RESIDUAL HERBICIDE IMPACT ON NATIVE PLANT RESTORATION AS AN INTEGRATED APPROACH TO COGONGRASS MANAGEMENT

By

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RESIDUAL HERBICIDE IMPACT ON NATIVE PLANT RESTORATION AS AN INTEGRATED APPROACH TO COGONGRASS MANAGEMENT

By

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Field studies were conducted to evaluate the impact of soil residues of imazapyr on native species establishment. Both broomsedge and silkgrass showed at least 30% injury at all rates of imazapyr, and only *Eucalyptus grandis* showed less than 30% injury at rates above 0.033 kg ai/ha. Imazapyr caused significant injury to all species at rates higher than 0.56 kg ai/ha. Wax myrtle and longleaf pine showed greater than 60% mortality at the lowest rate of imazapyr (0.018 kg ai/ha), while mimosa and both *Eucalyptus* species show less than 60% mortality at the highest rate of 1.12 kg ai/ha.

Three areas were sprayed with 0.84, 1.68, and 3.36 kg ai/ha imazapyr in 2002 and soil core sampling occurred immediately prior to application, immediately after application, and at 1, 3, 6, and 12 months after treatment (MAT). Imazapyr concentration was determined using a corn-root bioassay. At the lowest application rate of 0.84 kg ai/ha, sand soil samples give a consistently similar rate at 0 MAT. There was no detection of imazapyr at 1 MAT, and a trace amount was detected at 3 MAT (0.0005 kg

ai/ha). In the clay soil, samples taken 0 MAT were similar in value (0.078, 0.066, and 0.074 kg ai/ha for the plots sprayed with 0.84, 1.68, and 3.36 kg ai/ha, respectively). In the overburden area, the plots treated with 0.84 kg ai/ha had measured residues that decreased to 0.016 kg ai/ha 1 MAT and 0.0095 kg ai/ha 3 MAT. Overall, imazapyr dissipation was faster in sand tailings, with mixed results occurring between clay and overburden soil.

In the area treated in 2000, 25 random soil samples were taken from each plot and categorized based on proximity to cogongrass. Approximately half of all samples were in a cogongrass-free area for both glyphosate and imazapyr plots. Thirty-eight percent of samples taken were within 2 feet of cogongrass and approximately half of these samples contained rhizomes. Only 9 and 6% of samples from the glyphosate and imazapyr plots were within cogongrass patch and all these samples contained rhizomes.

Bioassay data were combined with plant species injury and mortality data to create a timetable to best estimate optimal planting dates per species. In both the clay and overburden area, six species can be planted immediately after imazapyr application and expect to show at least a 40% survival rate. *E. grandis* can be planted after one month in clay and overburden to exhibit no more than 30% injury 10 weeks after planting (WAP). *E. amplifolia*, mimosa, and bluejack oak also show slightly longer time periods in overburden soils as compared to clay soils. Silkgrass and broomsedge need three months before planting until soil residues are within range of I_{30} values. Wiregrass was the most sensitive showing at least 30% injury at all rates of imazapyr regardless of plantback interval. In a repeated study, similar predicted dates were generated according to I_{30} values for *E. grandis* and switchgrass.

CHAPTER 1
INTRODUCTION

Cogongrass [*Imperata cylindrica* (L.) Beauv.] is a rhizomatous perennial grass species found throughout much of the tropical and sub-tropical regions of the world, being widely distributed in Africa, Asia, Europe, North and South America, and Australia (Holm et al. 1977). This species predominates in the eastern hemisphere, where it covers over 200 million hectares in Asia alone (Garrity et al. 1996). Worldwide, cogongrass infests over 500 million hectares and is considered the world's seventh worst weed (Holm et al. 1977). In the United States, it is widely spread throughout Florida and much of southern Alabama and Mississippi, infesting several hundred thousand acres (Johnson et al. 1999). Cogongrass can usually be found in predominately non-agricultural settings in the United States, and spreads over vast areas where vegetation is marginally supported, suppressing and displacing many native plants (Bryson and Carter 1993).

Cogongrass Characteristics

First introduced into the U.S. as a packing material from Japan in 1912, cogongrass initially invaded areas of Alabama (Dickens 1974). The weed was later introduced purposefully in Mississippi as potential forage in 1921 (Patterson et al. 1979). Other forage evaluations of cogongrass were later carried out in Texas, Alabama, Mississippi, and Florida with spread being hindered from the Texas site due to winter kill (Dickens and Moore 1974). Studies concluded that this potential forage was not suitable for livestock because of its high silica content in the leaf tissue. This highly aggressive weed is now a primary invader of disturbed lands, displacing desirable and native vegetation

(Terry et al. 1997). Unfortunately, the occurrence of cogongrass has increased drastically during the past twenty years (Bryson and Carter 1993) and is currently reported in much of the southeast United States.

Cogongrass tolerates a wide range of soil conditions but appears to grow best in soils with acidic pH, low fertility, and low organic matter. Cogongrass infestations occur in a wide range of habitats from shoreline course sands to the >80% clay soils of reclaimed phosphate settling ponds (MacDonald 2004). Cogongrass is highly efficient in nutrient uptake (Saxena and Ramakrishnan 1983) and reportedly has an association with mycorrhiza, which may help explain its competitiveness in unfertile soils (Brook 1989). Cogongrass is able to spread and persist through several survival strategies including an extensive rhizome system, adaptation to poor soils, drought tolerance, prolific wind disseminated seed production, fire adaptability, and high genetic plasticity (Holm et al. 1977; Dozier et al. 1998). With the exception of a flowering stalk, cogongrass is virtually stemless. The leaves are slender, flat, and linear-lanceolate, and possess serrated margins and a prominent off-center white mid-rib (Terry et al. 1997). Silicates accumulate in the serrated margins of the leaves, which deter herbivory (Dozier et al. 1998).

Cogongrass rhizomes can comprise over 60% of the total plant biomass (Sajise 1976). This low shoot to root/rhizome ratio contributes to its rapid regrowth after cutting or burning. Cogongrass rhizomes are white and tough with shortened internodes. Specialized anatomical features help to conserve water within the central cylinder and help to resist breakage and disruption when trampling or disturbance occurs (Holm et al. 1977). Rhizomes are predominately found within the top 15 cm of fine textured soils or the top 40 cm of course textured soils. However, rhizomes have been discovered growing at depths of 120 cm (Holm et al. 1977; Gaffney 1996). According to Tominaga (2003), cogongrass rhizomes can be grouped in the following three categories: tillering, secondary colonizing, and pioneer rhizomes. Unlike cogongrass seedlings, which are defined as R-strategist (ruderal) and invade open patches in disturbed habitats, rhizomes from current cogongrass stands are defined as C-strategist (competitor) that can persist in established populations (Tominaga 2003). These rhizomes provide a tremendous amount of biomass for regeneration after foliar loss, with one study showing rhizome length of over 89 meters within one square meter of soil surface area (Lee 1977).

Cogongrass is also a prolific seed producer, with shortly branched, compacted and dense seed heads producing over 3000 seeds per plant. Each brownish colored seed (grain) possesses a plume of long hairs that affect wind dispersal. These plumed seeds travel over long distances averaging 15 meters (Holm et al. 1977), but Hubbard (1944) stated that cogongrass seeds could travel up to 24 kilometers over open country. Flowering is highly variable depending on region and environment. Cogongrass flowering occurs year-round in the Philippines (Holm et al. 1977), whereas flowering in the United States occurs in the late winter/early spring (Shilling et al. 1997). Disturbances including burning, mowing, grazing, frost, or the addition of nitrogen can also stimulate flowering (Holm et al. 1977; Soerjani 1970; Sajise 1972).

Current Management Strategies

Current control methods for cogongrass rely heavily on chemical treatments, which provide limited long-term control. The main reason for this limited control is the presence of cogongrass rhizomes, which can comprise over 2/3 the total plant biomass. These rhizomes contain multiple nodes from which regrowth may occur, but generally only a fraction sprout at any given time (English 1998). Mowing is also often included as a control method with chemical application. While mowing alone does not effectively control cogongrass, it has been shown to reduce rhizome and foliar biomass (Willard and Shilling 1990). However, the integration of mowing with chemical applications resulted in poor control compared to conventional application techniques (Marchbanks et al. 2002). Cultivation has proven effective, with little or no regrowth occurring under continuously cultivated conditions (Hartley 1949). However, the high costs and limited utility in many areas precludes use of this type of method. Johnson et al. (1999) showed that a single discing in combination with herbicides did not significantly enhance cogongrass control compared to herbicide alone. A second discing provided better control than just single discing but also did not enhance control over herbicide treatments. Therefore, sporadic mechanical control treatments are less effective than other approaches and often exacerbate the situation.

Over the last three decades, several herbicides have been evaluated for cogongrass control with minimal success (Dickens and Buchanan 1975). Presently, the most effective herbicides are glyphosate [N-(phosphonomethyl)glycine] and imazapyr {(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imadazol-2-yl]-3-pyridinecarboxylic acid (Dozier et al. 1998). Generally, imazapyr provides control for a longer period of time due to soil activity, but off-target effects limits use in certain areas (MacDonald et al. 2002). These chemicals are broad-spectrum, systemic herbicides that, in general, can effectively control cogongrass for one year after application (Miller, 2000). Imazapyr is used to control annual and perennial weeds, deciduous trees, and vines in rights-of-way and other noncropland areas, as well as in forestry as a conifer releasing agent (Anon. 2002). The mode of action of imazapyr, a member of the imidazolinone family of herbicides, involves the inhibition of acetohydroxyacid synthase (AHAS), which is needed for branched chain amino acid synthesis (Shaner 1991). Field half-life values range from 25-142 days depending on soil type and environmental conditions, with soil adsorption increasing as organic matter and clay content increase (Anon. 2002). Imazapyr is relatively harmless to animals, and if used correctly, has minimal off-target impacts (Mangels 1991). Research to date has indicated imazapyr at 1.12 kg ai/ha applied late summer/early fall provides cogongrass control for as long as 18 months (Dozier et al. 1998). This application timing has been attributed to the basipetal flow of photosynthates and herbicides that occur at this time of year, which results in improved rhizome lethality (Gaffney 1996). After this time, cogongrass will re-form a monotypic stand within 1-2 years if additional treatments are not imposed (Dozier et al. 1998). Burning prior to herbicide application has shown the ability to remove old growth and dead biomass and provides several benefits (Johnson et al. 1999). Starch storage reserves in rhizomes are forced to re-allocate to produce new shoot growth, thereby weakening the rhizomes. Also, removal of the substantial biomass improves the ability to effectively apply herbicides. Herbicide application to the regrowth of new plant tissues also maximizes absorption and results in greater efficacy (Johnson et al. 1999).

Imazapyr provides good control of cogongrass but has limited utility due to the long residual effects of this compound, which could hinder revegetation strategies and native recruitment. In previous research, several native species were evaluated under greenhouse conditions for response to imazapyr used in non-cropland situations. Imazapyr caused severe injury to most species evaluated, but injury was restricted to a foliar application only (Miller et al. 2002). A more accurate assessment of successful native species growth and establishment is when the concentration of residual herbicide in the soil is at a tolerable level. Initial research indicates the residual activity of imazapyr may be less than theorized, allowing for more flexibility in a revegetation scheme. A better understanding of native species response to imazapyr soil concentration could provide greater flexibility when developing revegetation schemes. Varying initial rate and time of transplanting after application could provide land managers with a greater number of native species to select.

Other major factors in the determination of timing and revegetation include the total amount of chemical used and the soil type to which the herbicide is applied. Soil type has an important influence on the residual amount of herbicide due to the soil structure and content of clay and organic matter. In sandy soils, there are fewer charged sites that the herbicide can adsorb to, and leaching often occurs. Therefore, sandy soils contain less residual matter after a given period of time than a clay soil, which has a much greater affinity for adsorption (McBride, 1994). Also, herbicides tend to persist longer in loamy and silty soils due to reduced leaching compared to sandy soils. Because of the diversity of soils in Florida, as well as much of the U.S., an understanding of herbicide persistence as a function of soil type is important in predicting the best time to revegetate.

In central Florida, reclaimed mining sites have a diverse collection of soil types with overburden, sand tailings and phosphatic clay pits being three of the most prominent (Richardson et al. 2003). Overburden, a mixture of sand and clay, is removed from the land surface above the ore body and piled on the side. Overburden shows the highest variability in soil texture, soil color and soil chemical parameters (Segal et al. 2001).

This soil type is on average composed of 80% sand, 8% silt, and 12% clay with a pH of 5.8.[1] Overburden has slightly greater clay and silt content, higher water-holding capacity, and greater P and K content than native Floridian soils, which may give aggressive weeds a competitive advantage over slower-growing natives (Richardson et al. 2003). The phosphate ore currently being mined is an unconsolidated mixture of sand, clay, and phosphate mineral. The sand tailings are separated from this ore and hydraulically pumped to fill mine cuts between overburden piles. Although sand tailings are usually nutrient-poor and droughty compared with these three other soil types (Segal et al. 2001), they have higher P and K contents and slightly coarser grain sizes than native soils (Kluson et al. 2000). Phosphatic clay is washed from phosphate ore and pumped, at about 3-5% solids, to settling areas. This clay commonly has pH values near 7.5, while some older sites with good forest cover and higher organic matter have pH values near 6.8. This soil type covers about 40% of the mined area and is considered highly fertile (Stricker 2000).

These three soil types involved in phosphate mining processes are highly diverse in nature, yet they are all susceptible to cogongrass and other non-native weed invasions. This is due to the disturbance of the areas during the mining process and the associated harsh conditions to which plants are subjected.

For long-term control of cogongrass, further methods need to be integrated into the traditional control techniques mentioned above. Even in areas where management has been successful, cogongrass re-infestation will often occur. Because of this, studying the

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[1] Richardson, S.G. 2004. Personal Communication.

reinfestation aspects of cogongrass, especially from rhizomes, is also an important aspect of overall integrated control.

Revegetation

In Florida, reclaimed phosphate mining areas are important areas for cogongrass control and native plant restoration. Because mining disturbance creates a hospitable environment for weed invasion, one of the most difficult barriers to successful restoration is the control of cogongrass and other invasive weeds. Effectively returning mined lands and lands infested with cogongrass to self-sustaining native upland communities with functional ecological value would be beneficial to the mining industry, local communities, and the state of Florida (Miller et al. 2002). Mined land restoration is crucial in Florida because upland ecosystems in Florida have been dramatically reduced in area (Richardson et al. 2003) due to a variety of causes, including mining, development, and agriculture. Determining which species will be most successful in a restoration scheme involves several factors, such as imazapyr tolerance, competitiveness with cogongrass and other invasive species, and overall desirability.

The cornerstone of integrated management and restoration is the establishment of a self-sustaining native plant community. Previous studies show that wiregrass (*Aristida beyrichiana* Trin. and Rupr.) is a pivotal native grass in areas of phosphate mining and is highly desired for use in reclamation (Norcini et al. 2003). Wiregrass is often the dominant grass species in Florida uplands, and foresters have long preferred this species as well as broomsedge (*Andropogon virginicus* L.) for pine forest understory because of their ability to carry a fire (Pfaff et al. 2002). Silkgrass [*Pityopsis graminifolia* (Michx.) Nutt.] also proved highly adaptable to reclaimed mining land soils and was selected as a candidate for future large-scale assembly and seed source development (Pfaff et al.

2002). Gopher apple (*Licania michauxii* Prance) is a drought-tolerant woody plant native to Florida uplands, is locally abundant, and can function as a ground cover. It is consistently demanded for use in a variety of restoration and mitigation projects, and it is a prime candidate for use in mine reclamation (Norcini et al. 2003). Another species of interest is lovegrass [*Eragrostis spectabilis* (Pursh) Steud.]. This pioneer species is important because it has the potential to be a good competitor against aggressive species while allowing other slow-growing species to become established (Segal et al, 2001). Wax myrtle [*Myrica cerifera* (L.) Small], switchgrass (*Panicum virgatum* L.), and creeping mimosa (*Mimosa strigillosa* Torr. and Gray) are three additional perennial species that have been studied in plantback studies involving imazapyr (Miller et al, 2002).

Tree species are also important in successful native plant restoration. Weed management in pine (*Pinus* spp.) has been extensively studied, and imazapyr is widely used in pine culture throughout the south (Lauer et al. 2002). Longleaf pine (*Pinus palustris* P. Mill.) is native to Florida and is widely desired in revegetation scenarios. In addition to pines, Florida was historically heavily forested with stands of bluejack oak (*Quercus incana* Bartr.) and sand live oak (*Quercus geminata* Small). Recent studies have tested imazapyr as a site preparation herbicide for oak species with promising results (Schuler et al. 2004). Other trees for potential use in a revegetation scheme are eucalyptus (both *Eucalyptus grandis* W. Hill ex Maid. and *Eucalyptus amplifolia* Naudin). Although these eucalyptus species are considered exotic and non-native, they are shown to be non-invasive. This is because eucalyptus has been grown in south and central Florida since the 1970’s with no evidence of escaping into the environment

(Rockwood 1996). These trees are potentially good at suppressing cogongrass after initial control because of good growth during the first year while typically dominating other vegetation for the rest of the rotation (Stricker 2000). Eucalyptus also grows faster than native tree species in peninsular Florida (Rockwood et al. 1996), making them good candidates for bioenergy crop production. The humid Lower South has the most suitable climate (warm temperature, high rainfall, and longest warm growing season) for biomass crops in the continental US, and Eucalyptus species, especially *Eucalyptus grandis*, is now showing the greatest potential for reclaimed mining lands (Prine and French 1999). Under intensive cultivation and close spacing, *E. amplifolia* can yield as much as 25 dry mg/ha/yr on good sites in northeastern Florida, and *E. grandis* can yield up to 35 dry mg/ha/yr in central and southern Florida (Prine and French 1999; Segrest et al. 1998).

This wide selection of both native and non-native plant species possesses qualities that are desirable for many revegetation studies for reclamation. Characteristics such as tolerability to variable amounts of imazapyr in the soil and effective competitiveness with cogongrass regrowth are important in choosing which plant species to use in successful revegetation work. In combination with more traditional control methods, a comprehensive revegetation plan might be the most important link in overall cogongrass control and spread prevention.

