quickly removed. Forty seeds from each container were weighed, dried at 50 C for 3 days, and weighed a second time. This data was used to determine seed moisture content at the time of removal from the containers. The remaining seeds were tested to determine germination levels.

Germination tests were performed by placing thirty seeds evenly in a 9 cm Petri dish[22] containing 1 piece of filter paper[23]. The filter paper was moistened with 4 mL of deionized water (pH = 6). Each Petri dish was sealed with parafilm and placed in a growth chamber at 30 ± 1 C under constant light. Germination was visually determined after 14 d. Any ungerminated seeds were tested for viability using a 0.25% tetrazolium solution. Seeds were removed from the husk and seed coat and placed in the tetrazolium solution for 24 h in the dark. Seeds were examined under a dissecting microscope and were counted as viable if the entire embryo was stained red or pink. Percentage of seed germination was calculated by dividing the number of germinated seeds by the number of total viable seeds in each Petri dish, then multiplying by 100. Each treatment was replicated 4 times.

[22] Fisherbrand Petri dishes, Fisher Scientific, 2000 Park Lane Drive, Pittsburgh, PA 15275.

[23] Fisherbrand P8 filter paper, Fisher Scientific, 2000 Park Lane Drive, Pittsburgh, PA 15275.

Results and Discussion

No reportable results were obtained from this experiment. At 3, 6 and 9 weeks after the beginning of the experiment, seeds were removed, weighed and tested for germination. However, accurate weights were not obtained and it was not possible to determine the moisture content of the seeds. If this experiment was performed a second time, a larger quantity of seeds should be weighed to ensure a more accurate measurement. Because natalgrass seeds are so light in weight, 40 seeds was not an adequate amount to measure the difference between dry and fresh weight (the fresh weight of 40 seeds was as low as 0.00426 g in this experiment). At such low weights, even small vibrations or tiny bits of debris can greatly influence measurements.

Table A-1. Saturated salt solutions and the corresponding relative humidity levels at 25 C[1].

Salt	Approximate Relative Humidity (%)
Phosphorus pentoxide [P_2O_5]	0
Lithium chloride [LiCl]	12
Magnesium chloride [$MgCl_2$]	33
Calcium nitrate [$Ca(NO_3)_2$]	51
Potassium chloride [KCl]	85
Potassium nitrate [KNO_3]	93

[1] From Winston and Bates 1960; Rockland 1960

LIST OF REFERENCES

Adjei, M. B. and J. E. Rechcigl. 2004. Interactive effect of lime and nitrogen on bahiagrass pasture. Pages 52–56 in Proceedings of the Soil and Crop Science Society of Florida. Gainesville, FL: Soil and Crop Science Society of Florida.

Baskin, C. C. and J. M. Baskin 1998. Seeds: Ecology, biogeography and evolution of dormancy and germination. San Diego, CA: Academic Press. 666 p.

Benvenuti, S. and M. Macchia. 1995. Effect of hypoxia on buried weed seed germination. Weed Res. 35:343–351.

Bradford, K. J. 1990. A water relations analysis of seed germination rates. Plant Physiol. 94:840–849.

Connell, J. H. and R. O. Slatyer. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. Amer. Natur. 111:1119–1144.

Evans, C. E. and J. R. Etherington. 1990. The effect of soil water potential on seed germination of some British plants. New Phytol. 115:539–548.

[FAWN] Florida Automated Weather Network. 2010. Archived Weather Data. http://fawn.ifas.ufl.edu/. Accessed October 13, 2010.

[FLEPPC] Florida Exotic Pest Plant Council. 2009. Florida Exotic Pest Plant Council's 2009 List of Invasive Plant Species. http://www.fleppc.org/list/List-WW-F09-final.pdf. Accessed October 1, 2010.

[FLMNH] Florida Museum of Natural History/University of Florida Herbarium. 2010. Collections Catalog. http://www.flmnh.ufl.edu/herbarium/cat/. Accessed October 8, 2010.

Foley, M. E. 1994. Temperature and water status of seed affect afterripening in wild oat (*Avena fatua*). Weed Sci. 42:200–204.

Foley, M. E. 2001. Seed dormancy: an update on terminology, physiological genetics, and quantitative trait loci regulating germinability. Weed Sci. 49:305–317.

Häfliger, E. and H. Scholz. 1980. *Rhynchelytrum repens* (Willd.) Hubb. Page 118 in Grass weeds I. Basle, Switzerland: Ciba-Geigy, Ltd. 142 p.

Haselwood, E. L. and G. G. Motter. 1966. Natal redtop. Page 75 in Handbook of Hawaiian weeds. Honolulu, HI: Hawaiian Sugar Planters' Association. 491 p.

Hernández-Quiroz, N., C. Ortega-Ochoa, C. Pinedo-Alvarez, O. Viramontes-Olivas, and J. A. Ortega-Gutierrez. 2010. Fire effect over soil seed bank seedling emergency of natal grass (*Melinis repens* (Willd.) Zizka) in Chihuahua grasslands. Proceedings of the Weed Science Society of America. In press.

Hitchcock, A. S. 1950. *Rhynchelytrum* Nees. Pages 716–717 in A. Chase, ed. Manual of the grasses of the United States, 2nd ed. Washington, DC: United States Department of Agriculture Miscellaneous Publication 200. 1051 p.

Klages, K. H. W. 1947. Ecological crop geography. New York City, NY: The Macmillan Company. 615 p.

Kleinschmidt, H. E. and R. W. Johnson. 1977. Red natal grass (*Rhynchelytrum repens*). Page 106 in Weeds of Queensland. Queensland, Australia: S.R. Hampson, Government Printer. 469 p.