If complete cogongrass control is the ultimate goal, the utilization of current management techniques has been shown to be only marginally successful. Eradication with herbicides such as imazapyr is theoretically possible but is undesirable for several reasons. This type of approach invites erosion, is unsightly, and will prevent the introduction of desirable native species. Ideally, cogongrass should be gradually eliminated while desirable species are introduced. Taking into consideration factors such as residual herbicide amount, plant tolerance levels, and soil types can be very beneficial to an overall cogongrass control strategy. Also, visual monitoring of both disturbed and undisturbed areas previously treated for cogongrass will provide information on plant succession, rhizome dormancy and spread, and long-term growth habits of cogongrass in competition with other, more desirable plant species.

CHAPTER 2
THE RESPONSE OF SELECTED REVEGETATION SPECIES TO IMAZAPYR CONCENTRATIONS IN SOIL

Introduction

Cogongrass [*Imperata cylindrica* (L.) Beauv.] is an aggressive perennial grass species which infests over 500 million hectares worldwide and is considered the world's seventh worst weed (Holm et al. 1977). In the United States, it is widely spread throughout Florida and much of southern Alabama and Mississippi, infesting several hundred thousand acres (Johnson et al. 1999). Cogongrass can usually be found in predominately non-agricultural settings in the United States. Cogongrass tends to spread over vast areas where vegetation is marginally supported, suppressing and displacing many native plants (Bryson and Carter 1993). Cogongrass tolerates a wide range of soil conditions but appears to grow best in soils with acidic pH, low fertility, and low organic matter. This invasive plant is able to spread and persist through several survival strategies including an extensive rhizome system, adaptation to poor soils, drought tolerance, prolific wind disseminated seed production, fire adaptability, and high genetic plasticity (Holm et al. 1977, Dozier et al. 1998).

Current control methods for cogongrass rely heavily on chemical treatment, which provides limited long-term control. To date, the most effective herbicides for cogongrass management are glyphosate and imazapyr (Dozier et al. 1998; Barnett et al. 2000; MacDonald et al. 2002). Generally, imazapyr provides control for a longer period of time due to soil activity, but off-target effects limits use in certain areas (MacDonald et al. 2002). Research to date has indicated imazapyr at 1.12 kg-ai/ha applied late summer/early fall provides control for as long as 18 months (Dozier et al. 1998). Burning prior to herbicide application provides several benefits including rhizome weakening due to new shoot growth and removal of old biomass for more effective herbicide application (Johnson et al. 1999).

Imazapyr provides good control of cogongrass but has limited utility in reclamation projects due to the long residual effects of this compound. Although there is ample information on the effect of several herbicides on weedy species, little information regarding the herbicide tolerance (i.e., selectivity potential) of native species is available. In previous research by Miller et al. (2002), several native species were evaluated under greenhouse conditions for response to imazapyr used in non-cropland situations. Imazapyr caused severe injury to most species, but this injury was reflective to a foliar application only. In most practical field situations, herbicides are usually sprayed to control cogongrass with little or no subsequent control measures. These areas often become reinfested because of a lack of suppressive cover and/or incomplete initial control. An important step in the further suppression of cogongrass is to establish a native plant cover as soon as the residual herbicide levels in the soil become tolerable to the revegetation species. It is important to quantify soil residual levels to best predict effective revegetation timing for the most effective suppression of cogongrass. Therefore, an understanding of plant species response to imazapyr residues in soil will ultimately be beneficial for restoration purposes in southeastern ecosystems (MacDonald et al., 2002).

Many plants tolerate herbicides, including imazapyr, differentially, so an understanding of the effects of imazapyr on the selected revegetated species is crucial. Determining which species will be most successful in plantback situations involves several factors, such as imazapyr tolerance, competitiveness with cogongrass and other invasive species, and overall desirability. Because the cornerstone of integrated management and restoration is the establishment of a self-sustaining native plant community, primary emphasis for this study was placed on native Floridian plant species. Species such as wiregrass (*Aristida beyrichiana*), broomsedge (*Andropogon virginicus*), and silkgrass (*Pityopsis graminifolia*) are desired native grasses for use in reclamation (Norcini et al. 2003). Woody plants such as gopher apple (*Licania michauxii*), wax myrtle (*Myrica cerifera*), and creeping mimosa (*Mimosa strigillosa*) have also been studied in plantback research involving imazapyr (Miller et al, 2002). Other species of interest are lovegrass (*Eragrostis spectabilis*) and swichgrass (*Panicum virgatum*), which can potentially be good competitors against aggressive species while allowing other slow-growing species to become established (Segal et al, 2001).

Tree species are also important in successful native plant restoration. Longleaf pine (*Pinus palustris*) is native to Florida and is widely desired in revegetation schemes. In addition, Florida was historically heavily forested with stands of bluejack oak (*Quercus incana*) and sand live oak (*Quercus geminata*). Recent studies have tested imazapyr as a site preparation herbicide for oak species with promising results (Schuler et al. 2004). Other trees for potential use in a revegetation scheme are eucalyptus (both *Eucalyptus grandis* and *Eucalyptus amplifolia*). Although these eucalyptus species are considered exotic and non-native, they are non-invasive. These trees are potentially good at suppressing cogongrass after initial control because they show good growth during the first year while typically dominating other vegetation for the rest of the rotation (Stricter 2000). Eucalyptus also grow faster than native tree species in peninsular Florida (Rockwood et al. 1996), making them good candidates for bioenergy crop production.

This wide selection of both native and non-native plant species possesses qualities that are desirable for many revegetation scenarios. Characteristics such as tolerability to variable amounts of imazapyr in the soil and effective competitiveness with cogongrass regrowth are important in choosing which plant species to use in successful revegetation work.

Materials and Methods

Field experiments were conducted in the summer of 2004 at the Plant Science Research and Education Unit (PSREU) in Citra, Florida. The soil type at Citra is a Sparr sand (loamy, siliceous, hyperthermice Grossa-renic paleudult) with 1% organic matter and a pH of 6.4. The field area was conventionally prepared using standard tillage practices. Imazapyr (Arsenal 4 SC) was applied at 0.0, 0.018, 0.036, 0.071, 0.14, 0.28, 0.56, and 1.12 kg-ai/ha using a backpack CO_2 sprayer calibrated to deliver 187 L/ha. Applications occurred on June 22 and July 21, 2004, for the first and second experiments, respectively. Immediately after application, the herbicide was lightly incorporated into the soil to a depth of 5 to 7.6 centimeters. Plots were 6 x 7.6 m^2 plots and arranged in a completely randomized block design with four replications. Within 24 hours of herbicide application, 3 seedling plants of each species were hand planted into the soil in a 76 cm x 76 cm spacing per plant. A native plant nursery supplied all native plant seedlings used in the studies,[1] and the two Eucalyptus species were obtained from Dr. Don Rockwood of the University of Florida.[2] Common name, scientific name, and plant size at time of transplanting for all species are listed in Table 2.1. All species were evaluated for percent mortality at 10 weeks after planting. In addition, several species were evaluated for percent injury at 6 and 10 weeks after planting where 0 = no injury and 100 = plant death. Data were subjected to analysis of variance to test for main effects and interactions. Regression analysis was used to predict species response to imazapyr.

Results and Discussion

There was a significant interaction ($p < 0.05$) between experiments; therefore data for the two studies are reported separately. Of the 13 species used in the revegetation study, only 7 were observed for percent injury in each experiment. These seven species showed the greatest range of injury over the varying levels of imazapyr in the soil. Mortality ratings were recorded for all 13 species.

Mortality data for experiment 1 are shown in Table 2.2. Regression analysis was used to predict the mortality response to imazapyr for each species. P_{60} values were calculated to define the highest amount of imazapyr in the soil at which at least 40% of plants remaining alive. Due to the slow activity of imazapyr, only the 10 WAP data is shown to allow for greatest plant response and possible recovery. In this experiment, only *E. amplifolia* showed less than 60% mortality at all rates of imazapyr, followed by *M. strigillosa*, which could tolerate imazapyr up to 0.82 kg ai/ha. *P. palustris* and *E. grandis* had P_{60} values of 0.443 and 0.381 kg ai/ha, which were still significantly greater

[1] The Natives, Inc., Davenport, FL, USA.

[2] Professor of Tree Improvement, University of Florida School of Forest Resources and Conservation, Gainesville, FL, USA.

than the other species listed in Table 2.2. *P. graminifolia* and *A. beyrichiana* had P_{60} values of 0.17 and 0.11 kg ai/ha imazapyr, while *Q. geminata*, *A. virginicus*, *L. mixhauxii*, and *E. spectabilis* were the most sensitive to imazapyr with P_{60} values from 0.066 to 0.041 kg ai/ha imazapyr. Only *M. cerifera* showed greater than 60% mortality ratings at all levels of imazapyr in the soil, but this could be reflective of low transplant survival, not necessarily sensitivity to imazapyr.

Mortality data for experiment 2 are shown in Table 2.3. In this experiment, most species showed greater tolerance to imazapyr than in experiment 1, which is reflected in greater P_{60} values. *E. amplifolia*, *E. grandis*, *M. strigillosa*, and *L. michauxii* all showed less than 60% mortality at all rates of imazapyr. *A. beyrichiana* showed a tolerance up to 0.974 kg ai/ha, followed by *P. graminifolia* and *P. virgatum*, with values of 0.773 and 0.739 kg ai/ha, respectively. *A. virginicus* was moderately sensitive with a P_{60} value of 0.544 kg ai/ha, followed by *Q. geminata* and *E. spectabilis* (0.437 and 0.325 kg ai/ha imazapyr). Data for *Q. incana* had such high variability that a response could not be calculated. *P. palustris* and *M. cerifera* showed greater than 60 % mortality ratings at all levels of imazapyr in the soil.

Only 10 WAP injury data were recorded in experiment 1. All seven species evaluated exhibited an exponential increase in injury score in response to imazapyr injury. In Table 2.4, I_{30} values were calculated for species 10 WAP. These are values of imazapyr in soil (kg ai/ha) that cause no more than 30% injury to the plant species. *Andropogon virginicus* showed immediate dose response at very low concentrations increasing up to 0.15 kg ai/ha imazapyr (Figure 2.1), with injury of 83%. Injury levels did not increase dramatically as the rates increased from 0.15 to the maximum rate of

1.12 kg ai/ha. *A. virginicus* exhibited 20% injury in the plots where there was no imazapyr, which might be reflective of transplant stress. *Mimosa strigillosa* and *Aristida beyrichiana* exhibited a more gradual response to imazapyr with increasing herbicide concentration (Figures 2.2 and 2.3), although *M. strigillosa* showed less injury at 0.4 kg ai/ha than *A. beyrichiana* (63% and 90%, respectively). *A. beyrichiana* also showed injury (38%) in areas where there was no imazapyr, again reflective of potential transplant stress of the seedlings. *Pityopsis graminifolia* also had a relatively high injury rate at 0.2 and 0.4 kg ai/ha (78 and 90% injury) as seen in Figure 2.4. *Eucalyptus amplifolia* and *E. grandis*, the two energy crop species, had comparatively low injury responses at 0.2 kg ai/ha (66 and 60%, respectively) when compared to the other species in the study (Figures 2.5 and 2.6). Also, *Panicum virgatum* showed 69% injury at 0.2 kg ai/ha (Figure 2.7). Of the 7 species, *M. strigillosa*, *E. amplifolia*, and *E. grandis* showed the lowest injury ratings at 0.2 kg ai/ha (no greater than 66%).

For experiment 2, both 6 and 10 WAP injury data were recorded. Once again, the relationship between injury and imazapyr rate was exponential, but overall percent injury per concentration was lower in this experiment. In Table 2.5, I_{30} values were calculated for species 10 WAP. These are the highest values of imazapyr in soil (kg ai/ha) that cause no more than 30% injury to the plant species. *A. beyrichiana* and *P. graminifolia* showed the lowest injury at 0.2 kg ai/ha of all the 7 species monitored (41 and 40%, respectively) at 6 WAP, shown in Figures 2.10 and 2.11. Even at the highest rate of 0.4 kg ai/ha imazapyr, these two species show a minimal increase in injury (60% injury for *A. beyrichiana* and 55% for *P. graminifolia*) at 6 WAP. At 10 WAP, these two species have only a slight increase in injury at 0.4 kg ai/ha (64% for both species), as shown in

Figures 2.17 and 2.18. *M. strigillosa* follows a similar trend, with 44% injury at 0.2 kg ai/ha and 59% injury at 0.4 kg ai/ha 6 WAP (Figure 2.9). At 6 WAP, *M. strigillosa* showed no greater than 78% damage at the maximum rates of imazapyr. *M. strigillosa* showed no significant change in reported injury between 6 and 10 WAP for rates of 0.4 kg ai/ha imazapyr (59 and 61%, respectively). *A. virginicus* showed 33% injury at 6 WAP in plots with no imazapyr, as well as 39% injury in the same plots 10 WAP. This high rate of injury is thought to be related to either transplanting or water stress (due to three days without watering immediately after transplanting in experiment 2). *E. amplifolia* and *E. grandis* showed higher rates of injury compared to experiment 1 at 0.4 kg ai/ha for both 6 and 10 WAP, as shown in Figures 2.12, 2.13, 2.19, and 2.20. *E. amplifolia* exhibited 76 and 78% injury at 0.4 kg ai/ha at 6 and 10 WAP, while *E. grandis* exhibited 75 and 80% injury at 6 and 10 WAP. *P. virgatum* had a marked increase in injury from 6 to 10 WAP for both 0.2 and 0.4 kg ai/ha imazapyr, as shown in Figures 2.14 and 2.21 (44 and 65% 6 WAP and 57 and 74% 10 WAP).

Overall, both *Eucalyptus* species, *M. strigillosa*, *A. beyrichiana*, and *P. graminifolia* show low mortality response to imazapyr in soil. However, *E. amplifolia* and *E. grandis* both show higher injury response than many other species to imazapyr in this study. These data show that these species might be able to “outgrow” the imazapyr injury after some period of time. Even though a plant might show initial injury symptoms, the overall ability of that plant to recover is a very important quality to look for in a potential revegetation species.

In addition to these data regarding the most tolerant species to be used as revegetation species, it is important to consider the costs involved with transplanting, as well as the overall desirability of the species by landowners. These data are beneficial from a research standpoint, but economic aspects should be taken into consideration as well.

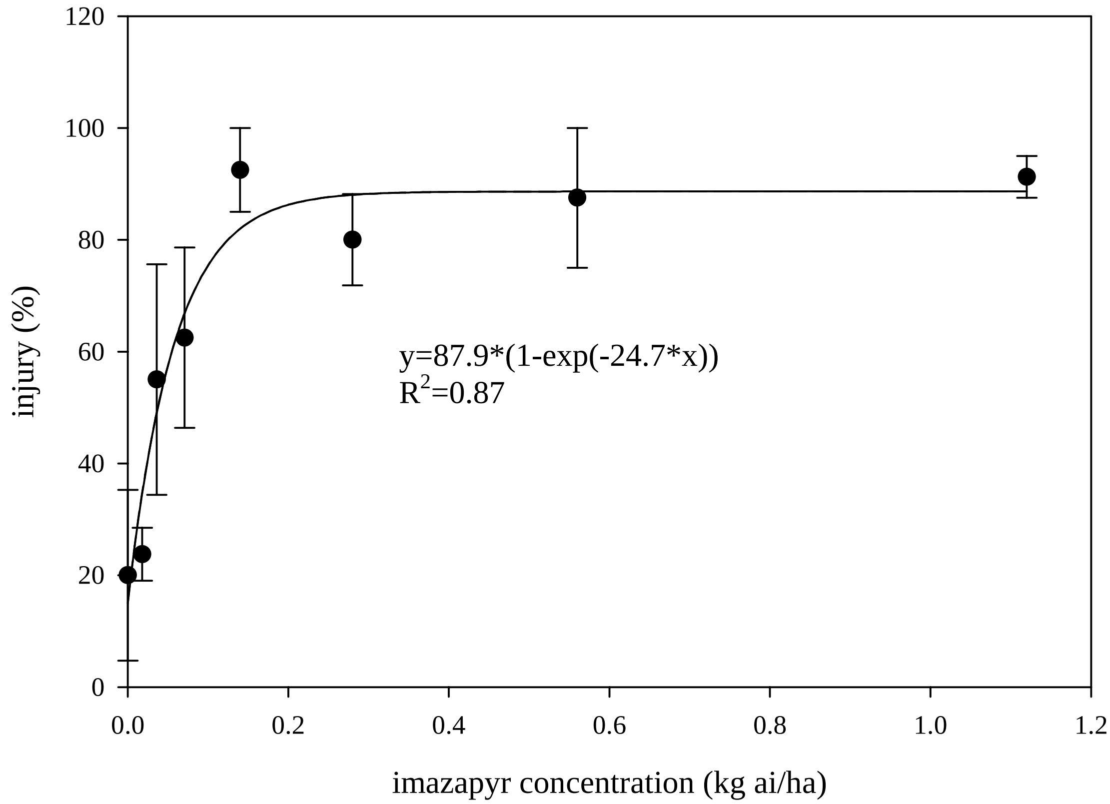

Figure 2.1. *Andropogon virginicus* (broomsedge) response to imazapyr concentration in soil 10 WAP (weeks after planting) immediately after imazapyr application for experiment 1. Means of 4 replications present with standard error.

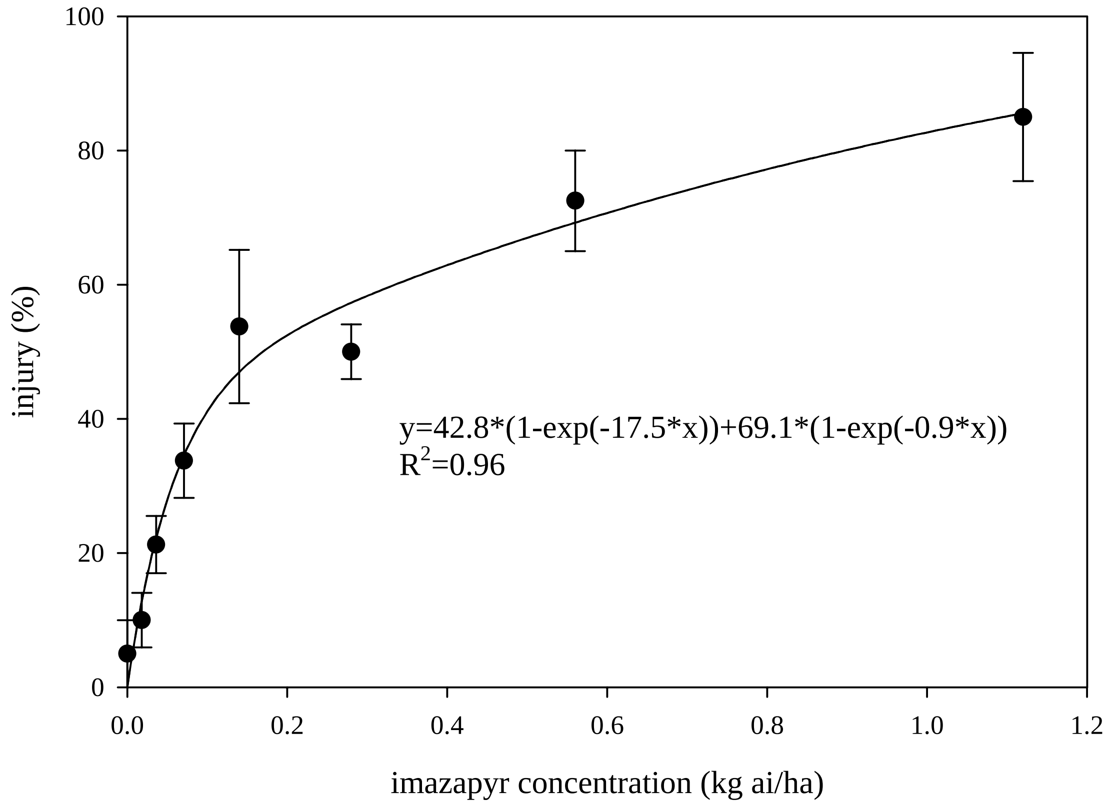

Figure 2.2. *Mimosa strigillosa* (mimosa) response to imazapyr concentration in soil 10 WAP (weeks after planting) immediately after imazapyr application. Experiment initiated on June 22, 2004, in Citra, Florida. Means of 12 replications present with standard error.

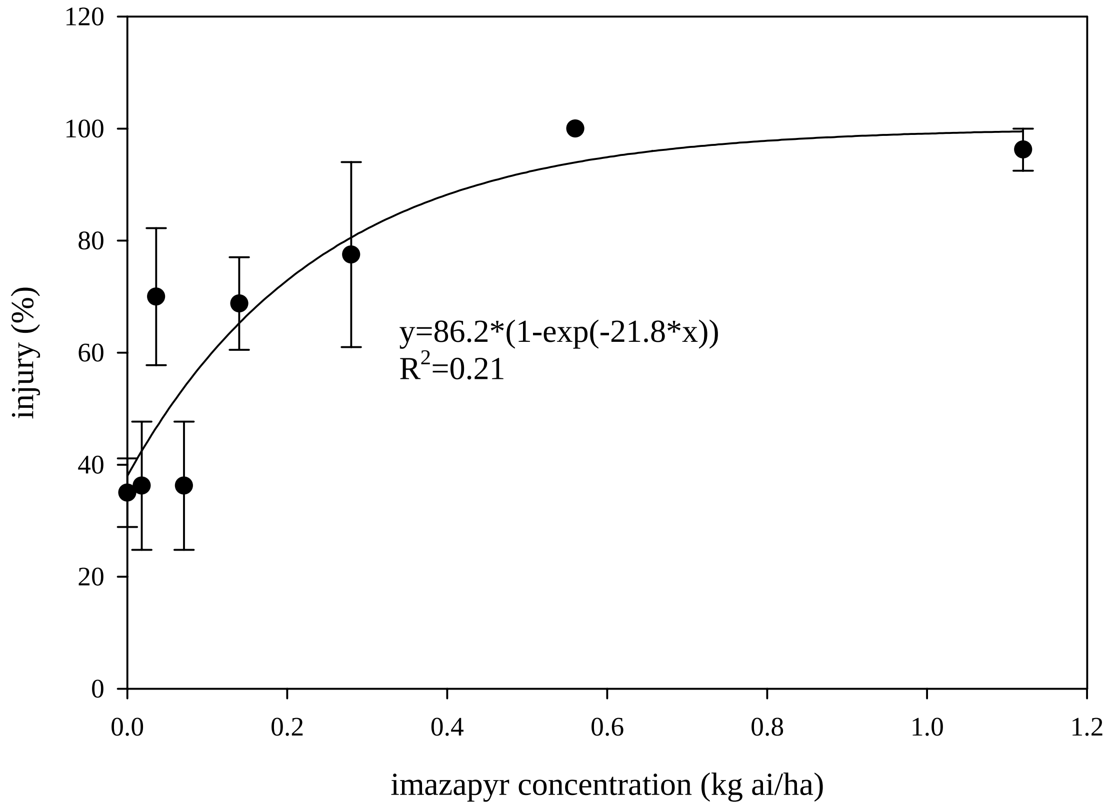

Figure 2.3. *Aristida beyrichiana* (wiregrass) response to imazapyr concentration in soil 10 WAP (weeks after planting) immediately after imazapyr application for experiment 1. Means of 4 replications present with standard error.

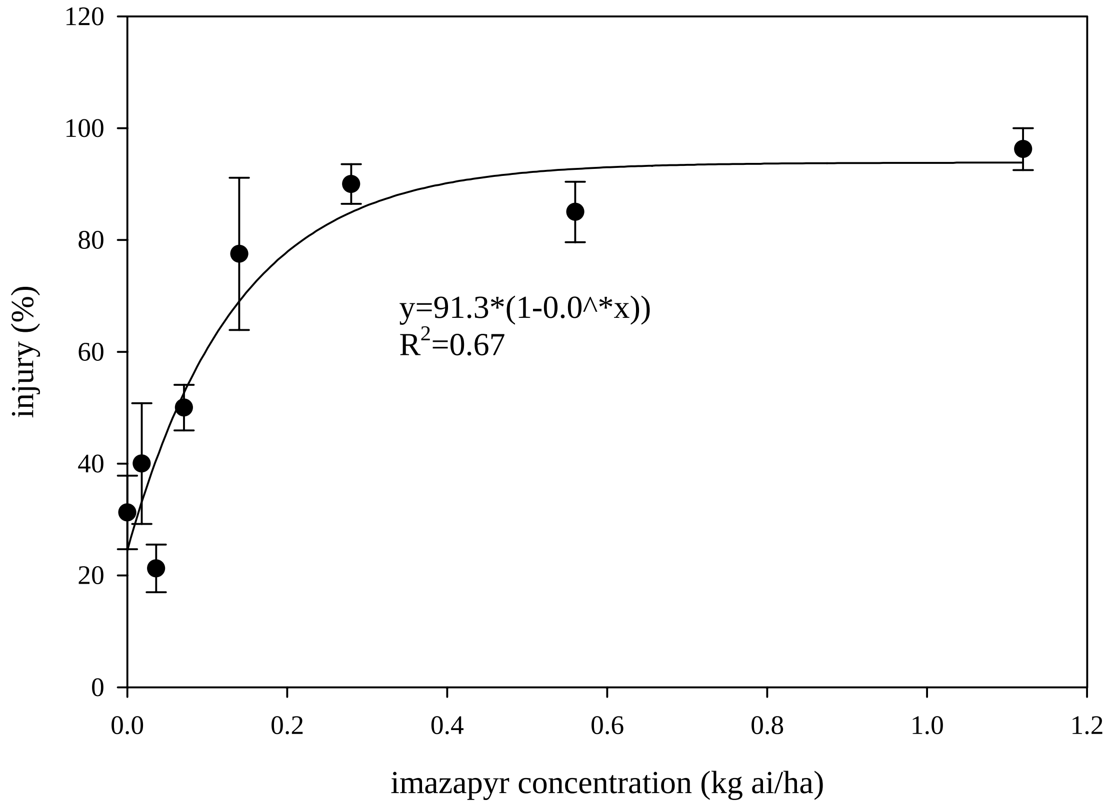

Figure 2.4. *Pityopsis graminifolia* (silkgrass) response to imazapyr concentration in soil 10 WAP (weeks after planting) immediately after imazapyr application for experiment 1. Means of 4 replications present with standard error.

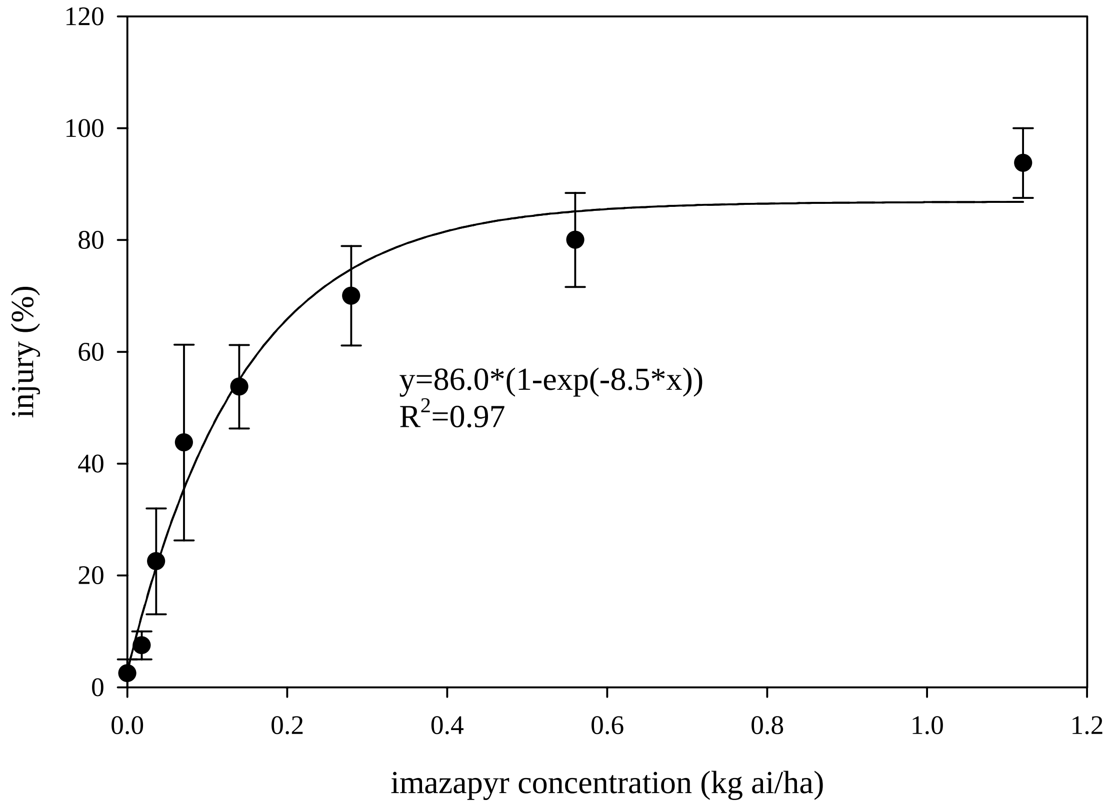

Figure 2.5. *Eucalyptus amplifolia* response to imazapyr concentration in soil 10 WAP (weeks after planting) immediately after imazapyr application for experiment 1. Means of 4 replications present with standard error.

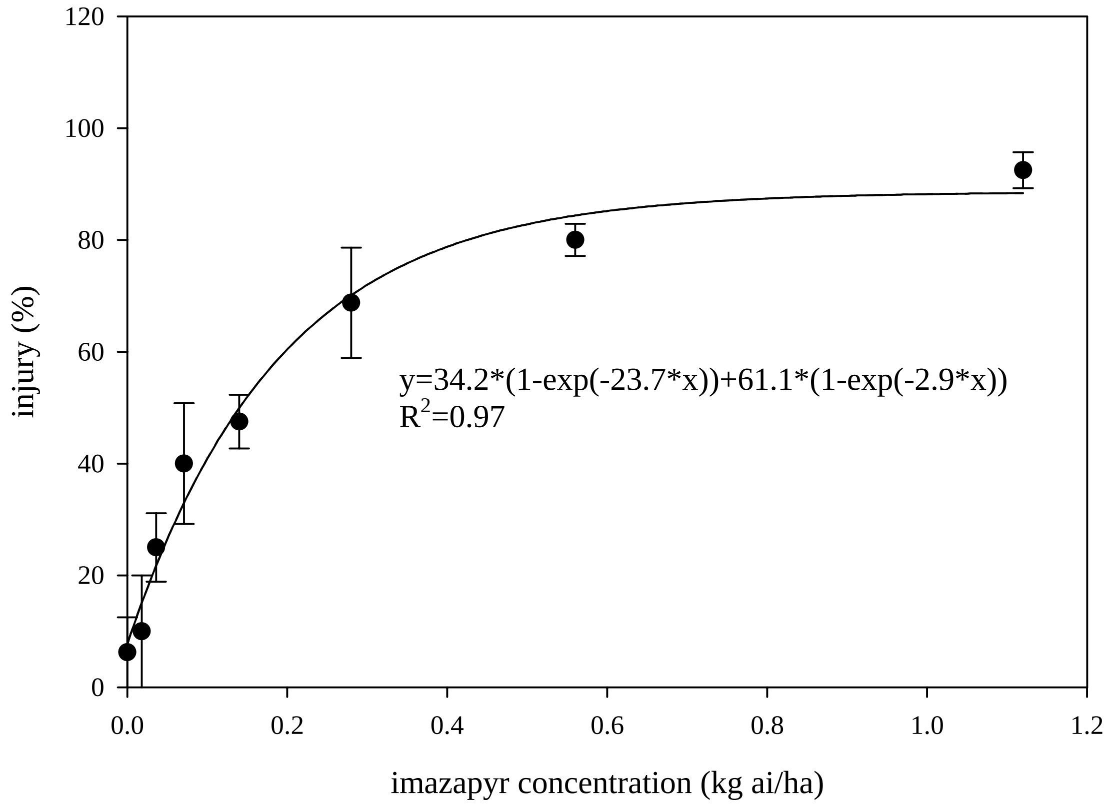

Figure 2.6. *Eucalyptus grandis* response to imazapyr concentration in soil 10 WAP (weeks after planting) immediately after imazapyr application for experiment 1. Means of 4 replications present with standard error.

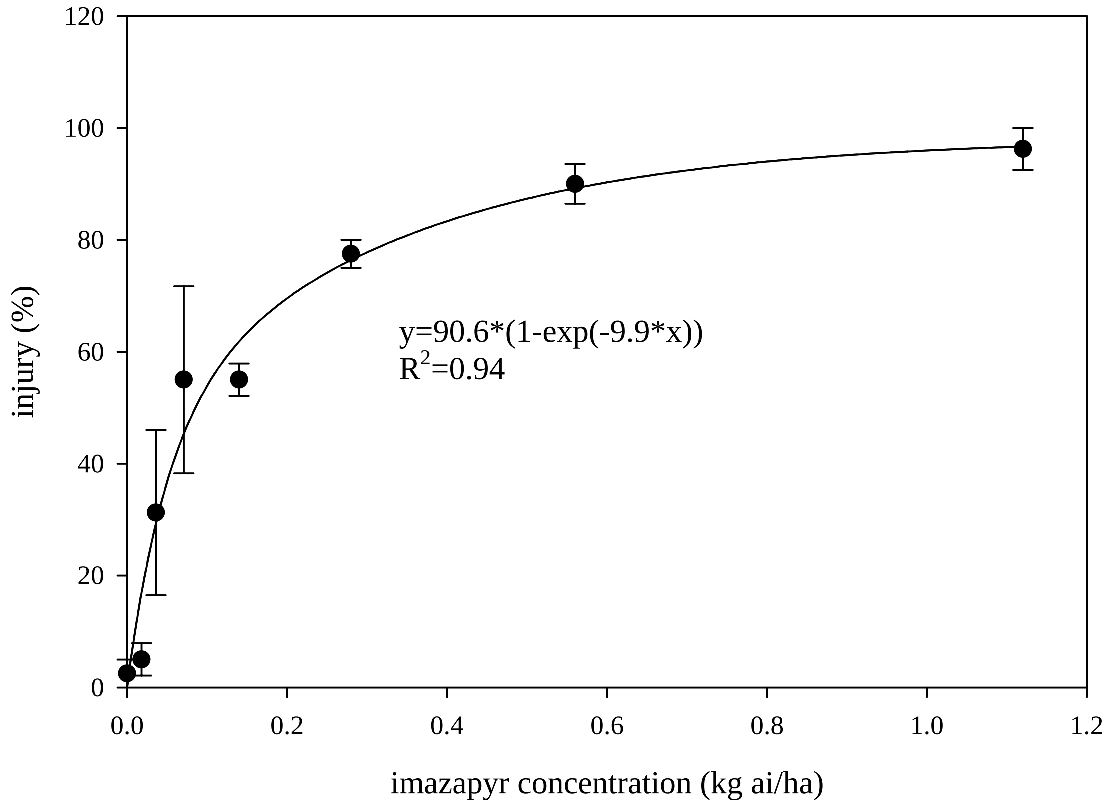

Figure 2.7. *Panicum virgatum* (switchgrass) response to imazapyr concentration in soil 10 WAP (weeks after planting) immediately after imazapyr application for experiment 1. Means of 4 replications present with standard error.