Kluson, R. A., S. G. Richardson, D. B. Shibles and D. B. Corley. 2000. Response of two native and two non-native grasses to imazapic herbicide on phosphate mined lands in Florida. Pages 49–57 in Proceedings of the Annual Meeting of the American Society for Surface Mining and Reclamation. Lexington, KY: American Society for Surface Mining and Reclamation.

Leopold, A. C., R. Glenister, and M. A. Cohn. 1988. Relationship between water content and afterripening in red rice. Physiol. Plant. 74:659–662.

Lonsdale, W. M. 1993. Losses from the seed bank of *Mimosa pigra*: soil micro-organisms vs. temperature fluctuations. J. Appl. Ecol. 30:654–660.

MacDonald, G. E. 2004. Cogongrass (*Imperata cylindrica*)—Biology, ecology and management. Crit. Rev. Plant Sci. 23:367–380.

MacDonald, G. E., B. J. Brecke, and D. G. Shilling. 1992. Factors affecting germination of dogfennel (*Eupatorium capillifolium*) and yankeeweed (*Eupatorium compositifolium*). Weed Sci. 40:424–428.

MacDonald, G. E., J. A. Ferrell, B. Sellers, K. A. Langeland, T. Duperron Bond, and E. Ketterer Guest. 2008. In Invasive species management plans for Florida. Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences Extension Circular 1529.

Mislevy, P. and K. H. Quesenberry. 1999. Development and short description of grass cultivars released by the University of Florida (1892–1995). Pages 12–19 in Proceedings of the Soil and Crop Science Society of Florida. Gainesville, FL: Soil and Crop Science Society of Florida.

Possley, J. and J. Maschinski. 2006. Competitive effects of the invasive grass *Rhynchelytrum repens* (Willd.) C.E. Hubb. on pine rockland vegetation. Nat. Areas J. 26:391–395.

Provencher, L., B. J. Herring, D. R. Gordon, H. L. Rodgers, K. E. M. Galley, G. W. Tanner, J. L. Hardesty, and L. A. Brennan. 2001. Effects of hardwood reduction techniques on longleaf pine sandhill vegetation in northwest Florida. Restor. Ecol. 9:13–27.

Quail, P. H. and O. G. Carter. 1969. Dormancy in seeds of *Avena ludoviciana* and *A. fatua*. Aust. J. Agric. Res. 20:1–11.

Richardson, S. G., N. Bissett, C. Knott, and K. Himel. 2003. Weed control and upland native plant establishment on phosphate mined lands in Florida. In Proceedings of the Annual Conference on Ecosystems Restoration and Creation. Tampa, FL: Hillsborough Community College.

Rockland, L. B. 1960. Saturated salt solutions for static control of relative humidity between 5 and 40 C. Anal. Chem. 32:1375–1376.

Scott, J. M. 1913. Natal grass. Gainesville, FL: University of Florida Agricultural Experiment Station Press Bulletin 208. 2 p.

Segal, D. S., V. D. Nair, D. A. Graetz, N. J. Bissett, and R. A. Garren. 2001. Post-mine reclamation of native upland communities. Bartow, FL: Florida Institute of Phosphate Research Publication 03-122-159. 287 p.

Simpson, G. M. 1990. Seed dormancy in grasses. New York City, NY: Cambridge University Press. 297 p.

Small, J. K. 1933. *Tricholaena* Schrad. Pages 83–84 in Manual of the southeastern flora. Lancaster, PA: The Science Press Printing Company. 1554 p.

Tracy, S. M. 1916. Natal grass: a southern perennial hay crop. Washington, DC: U.S. Department of Agriculture Farmers' Bulletin 726. 16 p.

[USDA] United States Department of Agriculture Natural Resources Conservation Service. 2010. The PLANTS Database Plant Profile for Melinis repens (Willd.) Zizka. http://plants.usda.gov/java/profile?symbol=MERE9. Accessed October 11, 2010.

Van Mourik, T. A., T. J. Stomph, and A. J. Murdoch. 2005. Why high seed densities within buried mesh bags may overestimate depletion rates of soil seed banks. J. Appl. Ecol. 42:299–305.

Wesson, G. and P. F. Wareing. 1969. The induction of light sensitivity in weed seeds by burial. J. Exp. Bot. 20:414–425.

Wilder, B. J. 2009. Seed biology and chemical control of giant and small smutgrass. Master's Thesis. Gainesville, FL: University of Florida. 66 p.

Winston, P. W. and D. H. Bates. 1960. Saturated solutions for the control of humidity in biological research. Ecology 41:232–237.

Wunderlin, R. P. and B. F. Hansen. 2008. Atlas of Florida Vascular Plants. http://www.plantatlas.usf.edu/. Accessed October 9, 2010.

BIOGRAPHICAL SKETCH

Courtney Ann Stokes was raised in Leesburg, Florida. After graduating as Salutatorian from Leesburg High School in 2004, she attended the University of Florida, where she earned a Bachelor of Science, Cum Laude, in plant science with an emphasis in sustainable crop production and management. While an undergraduate, Courtney was involved in the Agronomy-Soils Club and was a captain on the University of Florida Fencing team.

In May 2008, Courtney began graduate studies in agronomy with a concentration in weed science. As a graduate student, Courtney was inducted into Alpha Zeta and Gamma Sigma Delta and was department representative to the University of Florida Graduate Student Council for 2.5 years. Courtney also served as a Teaching Assistant for PLS4601, Principles of Weed Science.

Courtney received her master's degree from the University of Florida in the fall of 2010. She plans to pursue a doctorate degree. She would like to continue research involving invasive plants and further her knowledge of ecology.