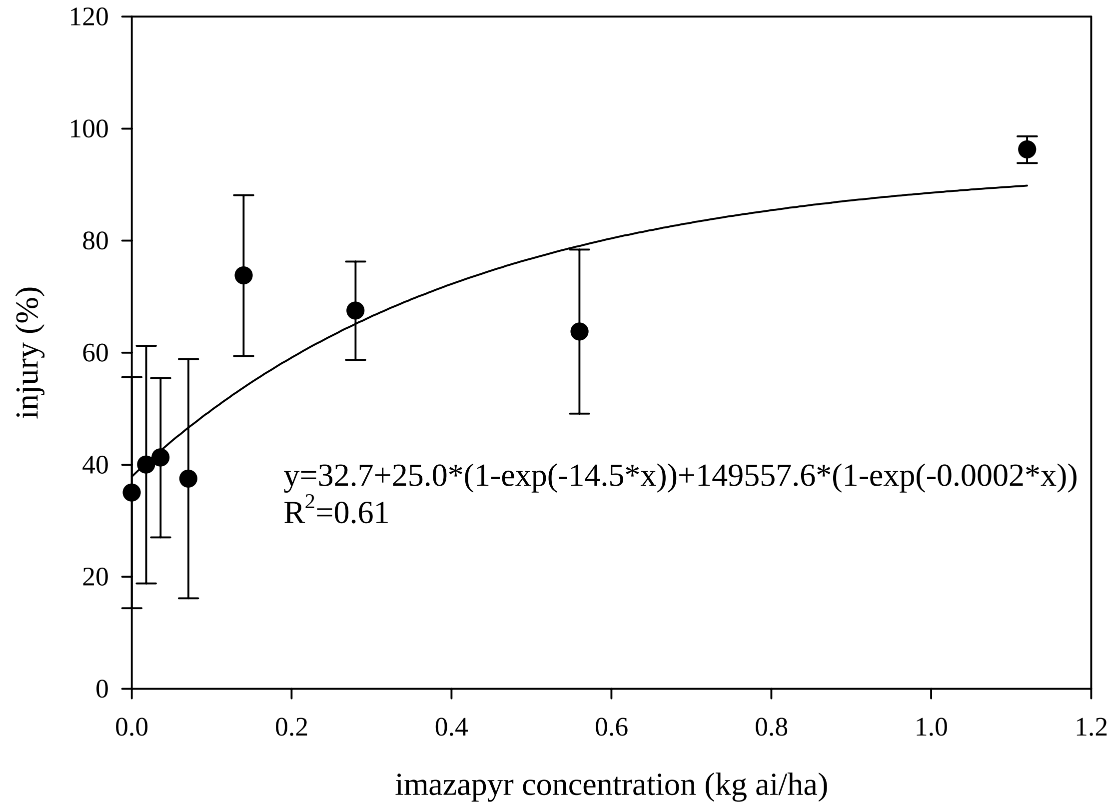

Figure 2.8. *Andropogon virginicus* (broomsedge) response to imazapyr concentration in soil 6 WAP (weeks after planting) immediately after imazapyr application for experiment 2. Means of 4 replications present with standard error.

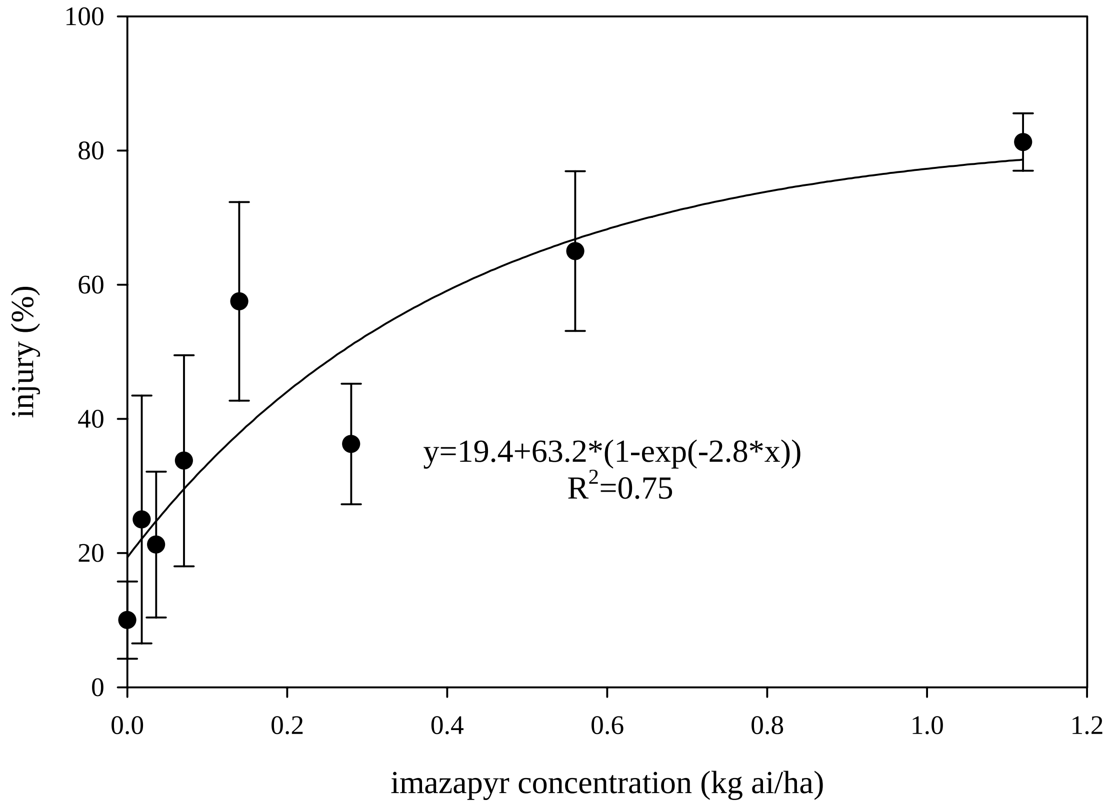

Figure 2.9. *Mimosa strigillosa* (mimosa) response to imazapyr concentration in soil 6 WAP (weeks after planting) immediately after imazapyr application for experiment 2. Means of 4 replications present with standard error.

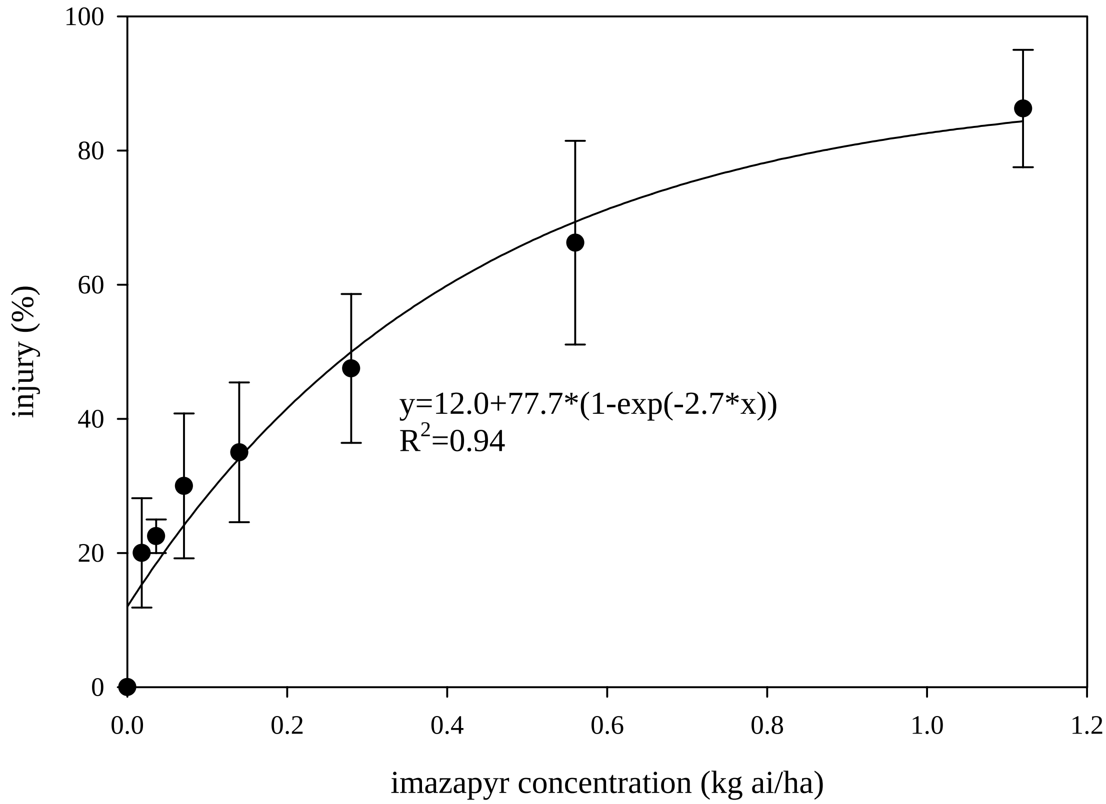

Figure 2.10. *Aristida beyrichiana* (wiregrass) response to imazapyr concentration in soil 6 WAP (weeks after planting) immediately after imazapyr application for experiment 2. Means of 4 replications present with standard error.

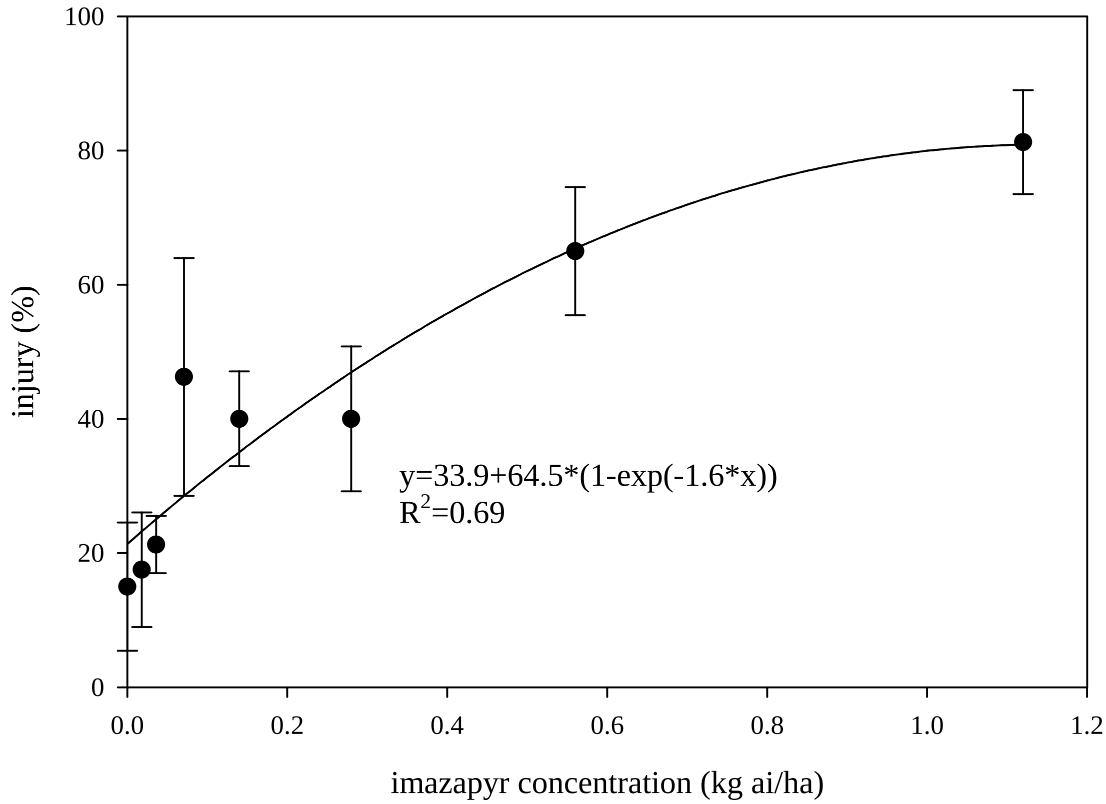

Figure 2.11. *Pityopsis graminifolia* (silkgrass) response to imazapyr concentration in soil 6 WAP (weeks after planting) immediately after imazapyr application for experiment 2. Means of 4 replications present with standard error.

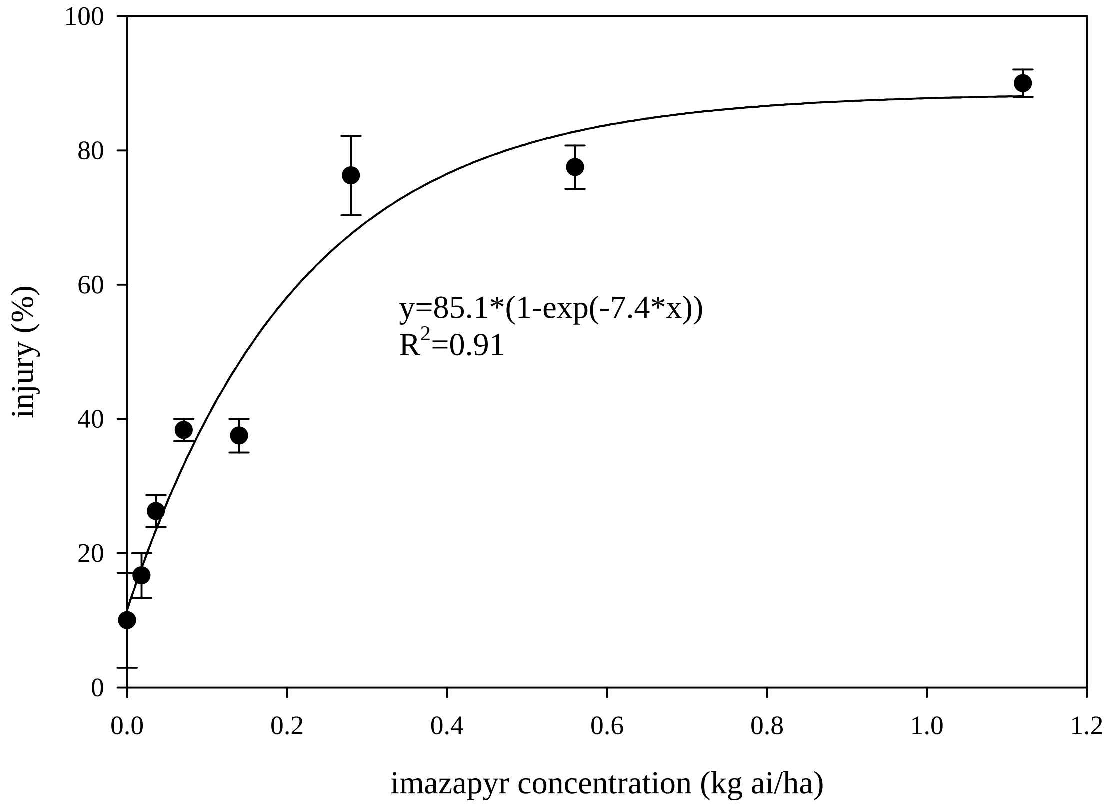

Figure 2.12. *Eucalyptus amplifolia* response to imazapyr concentration in soil 6 WAP (weeks after planting) immediately after imazapyr application for experiment 2. Means of 4 replications present with standard error.

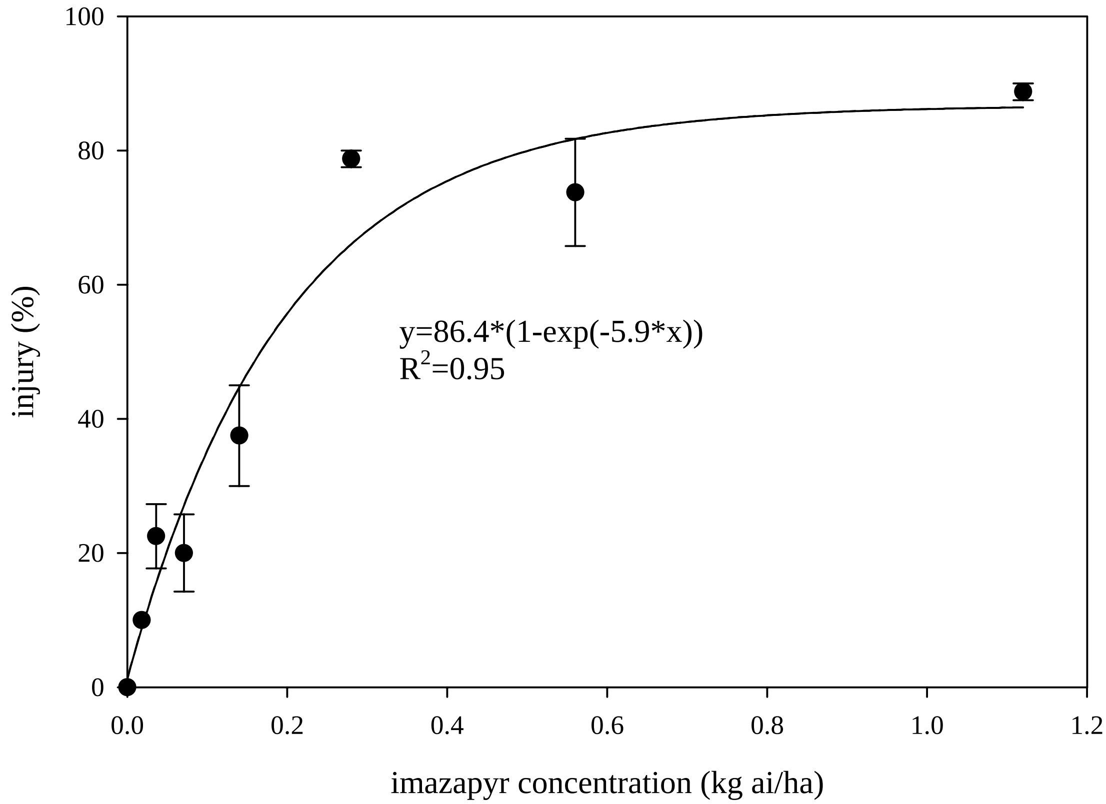

Figure 2.13. *Eucalyptus grandis* response to imazapyr concentration in soil 6 WAP (weeks after planting) immediately after imazapyr application for experiment 2. Means of 4 replications present with standard error.

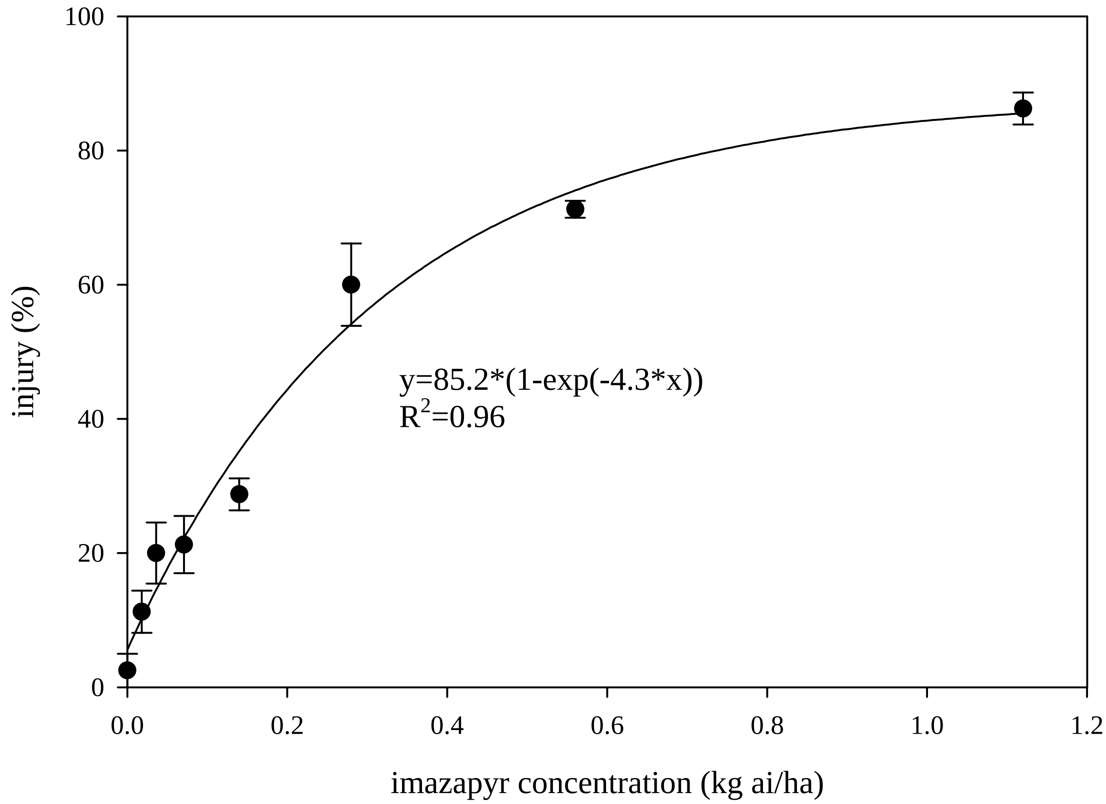

Figure 2.14. *Panicum virgatum* (switchgrass) response to imazapyr concentration in soil 6 WAP (weeks after planting) immediately after imazapyr application for experiment 2. Means of 4 replications present with standard error.

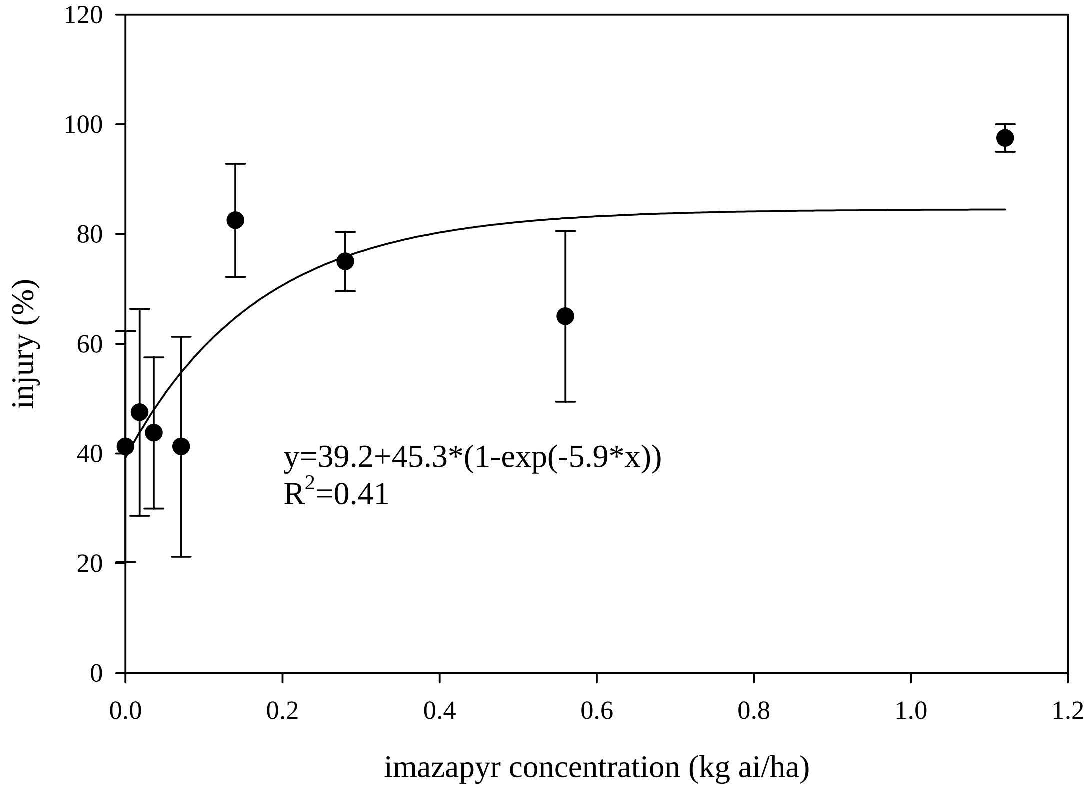

Figure 2.15. *Andropogon virginicus* (broomsedge) response to imazapyr concentration in soil 10 WAP (weeks after planting) immediately after imazapyr application for experiment 2. Means of 4 replications present with standard error.

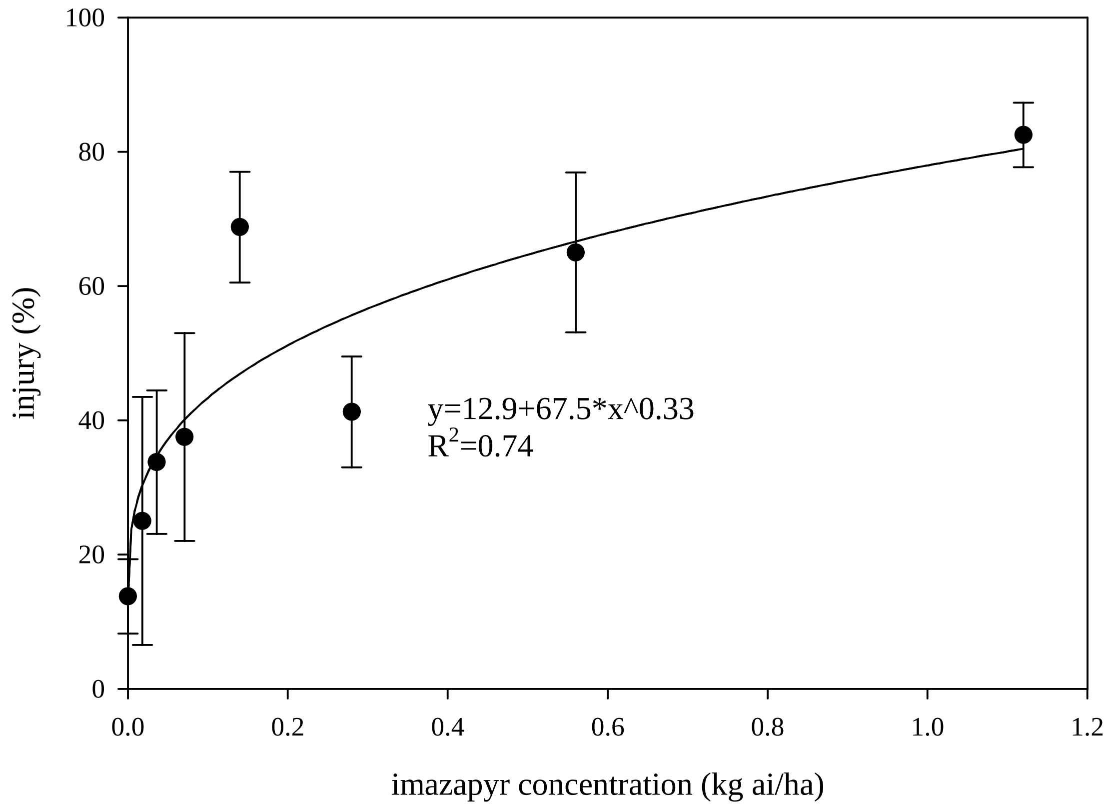

Figure 2.16. *Mimosa strigillosa* (mimosa) response to imazapyr concentration in soil 10 WAP (weeks after planting) immediately after imazapyr application for experiment 2. Means of 4 replications present with standard error.

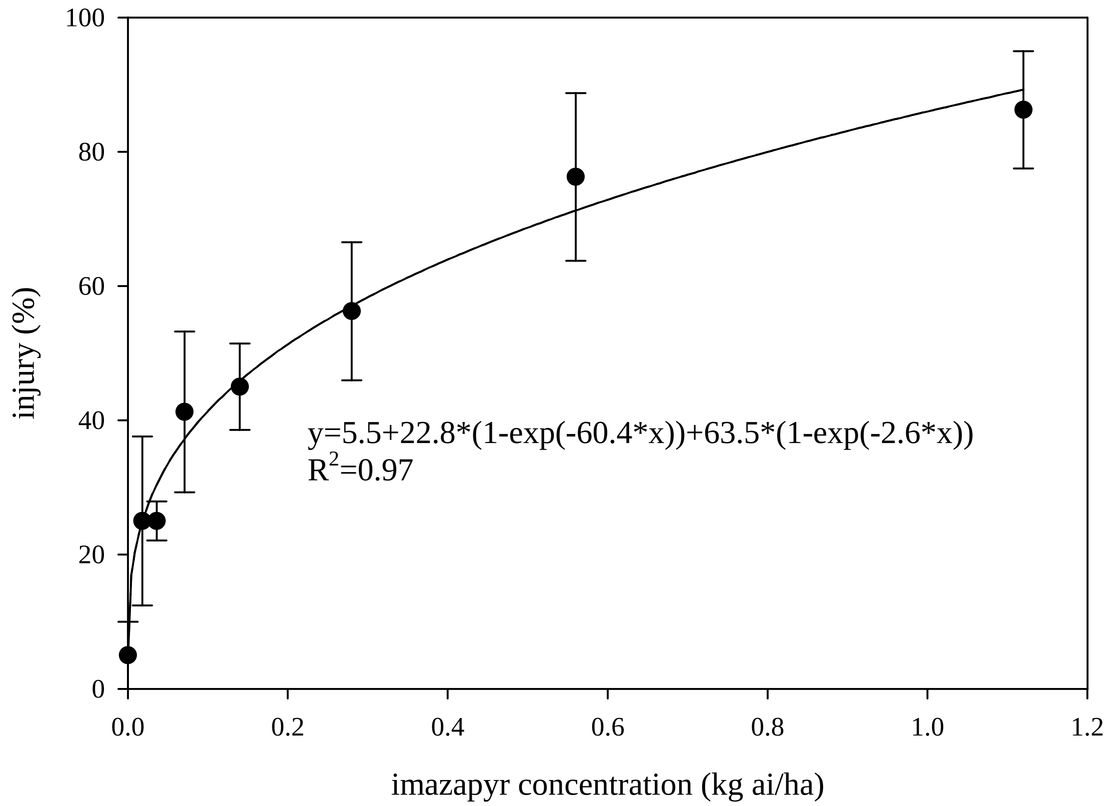

Figure 2.17. *Aristida beyrichiana* (wiregrass) response to imazapyr concentration in soil 10 WAP (weeks after planting) immediately after imazapyr application for experiment 2. Means of 4 replications present with standard error.

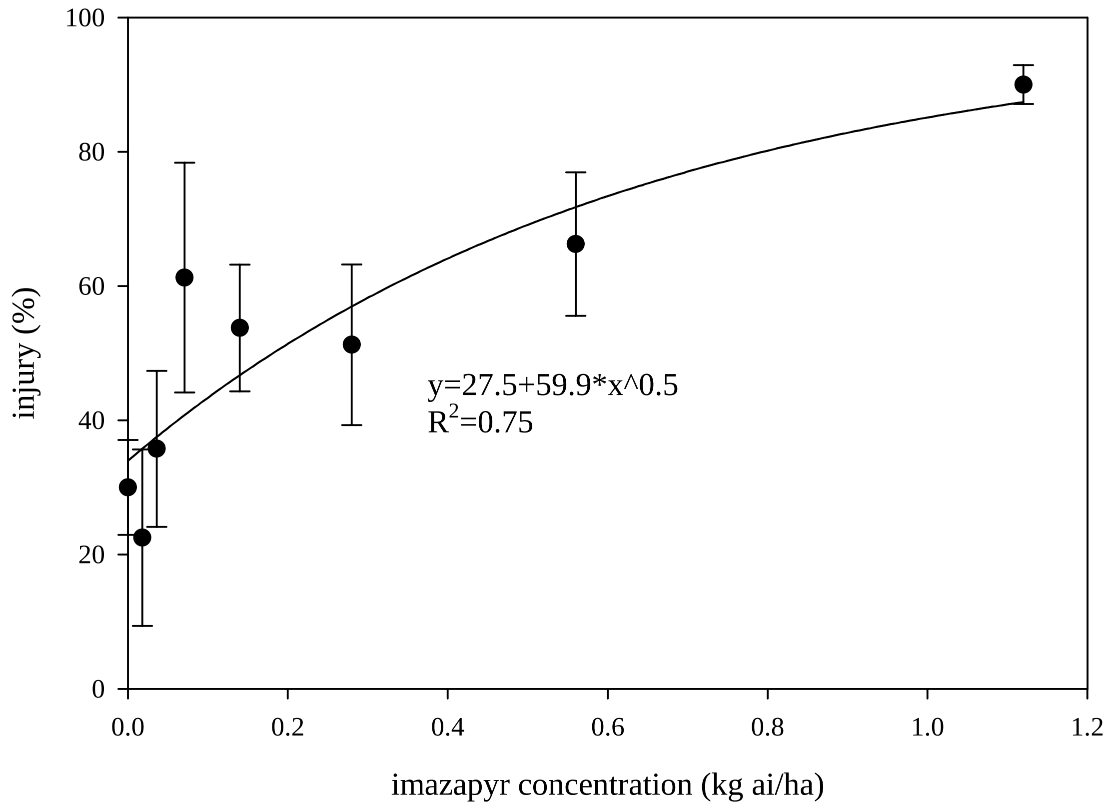

Figure 2.18. *Pityopsis graminifolia* (silkgrass) response to imazapyr concentration in soil 10 WAP (weeks after planting) immediately after imazapyr application for experiment 2. Means of 4 replications present with standard error.

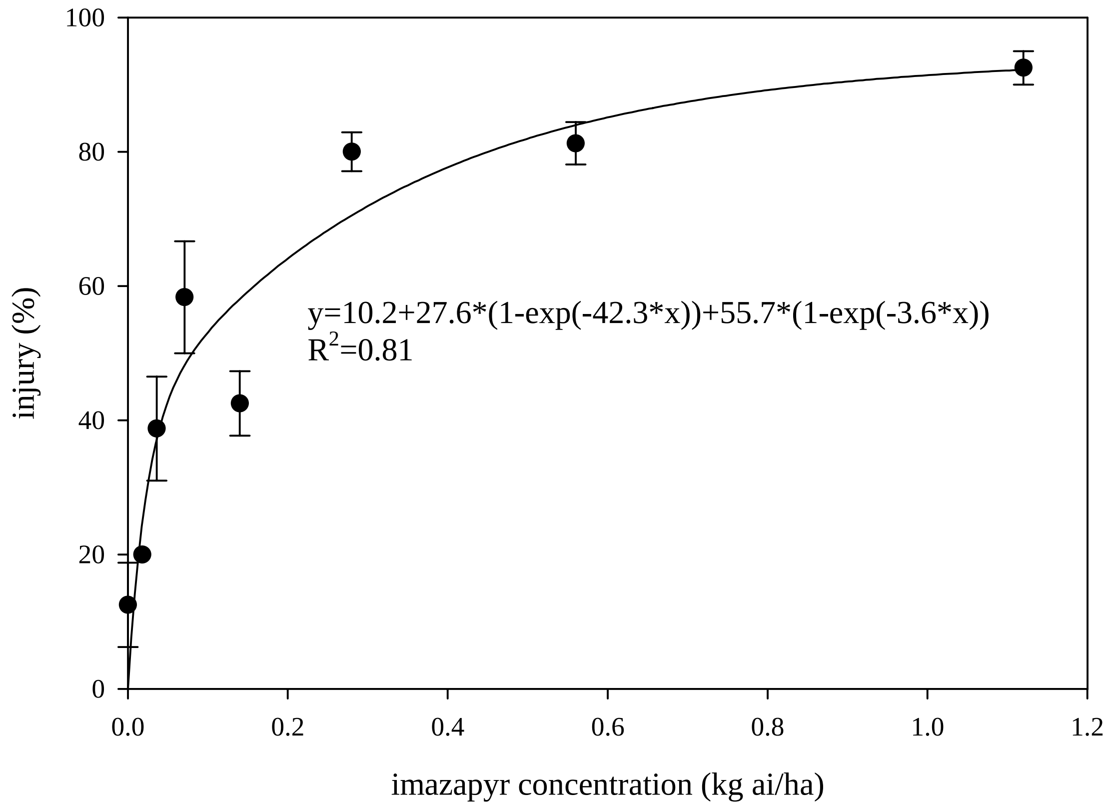

Figure 2.19. *Eucalyptus amplifolia* response to imazapyr concentration in soil 10 WAP (weeks after planting) immediately after imazapyr application for experiment 2. Means of 4 replications present with standard error.

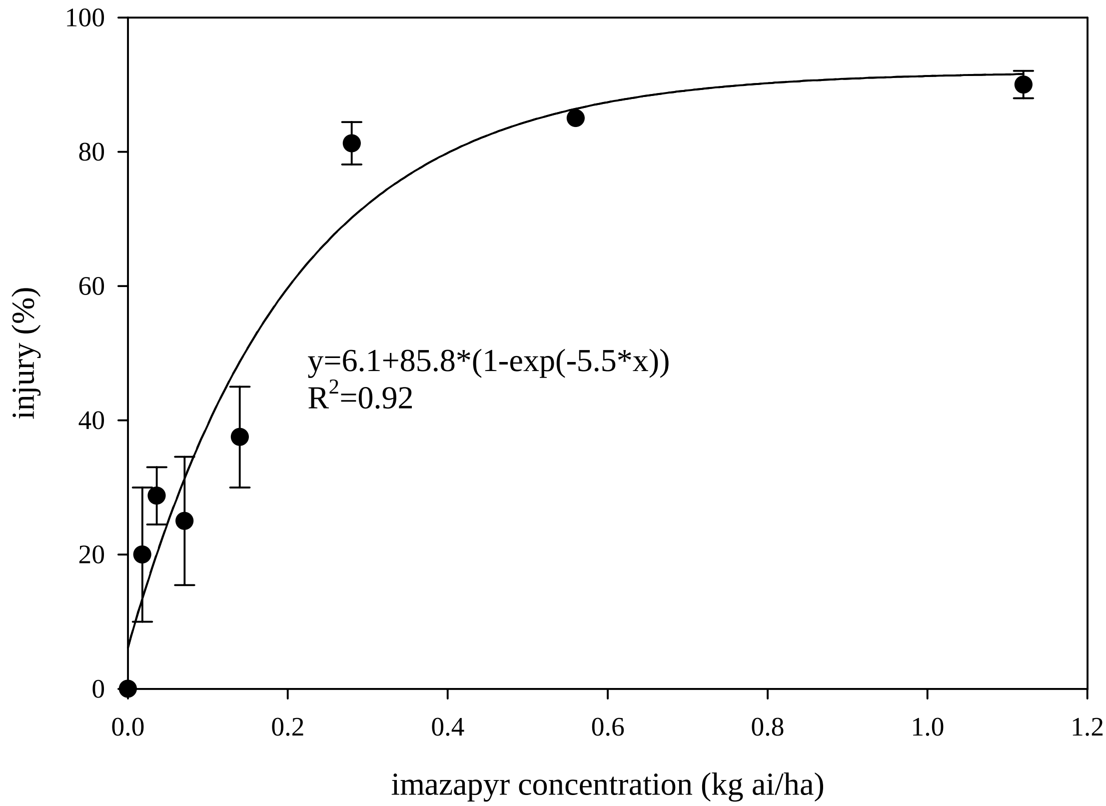

Figure 2.20. *Eucalyptus grandis* response to imazapyr concentration in soil 10 WAP (weeks after planting) immediately after imazapyr application for experiment 2. Means of 4 replications present with standard error.

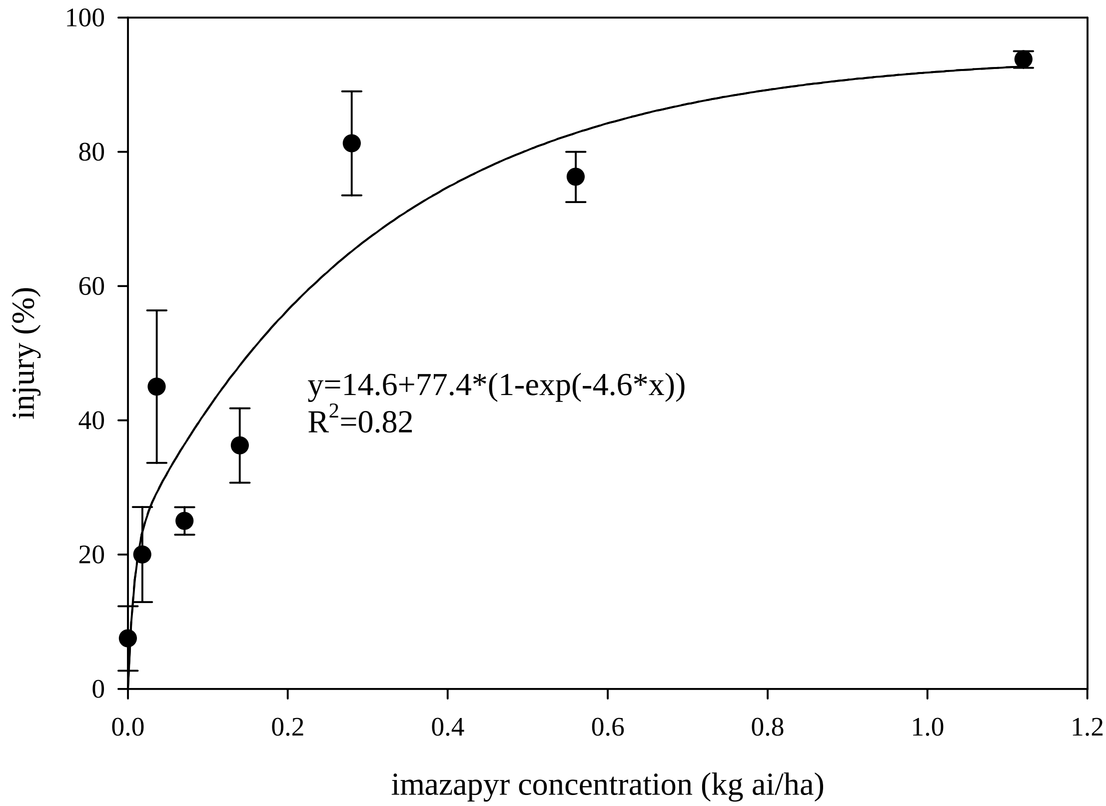

Figure 2.21. *Panicum virgatum* (switchgrass) response to imazapyr concentration in soil 10 WAP (weeks after planting) immediately after imazapyr application for experiment 2. Means of 4 replications present with standard error.

Table 2.1. Species used in revegetation study in Citra, Florida.

common name	scientific name	size of seedlings
broomsedge	*Andropogon virginicus*	10 centimeter tublings
mimosa	*Mimosa strigillosa*	10 centimeter pots
sand live oak	*Quercus geminata*	1 liter pots
bluejack oak	*Quercus incana*	1 liter pots
wiregrass	*Aristida beyrichiana*	10 centimeter tublings
silkgrass	*Pityopsis graminifolia*	10 centimeter tublings
gopher apple	*Licania michauxii*	5 centimeter cups
wax myrtle	*Myrica cerifera*	2.5 centimeter x 7.5 centimeter (tray)
lovegrass	*Eragrostis spectabilis*	10 centimeter tublings
longleaf pine	*Pinus palustris*	2.5 centimeter x 7.5 centimeter (tray)
switchgrass	*Panicum virgatum*	10 centimeter tublings
Eucalyptus grandis	*Eucalyptus grandis*	15 centimeter tublings
Eucalyptus amplifolia	*Eucalyptus amplifolia*	15 centimeter tublings

Table 2.2. The effect of imazapyr soil concentration on percent mortality of selected revegetation species 10 weeks after planting. Experiment 1 initiated on June 22, 2004, in Citra, FL. P_{60} values reflect the predicted imazapyr concentration that would result in less than 60% mortality.

Plant Species	Regression Equation	R^2	P_{60} imazapyr values (kg ai/ha)
Eucalyptus amplifolia	y=(-5518.4)+5614.4*exp(-0.0062*x)	0.78	> 1.12
mimosa	y=101.3*exp(-1.1*x)	0.99	0.82
longleaf pine	y=96.1*exp(-2.0*x)	0.97	0.443
Eucalyptus grandis	y=5.2+88.8*exp(-2.5*x)	0.87	0.381
silkgrass	y=10.1+55.3*exp(-3.6*x)	0.65	0.17
wiregrass	y=1.8+56.8*exp(-3.6*x)	0.68	0.11
sand live oak	y=25.2+22.7*exp(-6.3*x)	0.18	0.066
broomsedge	y=43.3*exp(-20.5*x)+27.6*exp(-0.15*x)	0.60	0.058
gopher apple	y=15.5+38.6*exp(-7.7*x)	0.65	0.058
lovegrass	y=(-1.9)+59.0*exp(-7.9*x)	0.95	0.041
bluejack oak	y=41.2*exp(-4.7*x)	0.85	0.0044
switchgrass	y=10.9+34.9*exp(-39.0*x)	0.59	0.0043
wax myrtle	y=35.6*exp(-4.9*x)	0.47	*

*Species exhibits greater than 60% mortality at all rates of imazapyr in soil.

Table 2.3. The effect of imazapyr soil concentration on percent mortality of selected revegetation species 10 weeks after planting. Experiment 2 initiated on July 21, 2004, in Citra, FL. P_{60} values reflect the predicted imazapyr concentration that would result in less than 60% mortality.

Plant Species	Regression Equation	R^2	P_{60} imazapyr values (kg ai/ha)
Eucalyptus amplifolia	y=93.7+(-58.5)*x+14.7*x^2	0.75	> 1.12
mimosa	y=88.8+10.0*exp(-3.7*x)	0.26	> 1.12
Eucalyptus grandis	y=98.2+(-6.3)*x+(-16.9)*x^2	0.81	> 1.12
gopher apple	y=69.5+6.2*x	0.12	> 1.12
wiregrass	y=92.3+(-12.9)*x+(-53.9)*x^2	0.90	0.974
silkgrass	y=(-501.5)+577.9*exp(-0.09*x)	0.67	0.773
switchgrass	y=95.7+(-81.3)*x+(-3.2)*x^2	0.67	0.739
broomsedge	y=(-1177.7)+1240.1*exp(-0.04*x)	0.31	0.544
sand live oak	y=37.5+16.0*exp(-2.7*x)	0.05	0.437
lovegrass	y=87.8+(-192.9)*x+104.9*x^2	0.96	0.325
bluejack oak	NS	--	--
longleaf pine	y=38.7*exp(-1.6*x)	0.78	*
wax myrtle	y=39.9+(-105.9)*x+74.2*x^2	0.63	*

*Species exhibits greater than 60% mortality at all rates of imazapyr in soil.

Table 2.4. The effect of imazapyr soil concentration on percent injury of selected revegetation species 10 weeks after planting. Experiment 1 initiated on June 22, 2004, in Citra, FL. I_{30} values reflect the highest predicted imazapyr concentration that would cause no greater than 30% injury.

Plant Species	Regression Equation	R^2	I_{30} imazapyr values (kg ai/ha)
Eucalyptus grandis	y=34.2*(1-exp(-23.7*x))+61.1*(1-exp(-2.9*x))	0.97	0.063
Eucalyptus amplifolia	y=86.0*(1-exp(-8.5*x))	0.97	0.056
mimosa	y=42.8*(1-exp(-17.5*x))+69.1*(1-exp(-0.9*x))	0.96	0.055
switchgrass	y=90.6*(1-exp(-9.9*x))	0.94	0.037
broomsedge	y=87.9*(1-exp(-24.7*x))	0.87	0.014
silkgrass	y=91.3*(1-0.0^*x))	0.67	0.012
wiregrass	y=86.2*(1-exp(-21.8*x))	0.21	*

*Species exhibits greater than 30% injury at all rates of imazapyr in soil.

Table 2.5. The effect of imazapyr soil concentration on percent injury of selected revegetation species 10 weeks after planting. Experiment 2 initiated on July 21, 2004, in Citra, FL. I_{30} values reflect the highest predicted imazapyr concentration that would cause no greater than 30% injury.

Plant Species	Regression Equation	R^2	I_{30} imazapyr values (kg ai/ha)
Eucalyptus grandis	y=6.1+85.8*(1-exp(-5.5*x))	0.92	0.066
switchgrass	y=14.6+77.4*(1-exp(-4.6*x))	0.82	0.041
wiregrass	y=5.5+22.8*(1-exp(-60.4*x))+63.5*(1-exp(-2.6*x))	0.97	0.034
Eucalyptus amplifolia	y=10.2+27.6*(1-exp(-42.3*x))+55.7*(1-exp(-3.6*x))	0.81	0.024
mimosa	y=12.9+67.5*x^0.33	0.74	0.017
silkgrass	y=27.5+59.9*x^0.5	0.75	*
broomsedge	y=39.2+45.3*(1-exp(-5.9*x))	0.41	*

*Species exhibits greater than 30% injury at all rates of imazapyr in soil.

CHAPTER 3
IMAZAPYR RESIDUAL MEASUREMENTS USING CORN ROOT BIOASSAY

Introduction

Cogongrass [*Imperata cylindrica* (L.) Beauv.], an aggressive perennial grass species which infests over 500 million hectares worldwide, is considered the world's seventh worst weed (Holm et al. 1977). In the United States, cogongrass infests several hundred thousand acres and it is widely spread throughout Florida and much of southern Alabama and Mississippi (Johnson et al. 1999). Cogongrass can usually be found in predominately non-agricultural settings in the United States., and this aggressive weed tends to spread over vast areas where vegetation is marginally supported, suppressing and displacing many native plants (Bryson and Carter 1993). Cogongrass tolerates a wide range of soil conditions but appears to grow best in soils with acidic pH, low fertility, and low organic matter. Several survival strategies lend to this invasive plant's ability to spread and persist, including an extensive rhizome system, adaptation to poor soils, drought tolerance, fire adaptability, and high genetic plasticity (Holm et al. 1977, Dozier et al. 1998).

Current control methods for cogongrass rely heavily on chemical treatment, which unfortunately provides limited long-term control unless used in conjunction with revegetation. The most effective herbicides for cogongrass management are glyphosate and imazapyr (Dozier et al. 1998; Barnett et al. 2000; MacDonald et al. 2002). Imazapyr is used to control annual and perennial weeds, deciduous trees, and vines in rights-of-way and other noncropland areas, as well as in forestry as a conifer releasing agent (Anon.

2002). The mode of action of imazapyr, a member of the imidazolinone family of herbicides, involves the inhibition of acetohydroxyacid synthase (AHAS), which is needed for synthesis of branched chain amino acids (Shaner 1991). Field half-life values range from 25-142 days depending on soil type and environmental conditions, with soil adsorption increasing as organic matter and clay content increase (Anon. 2002). Imazapyr is relatively harmless to animals and has minimal off-target impacts if used correctly (Mangels 1991).

Compared to glyphosate, imazapyr generally provides control for a longer period of time due to soil activity (MacDonald et al. 2002), and research to date has indicated imazapyr at 1.12 kg-ai/ha applied late summer/early fall provides control for as long as 18 months (Dozier et al. 1998). Burning prior to herbicide application has also proven effective, with benefits including weakened rhizomes due to re-allocation of starch reserves to new shoot growth and removal of old biomass. Herbicide application to the regrowth of new plant tissues maximizes absorption and results in greater efficacy (Johnson et al. 1999).

Although there is ample information on the effect of several herbicides on weedy species, little information regarding the herbicide tolerance (i.e., selectivity potential) of native species is available. In previous research by Miller et al. (2002), several native species were evaluated under greenhouse conditions for response to imazapyr. Imazapyr caused severe injury to most species, but this injury was reflected to a foliar application only. In practical field situations, herbicides are usually sprayed to control cogongrass with little or no subsequent implementations such as revegetation. These areas often become reinfested because of a lack of suppressive cover.

An important step in the further suppression of cogongrass is to establish a native plant cover into these sprayed areas as soon as the residual herbicide levels in the soil become tolerable to the plant. It is important to quantify these soil residual levels to best predict effective revegetation timing in order to effectively suppress cogongrass. One of the more popular tools for monitoring imidazolinone residues is through soil bioassay. Corn is highly sensitive to imidazolinone and sulfonylurea herbicides and has become the accepted bioassay species for the detection of these herbicides in soil (O'Bryan 1994). By using corn bioassay techniques, an understanding of plant species' response to imazapyr residues in soil can be obtained. With these data, a prediction model can be calculated to determine how long it takes imazapyr levels in soil to reach a concentration that will be tolerable to the plant in question. This information will ultimately be beneficial for restoration purposes in southeastern ecosystems (MacDonald et al. 2002).

Soil type plays an important role in residual herbicide levels due to its structure and content of clay and organic matter. In sandy soils, there are fewer charged sites that the herbicide can adsorb to, and leaching occurs more often. Therefore, sandy soils contain less residual matter after a given period of time than a clay soil, which has a much greater affinity for adsorption. Herbicides also tend to persist longer in loamy and silty soils due to less leaching compared to sandy soils.

In central Florida, reclaimed mining sites have a diverse collection of soil types with overburden, sand tailings and phosphatic clay pits being three of the most prominent. Overburden, a mixture of sand and clay, is removed from the land surface to the top of the ore body and piled on the side. Overburden shows the highest variability in soil texture, soil color and soil chemical parameters (Segal et al. 2001). This soil type is on average composed of 80% sand, 8% silt, and 12% clay with a pH of 5.8.[1] Overburden has slightly greater clay and silt content, higher water-holding capacity, and greater P and K content than native Floridian soils, which may give aggressive weeds a competitive advantage over slower-growing natives (Richardson et al. 2003). The phosphate ore currently being mined is an unconsolidated mixture of sand, clay, and phosphate mineral. The sand tailings are separated from this ore and hydraulically pumped to fill mine cuts between overburden piles. Although sand tailings are usually nutrient-poor and droughty compared with these three other soil types (Segal et al. 2001), they have higher P and K contents and slightly coarser grain sizes than native soils (Kluson et al. 2000). Phosphatic clay is washed from phosphate ore and pumped, at about 3-5% solids, to settling areas. This clay commonly has pH values near 7.5, while some older sites with good forest cover and higher organic matter have pH values near 6.8. This soil type covers about 40% of the mined area and is considered highly fertile (Stricker 2000).

Imazapyr provides good control of cogongrass but has limited utility due to the long residual effects of this compound, which could hinder revegetation strategies. Initial research indicates the residual activity of this compound may be less than theorized, allowing for more flexibility in a revegetation scheme. Because of the diversity of soils in Florida, as well as much of the U.S., an understanding of herbicide persistence as a function of soil type would be important to predict the best time for revegetation. By taking samples of the three distinct types of soil after a certain amount of time after herbicide application, information on residue amounts can be generated. With such

[1] Richardson, S.G. 2004. Personal Communication.

residual data, a timetable could be calculated to best predict when revegetation should occur.

Materials and Methods

Research was conducted at Tenoroc Fish Management Area, a 2,430-hectare tract of land that was mined for phosphate until the mid-1970's. The area is located 3.2 kilometers northeast of Lakeland, Florida. Approximately 4000 hectares of lakes locally referred to as "phosphate pits" remained from early mining operations. This area has three distinct soil types that were results of the mining process: sand tailings, overburden, and phosphatic clay settling ponds. Studies were conducted on each of the three soil types to gain better understanding of imazapyr persistence in each of these areas.

In each of the three soil types, a total area of 24 x 30 meters was mowed in October 2002, immediately before herbicide application. The plots measured 6 x 6 meters in a randomized complete block design with 5 replications. Treatments were applied using a CO_2 backpack sprayer with 11002 flat fan nozzles calibrated to deliver 187 L/ha. The treatments were 0.84, 1.68, and 3.36 kg ai/ha imazapyr[2] with an untreated check. Both the overburden and sand areas were sprayed on November 19, 2002, while the clay settling area was sprayed December 12, 2002. Within each plot for all 3 areas, a total of 10, 2.5-cm diameter, 15-cm deep soil cores were randomly taken. Sampling occurred immediately prior to application, immediately after application, and at 1, 3, 6, and 12 months after application. Samples were put in labeled plastic freezer bags and placed on

[2] Arsenal 4 Applicators Concentrate (AC), BASF, USA.

ice for transport to Gainesville. These soil samples were stored frozen at -20ºC until bioassay work was performed.

Imazapyr concentration was determined using a corn-root bioassay, which was conducted in the greenhouse at the Gainesville campus. Individual frozen soil samples from each location were thawed, dried, and equally distributed into 3 cone shaped vessels (Cone-tainers, 40 x 200 mm)[3] which were used as growth containers.

Each bioassay experiment was conducted with an accompanying series of imazapyr concentrations which allowed for the development of a standard response curve. To develop this curve, untreated soil from each of the three locations was sifted through a 2mm screen and air dried for 3 days. Soils were put in small pots (10 x 15 cm) to simulate the surface area of the previous field sampling. Known amounts of imazapyr were applied to the samples using a CO_2 backpack sprayer with 11002 flat fan nozzles calibrated to deliver 187 L/ha. For these standards, a wide range of imazapyr rates were applied: 0.0, 0.018, 0.036, 0.071, 0.14, 0.28, 0.56, and 1.12 kg ai/ha. This was performed because imazapyr in the original field samples would decrease as the sampling continued over time. Having lower concentrations in the standard response curve component would aid in accuracy of predicted concentration. After imazapyr rates were sprayed, treated soil was equally mixed in a plastic bag and similarly divided into 3 Cone-tainers.

Seeds of field corn[4] were pre-germinated by placement under wet paper towels for 2-3 days. For all field and standard samples, one pre-germinated corn seed (radical

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[3] Cone-Tainer Nursery, 150 North Maple, Canby, OR 97013.

[4] Pioneer 33J 56.

length approximately 0.5 cm) was planted 2 cm below the soil surface. The soil-filled cone-tainers were immediately subirrigated to field capacity and then placed in a greenhouse environment of 16 hours daylight and 8 hours darkness at 30ºC mean temperature. After 9 days, corn seedlings were removed, washed, and primary root length measured. Regression equations were calculated to best fit the recorded data.

Results and Discussion

Only 0, 1 and 3 month after treatment (MAT) soil samples were successfully utilized using corn root bioassay. Standard curves were calculated each time a bioassay was performed and are shown in the Appendix. These generated regression equations are shown on each graph, along with adjusted R^2 values. Corn root data were fitted to the corresponding regression equations and the predicted values of imazapyr in the soil are listed in Tables 3.1, 3.2, and 3.3.

In all three areas sprayed, detected residues were substantially lower than expected. This can especially be seen in the 0 MAT data, where significantly low levels of imazapyr were detected immediately after application. This could be due to a dense vegetative cover found in the areas during herbicide application, which might have prevented imazapyr from fully reaching the soil surface. Vegetative cover, either as dead biomass or thatch, is common in areas chemically treated for cogongrass. This might be beneficial in revegetation planning since soil imazapyr residues might be lower than expected due to this foliar uptake.

Sand tailing data for all samples taken at 0, 1, and 3 MAT were averaged and replications were combined. This combined data are shown in Table 3.1. At the lowest application rate of 0.84 kg ai/ha, the soil samples average a consistently similar rate at 0 MAT. At 1 MAT of the 0.84 kg ai/ha, there was no detection of imazapyr, and a trace amount was detected at 3 MAT (0.003 kg ai/ha). In the areas sprayed with 1.68 and 3.36 kg ai/ha, 1.12 kg ai/ha were predicted for sand tailings at 0 MAT. Since the maximum rate of the standards was 1.12 kg ai/ha, no greater value could be comparatively quantified. For 1 MAT, predicted imazapyr values were 0.011 and 0.026 kg ai/ha for the 1.68 and 3.36 kg ai/ha sand tailing applications. In the 1.68 kg ai/ha areas, imazapyr rates were reduced at 3 MAT (0.003 kg ai/ha). For the replications treated with 3.36 kg ai/ha, a reduction was seen 3 MAT (0.0087 kg ai/ha).

In the clay soil, higher concentrations of imazapyr than in the sand tailings area were detected 3 MAT in the areas treated with 1.68 and 3.36 kg ai/ha (Table 3.2). For all treatments, samples taken 0 MAT were similar in value (0.062, 0.064, and 0.054 kg ai/ha for the plots sprayed with 0.84, 1.68, and 3.36 kg ai/ha, respectively). This inconsistent data could be credited to the variability of the soil sampling techniques. Soil imazapyr residues were continually reduced at 1 and 3 MAT for all treatments in the clay soil.

In the overburden soil, 0 MAT residues were greater than those of the clay and less than those in the sand area (Table 3.3). For the area sprayed with 0.84 kg ai/ha, residues decreased to 0.018 kg ai/ha 1 MAT and 0.01 kg ai/ha 3 MAT. The plots treated with 1.68 kg ai/ha also decreased to 0.027 kg ai/ha 1 MAT and 0.015 kg ai/ha 3 MAT. Finally, plots treated with 3.36 kg ai/ha were reduced to 0.033 kg ai/ha 1 MAT and 0.025 kg ai/ha 3 MAT.

Overall, imazapyr concentration was more quickly reduced in sand tailings. Mixed results occur between clay and overburden soil. This overall decreased concentration of imazapyr in the soil is expected, and the different rates and change with concentrations among soil types are useful data for selecting successful revegetation species.

These bioassay data, coupled with the plant species injury and mortality data from Chapter 2, were used to create a timetable to best estimate optimal planting dates per species. The dates reflect the estimated time it takes for imazapyr residues in soil to decrease to a tolerable level for the plants. Estimated time intervals are expressed in months after treatment (MAT) and were estimated from the predicted P_{60} and I_{30} values for each species. These data are based on an imazapyr application rate of 0.84 kg ai/ha and are shown in Tables 3.4 and 3.5 (Experiment 1 and 2, respectively). Regression figures and equations are also shown in the Appendix.

As seen in Table 3.1, no correlation can be found among the measurements taken in the sand area sprayed with 0.84 kg ai/ha imazapyr. This is because imazapyr was not detected 1 MAT, yet trace amounts were detected 3 MAT. For this reason, only estimations for clay and overburden areas were formulated. In both the clay and overburden area in Experiment 1, six species can be planted immediately after imazapyr application and expect to show at least a 40% survival rate 10 WAP (P_{60}). These species are *E. amplifolia*, mimosa, longleaf pine, *E. grandis*, silkgrass, and wiregrass. Sand live oak, broomsedge, and gopher apple show some sensitivity, therefore at least one month should be waited before planting. Lovegrass should be planted at least one month after treatment, while bluejack oak and switchgrass have significantly longer times of 3 MAT to allow for at least 40% survival. Since wax myrtle showed greater than 60% mortality at all imazapyr rates in both experiments, no predicted plantback date could be given within the limit of 60 days. In Experiment 2, all plant species show at least 40% survival in both soil types immediately after application. In addition to wax myrtle, switchgrass shows greater than 60% mortality at all rates in Experiment 2, therefore no date could be predicted.

Predicted dates according to injury data from Chapter 2 (I_{30} values) are listed for the seven monitored species for Experiment 1 and 2, as well. In Experiment 1 (Table 3.4), *E. grandis* can be planted 1 MAT in clay and 1 MAT in overburden to exhibit no more than 30% injury 10 WAP. *E. amplifolia*, mimosa, and bluejack oak also show slightly longer time periods for I_{30} predictions in overburden soils as compared to clay soils. Silkgrass and broomsedge have the longest delay in planting until soil residues are within range of I_{30} values (3 MAT in clay and 3 MAT in overburden). Wiregrass shows at least 30% injury at all rates of imazapyr, so no predicted date could be made within the range of 60 days. Experiment 2 (Table 3.5) shows similar predicted dates according to I_{30} values for *E. grandis* and switchgrass, although *E. amplifolia*, mimosa, and wiregrass show increased predicted plantback time (MAT) in which soil residues cause no more than 30% injury in both clay and overburden areas. These extended dates are in contrast with those for silkgrass and broomsedge, in which all rates of imazapyr caused at least 30% injury in Experiment 2. Therefore, no predicted dates could be made for these species since the study range was only 60 days.

Based on the plant-back time in relation to injury data, *E. grandis* and switchgrass are good candidates for use in revegetation planning. Several additional species, including *E. amplifolia*, mimosa, longleaf pine, silkgrass, and wiregrass, would be good choices in a plantback scenario if percent mortality is a more desirable quality than injury. These predicted plantback dates after initial imazapyr application will be helpful in determining optimum timing of a revegetation project. Knowing what species will best tolerate imazapyr and how long to wait before planting can reduce the gap of time between initial cogongrass control and its reinvasion of an area.

Table 3.1. The predicted concentration values of imazapyr using a corn root bioassay from sand tailings soil in Polk County.

	Months after treatment		
Application rate	0 [1]	1 [2]	3 [3]
-- kg ai/ha --			
0	0	0	0
0.84	0.84 ± 0.33[4]	0	0.003 ± 0
1.68	1.12 ± 0	0.011 ± 0.01	0.003 ± 0
3.36	1.12 ± 0	0.026 ± 0.01	0.0087 ± 0.01

[1] Values derived from regression equation y=2.3+12.3*exp (-26.7*x); R^2= 0.87; See Figure A-1.
[2] Values derived from regression equation y=1.7+13.6*exp (-28.9*x); R^2=0.95; See Figure A-2.
[3] Values derived from regression equation y=2.0+10.8*exp (-44.0*x); R^2=0.97; See Figure A-3.
[4] Mean of 5 replications followed by Standard Deviation.

Table 3.2. The predicted concentration values of imazapyr using a corn root bioassay from clay soil in Polk County.

	Months after treatment		
Application rate	0 [1]	1 [2]	3 [3]
-- kg ai/ha --			
0	0	0	0
0.84	0.062 ± 0.01[4]	0.013 ± 0.01	0.0018 ± 0
1.68	0.064 ± 0.02	0.044 ± 0.01	0.023 ± 0.02
3.36	0.054 ± 0.02	0.032 ± 0.02	0.02 ± 0.02

[1] Values derived from regression equation y=1.7+15.2*exp(-40.5*x); R^2= 0.83; See Figure A-4.
[2] Values derived from regression equation y=1.4+16.4*exp(-36.7*x); R^2=0.97; See Figure A-5.
[3] Values derived from regression equation y=1.5+12.1*exp(-23.3*x); R^2=0.90; See Figure A-6.
[4] Mean of 5 replications followed by Standard Deviation.

Table 3.3. The predicted concentration values of imazapyr using a corn root bioassay from overburden soil in Polk County.

	Months after treatment		
Application rate	0 [1]	1 [2]	3 [3]
------------------------------------- kg ai/ha -------------------------------------			
0	0	0	0
0.84	0.29 ± 0.29[4]	0.018 ± 0.01	0.01 ± 0.01
1.68	0.17 ± 0.17	0.027 ± 0.02	0.015 ± 0.01
3.36	0.36 ± 0.36	0.033 ± 0.01	0.025 ± 0.02

[1] Values derived from regression equation y =2.0+12.6*exp(-28.3*x); R^2= 0.95; See Figure A-7.
[2] Values derived from regression equation y =1.6+11.8*exp(-33.0*x); R^2=0.94; See Figure A-8.
[3] Values derived from regression equation y =0.9+12.7*exp(-32.7*x); R^2=0.93; See Figure A-9.
[4] Mean of 5 replications followed by Standard Deviation.

Table 3.4. Estimated revegetation timeframe as related to plant species and soil type according to Experiment 1.

	Clay		Overburden	
	P_{40} Mortality	I_{30} Injury	P_{40} Mortality	I_{30} Injury
Plant Species	--------------Months after imazapyr application (0.84 kg ai/ha) in soil-------------			
Eucalyptus amplifolia	0	1	0	1
mimosa	0	1	0	1
longleaf pine	0	--	0	--
Eucalyptus grandis	0	1	0	1
silkgrass	0	3	0	3
wiregrass	0	*	0	*
sand live oak	1	--	1	--
broomsedge	1	3	1	3
gopher apple	1	--	1	--
lovegrass	1	--	1	--
bluejack oak	3	--	3	--
switchgrass	3	1	3	1
wax myrtle	*	--	*	--

* Time for imazapyr rate to become tolerable at the specified value exceeds period of monitoring.

Table 3.5. Estimated revegetation timeframe as related to plant species and soil type according to Experiment 2.

	Clay		Overburden	
	P_{40} Mortality	I_{30} Injury	P_{40} Mortality	I_{30} Injury
Plant Species	--------------Months after imazapyr application (0.84 kg ai/ha) in soil-------------			
Eucalyptus amplifolia	0	1	0	1
mimosa	0	3	0	3
longleaf pine	0	--	0	--
Eucalyptus grandis	0	1	0	1
silkgrass	0	*	0	*
wiregrass	0	1	0	1
sand live oak	0	--	0	--
broomsedge	0	*	0	*
gopher apple	0	--	0	--
lovegrass	0	--	0	--
bluejack oak	0	--	0	--
switchgrass	*	1	*	1
wax myrtle	*	--	*	--

*Time for imazapyr rate to become tolerable at the specified value exceeds period of monitoring.

CHAPTER 4
NATURAL RECRUITMENT OF PLANT SPECIES IN AREAS PREVIOUSLY INFESTED WITH COGONGRASS

Introduction

Cogongrass [*Imperata cylindrica* (L.) Beauv.] is a rhizomatous perennial grass species found throughout much of the tropical and sub-tropical regions of the world and is considered to be the world's seventh worst weed (Holm et al. 1977). Unfortunately, the occurrence of cogongrass has increased drastically during the past twenty years (Bryson and Carter 1993) and is currently reported in much of the southeast United States, including Florida, Mississippi, and Alabama (Johnson et al. 1999). Cogongrass tends to spread over vast areas where vegetation is marginally supported, suppressing and displacing many native plants (Bryson and Carter 1993). Cogongrass is able to spread and persist through several survival strategies including an extensive rhizome system, adaptation to poor soils, drought tolerance, prolific wind disseminated seed production, fire adaptability, and high genetic plasticity (Holm et al. 1977; Dozier et al. 1998).

Invasive, non-native weeds such as cogongrass are a cause for concern in natural areas within the United States. Once aggressive weeds such as this become established in an area, they may continue to proliferate and displace most of the native vegetation, many times resulting in a monoculture of cogongrass (Shilling et al. 1997). Invasive weeds can displace native plants by growing and reproducing more rapidly and being less sensitive to environmental stresses than native species (Marion 1986). Native xeric scrub and sand hill species commonly found throughout Florida typically grow slowly and provide low coverage. This is due to low moisture and fertility inherent in xeric soils, which allows for an open niche for invasive species (Segal et al. 2001). Once an invasive species dominates an area, natural fire and hydrology processes that influence the ecosystem may be altered. There is often less pressure placed upon these non-native species from disease, insects, or predation since they did not naturally evolve in these areas. Non-native invasive plants are often able to thrive when outside pressures are removed.

In Florida, reclaimed phosphate mining areas are important areas for cogongrass control and native plant restoration. Because mining disturbance creates a hospitable environment for weed invasion, one of the most difficult barriers to successful restoration is the control of cogongrass and other invasive weeds. In central Florida, reclaimed mining sites have a diverse collection of soil types with overburden, sand tailings and phosphatic clay pits being three of the most prominent (Richardson et al. 2003). Overburden, a mixture of sand and clay, is removed from the land surface to the top of the ore body and piled on the side. Phosphate ore, currently being mined, is an unconsolidated mixture of sand, clay, and phosphate mineral. Sand tailings are separated from the phosphatic ore and hydraulically pumped to fill mine cuts between overburden piles. Phosphatic clay is washed from phosphate ore and pumped, at about 3-5% solids, to settling areas. This soil type covers about 40% of the mined area and is considered highly fertile (Stricker 2000).

These three soil types involved in phosphate mining processes are highly diverse in nature, yet they are all susceptible to cogongrass and other non-native weed invasions. This is due to the disturbance of the areas during the mining process and the associated harsh conditions to which plants are subjected.

In phosphate reclamation areas and other natural areas, chemical weed control is the most common practice. Unfortunately, these herbicide control methods provide limited long-term control. To date, the most effective herbicides for cogongrass management are glyphosate and imazapyr (Dozier et al. 1998; Barnett et al. 2000; MacDonald et al. 2002). Generally, imazapyr provides control for a longer period of time due to soil activity and has minimal off-target effects if used correctly (MacDonald et al. 2002). Research to date has indicated imazapyr at 1.12 kg-ai/ha applied late summer/early fall provides control for as long as 18 months (Dozier et al. 1998). The main reason for this limited control is the presence of cogongrass rhizomes, which can comprise over 2/3 the total plant biomass. These rhizomes contain multiple nodes from which regrowth may occur, but generally only a fraction sprout at any given time (English 1998). This low shoot to root/rhizome ratio contributes to its rapid regrowth after cutting or burning (Sajise 1976). Cogongrass rhizomes are white and tough with shortened internodes. Specialized anatomical features help to conserve water within the central cylinder and help to resist breakage and disruption when trampling or disturbance occurs (Holm et al. 1977). Rhizomes are predominately found within the top 15 cm of fine textured soils or the top 40 cm of course textured soils. However, rhizomes have been discovered growing at depths of 120 cm (Holm et al. 1977; Gaffney 1996). According to Tominaga (2003), cogongrass rhizomes can be grouped in the following three categories: tillering, secondary colonizing, and pioneer rhizomes. Unlike cogongrass seedlings, which are defined as R-strategist (ruderal) and invade open patches in disturbed habitats, rhizomes from current cogongrass stands are more defined as C-strategist (competitor) that can persist in established populations (Tominaga 2003).

These rhizomes provide a tremendous amount of biomass for regeneration after foliar loss, with one study showing rhizome length of over 89 meters within one square meter of soil surface area (Lee 1977).

Cogongrass rhizomes are a major hindrance to continued suppression after initial control. For long-term management of cogongrass, further methods need to be integrated into the traditional control techniques that are currently used. Even in areas where initial control has been successful, cogongrass re-infestation will often occur. One objective of this study is to determine rhizome presence and density in areas previously treated with imazapyr and glyphosate, which will be helpful in understanding the mechanism of cogongrass re-infestation. In addition, the objective of monitoring natural recruitment of native species in areas previously treated with these herbicides may help us to understand which plant species are more competitive with cogongrass. This type of information will be beneficial in the long-term planning and management of natural areas for long-term cogongrass management and control.

Materials and Methods

Research was conducted at Tenoroc Fish Management Area, a 2,430-hectare tract of land that was mined for phosphate until the mid-1970's. The area is located 3.2 kilometers northeast of Lakeland, Florida. Approximately 400 hectares of lakes locally referred to as "phosphate pits" remain from early mining operations.

Three areas previously infested with cogongrass were sprayed in the fall of 2000, 2001, and 2003, following a late summer (August) burn. Burning removed accumulated thatch and simulated regrowth. Cogongrass was 30-45 cm tall at the time of treatment.

Long Term Cogongrass Control

Treatments included imazapyr at 0.84 kg ai/ha and glyphosate at 3.36 kg ai/ha in 76 m long x 15 m wide plots with 4 replications. In January 2004, visual observations were taken in these areas to monitor cogongrass reinfestation 0.25, 2, and 3 years after initial treatment to determine which herbicide had the greatest control over time. Percent control was recorded, where 0 = no control and 100 = complete control. Data were subjected to analysis of variance to test for main effects and interactions.

Rhizome Distribution

In the area sprayed on October 16, 2000, 25 samples of 10 cm x 20 cm soil cores were taken from each of the 8 plots, approximately 3 years post-treatment (January 13, 2004). The samples were taken at random locations within each plot and categorized according to proximity to cogongrass regrowth: 1) samples where no cogongrass was present within 0.6 meters; 2) samples within 0.6 meters of cogongrass; and 3) samples within a cogongrass patch. This sampling date was chosen after several growing seasons to allow for any natural progression of annual and perennial species that might establish after initial cogongrass control. Soil samples were transported back to Gainesville, FL, for rhizome removal. After 3 days in an oven drier at 60C, rhizome dry weight was determined. Plant species were evaluated for percent cover within each plot, where 0 = no coverage and 100 = complete coverage, and data were subjected to analysis of variance to test for main effects and interactions.

Native Species Recolonization

In addition, the Tenoroc area has three distinct soil types that result from the mining process: sand tailings, overburden, and phosphatic clay settling ponds. Mowing occurred in October 2002 in each of the three soil types immediately before herbicide application, with treatments including 0.0, 0.84, 1.68, and 3.36 kg ai/ha imazapyr. Plot size was 6 m x 6 m with 5 replications in a randomized complete block design. Treatments were applied using a CO_2 backpack sprayer with 11002 flat fan nozzles calibrated to deliver 187 L/ha. Both the overburden and sand areas were sprayed on November 19, 2002, while the clay settling area was sprayed December 12, 2002. In each of these three soil types, native species recolonization was observed in January 2004 (approximately 2 years after treatment) among the 3 imazapyr rates applied. All data were subjected to analysis of variance to test for main effects and interactions, and means separated using Fisher's LSD procedure at the 0.05 level.

Results and Discussion

Long Term Cogongrass Control

Table 4.1 shows percent cogongrass control in each of the previously sprayed areas in Polk County, Florida. Since these observations were made in January 2004, this table represents observations taken 4, 39, and 48 months after treatment (MAT) from separate sites. In the area sprayed in 2003, there was a significant difference between glyphosate and imazapyr plots (62 and 96% cogongrass control, respectively). There was also significant difference in the areas sprayed in 2001, 36 MAT (37% control in glyphosate plots and 88% control in imazapyr plots). These data show that up to 36 MAT, areas treated with 0.84 kg ai/ha imazapyr continue to provide statistically greater control of cogongrass than those treated with 3.36 kg ai/ha glyphosate. As time progressed to 48 MAT, there was no statistical difference between treatments. This continued control of cogongrass in imazapyr areas does not imply that imazapyr provides increased control as time progresses. The data might reflect differences in consistency with glyphosate control as seen in the difference in control with glyphosate between 2001 and 2000.

Also, the data possibly suggest that initial higher control of cogongrass with imazapyr compared to glyphosate possibly allowed for other species to enter the area and compete with the cogongrass as regrowth occurred.

Thirty nine MAT, there was no significant difference between herbicides in overall cogongrass control or the density of the 3 most commonly observed native species- dogfennel (*Eupatorium capillifolium*), broomsedge (*Andropogon virginicus*), and saltbush (*Baccharis halimifolia*), as shown in Table 4.2.

Rhizome Distribution

Both glyphosate and imazapyr plots had approximately half of all samples classified as category 1- no cogongrass within 0.6 meters, (52 and 56%, respectively) as shown in Table 4.3. Of these samples, only an average of 1.5% contained rhizomes, with low average weights (0.19g and 0.08g in glyphosate and imazapyr treatments.) Both herbicide treatments contained an average of 38% category 2 samples- cogongrass within 0.6 meters, with approximately half of these samples containing rhizomes with average weights of 0.9g and 0.38g, respectively (Table 4.4). Only 9 and 6% of glyphosate and imazapyr samples were classified as category 3- cogongrass present within core samples (Table 4.5). Of these samples, 100% contained rhizomes with average weights of 2.2g and 2.0g, respectively. These data help to support the hypothesis that the continued growth and spread of cogongrass after treatment in 2000 was due to patches remaining from initial control rather than regrowth from dormant rhizomes. This is because rhizomes were predominately associated with foliar patches.

Native Species Recolonization

Vegetation percent cover at the two of the three soil types in Polk County sprayed with imazapyr in 2002 was recorded. The third soil type was the clay settling pond area, but no data could be reported due to a fire that moved through the area in the fall of 2003. Due to the fire, all treatments in the clay area had cogongrass coverage averaging 100%. Data for the sand tailing area and the overburden area are shown in Tables 4.6 and 4.7.

At the sand area in Polk County (Table 4.6), the most common species present was the non-native *P. notatum*, which was present prior to treatment in 2002, followed by the windblown species *H. subaxillaris*. There was no significant difference in percent cover for either species among varying imazapyr rates. *Rhynchelytrum repens*, *Passiflora incarnata*, *Conyza canadensis*, and cogongrass were also present, but with no statistical difference among imazapyr rates, including the untreated plots. Since cogongrass was still present in all imazapyr treated areas, it is not known if it spread from dormant rhizomes in the plot or rhizome invasion from adjacent untreated areas.

In the overburden area, similar differences in imazapyr rates among all species is shown in Table 4.7. The most common species was again the non-native *P. notatum,* followed by *R. repens*, *E. capillifolium*, and *Euthamia caroliniana*, three species that spread by windblown seeds. Leguminous species such as *Indigofera hirsuta*, *Crotalaria pallida*, and *Chamaecrista fasciculata* were also present within the overburden plots, although at lower coverage. In related studies, legumes have shown tolerance in areas treated with imazapyr and show an ability to suppress cogongrass due to competitiveness (Akobundu et al. 2000; Gaffney 1996). *A. virginicus*, another wind-blown native species, was present in the check plots where no imazapyr was sprayed, yet only at minimal coverage.

Overall, results from these studies do not suggest there were significant long-term effects on native plant recruitment due to imazapyr treatment. After 2 years, there was no significant difference in native species growth in two soil types for all rates of imazapyr. These data are helpful in understanding how a more effective revegetation strategy could be developed as part of an overall integrated cogongrass management system.

Table 4.1. Cogongrass control over a 4-year period. Visual ratings taken in January 2004 in Polk County.

		2003	2001	2000
	kg ai/ha	% cogongrass control		
glyphosate	3.36	62	37	67
imazapyr	0.84	96	88	81
$LSD_{0.05}$		25	15	NS

Table 4.2. The effect of glyphosate and imazapyr on native species 39 months after application in Polk County (area sprayed in Fall 2000).

		Eupatorium capillifolium	*Andropogon virginicus*	*Baccharis halimifolia*
	kg ai/ha	% cover		
glyphosate	3.36	88	8	42
imazapyr	0.84	66	16	33
$LSD_{0.05}$		NS	NS	NS

Table 4.3. Category 1 soil samples- no cogongrass within 0.6 meters of core samples. Rhizome data taken 39 months after herbicide application in Polk County.

Category 1 – no cogongrass within 0.6 meters				
	kg ai/ha	% of all samples	% of samples with rhizomes	average rhizome dry wt.(g)
glyphosate	3.36	52	2	0.19
imazapyr	0.84	56	1	0.08
$LSD_{0.05}$		NS	NS	NS

Table 4.4. Category 2 soil samples- cogongrass within 0.6 meters of core samples. Rhizome data taken 39 months after herbicide application in Polk County.

Category 2 –cogongrass within 0.6 meters				
	kg ai/ha	% of all samples	% of samples with rhizomes	average rhizome dry wt.(g)
glyphosate	3.36	39	45	0.9
imazapyr	0.84	38	49	0.38
$LSD_{0.05}$		NS	NS	NS

Table 4.5. Category 3 soil samples- cogongrass present within core samples. Rhizome data taken 39 months after herbicide application in Polk County.

Category 3 –cogongrass present				
	kg ai/ha	% of all samples	% of samples with rhizomes	average rhizome dry wt.(g)
glyphosate	3.36	9	100	2.2
imazapyr	0.84	6	100	2.0
$LSD_{0.05}$		NS	NS	NS

Table 4.6. Natural presence of species on sand soil type burned and treated with imazapyr (Arsenal®) in the fall of 2002 at Tenoroc WMA. Visual evaluations of percent cover were taken in fall of 2004 (24 months after treatment).

	Rhynchelytrum repens	*Paspalum notatum*	*Heterotheca subaxillaris*	*Passiflora incarnata*	*Conyza canadensis*	cogongrass
imazapyr rate (kg ai/ha)	---% cover---					
0.0	30	70	40	23	10	50
0.84	30	39	33	--	30	20
1.68	27	65	26	20	30	25
3.36	12	32	49	5	15	15
LSD $_{0.05}$	NS	NS	NS	NS	NS	NS

Table 4.7. Natural presence of species on overburden soil type burned and treated with imazapyr (Arsenal®) in the fall of 2002 at Tenoroc WMA. Visual evaluations of percent cover were taken in fall of 2004 (24 months after treatment).

	Rhynchelytrum repens	*Eupatorium capillifolium*	*Euthamia caroliniana*	*Paspalum notatum*	legume spp.[1]	*Andropogon virginicus*
imazapyr rate (kg ai/ha)	---% cover---					
0.0	35	60	15	57	5	35
0.84	33	10	51	53	7	--
1.68	44	8	15	60	11	--
3.36	45	5	10	53	20	--
LSD $_{0.05}$	NS	NS	NS	NS	NS	NS

[1]Including *Indigofera hirsuta*, *Crotalaria pallida*, and *Chamaecrista fasciculata*.

CHAPTER 5
CONCLUSIONS

Cogongrass [*Imperata cylindrica* (L.) Beauv.] is a highly invasive grass species found throughout much of the tropical and sub-tropical regions of the world, infesting over 500 million hectares worldwide (Holm et al. 1977). Cogongrass can usually be found in predominately non-agricultural settings in the United States, and spreads over vast areas where vegetation is marginally supported, suppressing and displacing many native plants (Bryson and Carter 1993).

Cogongrass tolerates a wide range of soil conditions but appears to grow best in soils with acidic pH, low fertility, and low organic matter. This aggressive weed is able to spread and persist through several survival strategies including an extensive rhizome system, adaptation to poor soils, drought tolerance, prolific wind disseminated seed production, fire adaptability, and high genetic plasticity (Holm et al. 1977; Dozier et al. 1998).

Current control methods for cogongrass rely heavily on chemical treatments which provide limited long-term control due to the presence of multiple cogongrass rhizomes, which can comprise over 2/3 the total plant biomass. Research to date has indicated imazapyr at 1.12 kg ai/ha applied late summer/early fall provides control for as long as 18 months (Dozier et al. 1998). Burning prior to herbicide application helps to remove dead biomass and promote new shoot growth, allowing for more effective control. Unfortunately, cogongrass will re-form a monotypic stand within 1-2 years after this time if additional treatments are not imposed (Dozier et al. 1998).

Imazapyr provides good control of cogongrass but has limited utility due to the long residual effects of this compound, which could hinder revegetation strategies. An important step in the further suppression of cogongrass is to establish a native plant cover into these sprayed areas as soon as the residual herbicide levels in the soil become tolerable to the plant. Plant response to imazapyr in soil is useful information in determining which species would perform best in a plantback scenario. These studies showed that both *Eucalyptus* species (*E. grandis* and *E. amplifolia*), *Mimosa strigillosa*, *Aristida beyrichiana*, and *Pityopsis graminifolia* show low mortality response to imazapyr in soil. However, *E. amplifolia* and *E. grandis* both show higher injury response than many other species to imazapyr in this study. The data show that these species might be able to "outgrow" the imazapyr injury after some period of time. Even though a plant might show initial injury symptoms, the overall ability of that plant to recover is a very important quality to look for in a potential revegetation species.

Another concern with revegetation is the amount of imazapyr residues in different soils. Soil type has an important influence on the residual amount of herbicide due to the soil structure and content of clay and organic matter. Central Florida is home to many reclaimed mining sites which have a diverse collection of soil types, with overburden, sand tailings and phosphatic clay pits being the most prominent. These three soil types involved in phosphate mining processes are highly diverse in nature, yet they are all susceptible to cogongrass and other non-native weed invasions. This is due to the disturbance of the areas during the mining process and the associated harsh conditions to which plants are subjected. Because of this diversity of soils in Florida, as well as much of the U.S., an understanding of herbicide persistence as a function of soil type is important in predicting the best time for revegetation. Samples of these soils were taken after a certain amount of time after herbicide application and information on residue amounts was generated using corn bioassay techniques. These residual data were used to estimate the best time for revegetation to occur based on the imazapyr residues reaching a tolerable level in soil.

In all three areas sprayed, detected residues were substantially lower than expected, which could be due to a dense vegetative cover found in the areas during herbicide application that might have prevented imazapyr from fully reaching the soil surface. Vegetative cover, either as dead biomass or thatch, is common in areas chemically treated for cogongrass. This might be beneficial in revegetation planning since soil imazapyr residues might be lower than expected due to this foliar uptake. Six species can be planted immediately after an imazapyr application of 0.84 kg ai/ha and expect to show no less than 60% mortality 10 weeks after planting. These species (*E. amplifolia*, mimosa, longleaf pine, *E. grandis*, silkgrass, and wiregrass) could potentially suppress cogongrass regrowth if they are established at this critical time. Based on the wait time in relation to injury data, *E. grandis* and switchgrass are good candidates for use in revegetation planning. Several additional species, including *E. amplifolia*, mimosa, longleaf pine, silkgrass, and wiregrass, would be good choices in a plantback scenario if percent mortality is a more desirable quality than injury. These estimated plantback dates after initial imazapyr application will be helpful in determining optimum timing of a revegetation project. Knowing what species will best tolerate imazapyr and how long to wait before planting can reduce the gap of time between initial cogongrass control and its reinvasion of an area.

These data regarding the most tolerable plants to be used as revegetation species is valuable research, but it is important to consider the costs involved with transplanting, as well as the overall desirability of the species by landowners. Economical aspects should be studied in future research and be taken into consideration to ultimately identify the benefits of this type of revegetation planning.

As earlier stated, even in areas where management has been successful, cogongrass re-infestation will often occur. Because of this, studying reinfestation of dormant cogongrass rhizomes is also an important aspect of overall integrated control. In addition, monitoring natural recruitment of native species in areas previously treated with these herbicides will help to understand which plant species are more competitive with cogongrass. Studies conducted show that cogongrass is continually suppressed over a period of time after treatment with imazapyr. Glyphosate, also used on cogongrass, provided consistently less control. This continued control of cogongrass in imazapyr areas does not imply that imazapyr provides increased control as time progresses. Instead, the data suggests that initial higher control of cogongrass with imazapyr compared to glyphosate possibly allowed for other species to enter the area and compete with the cogongrass as regrowth occurred.

Studying rhizome presence in areas previously treated for cogongrass control gave data which help support the hypothesis that the continued growth and spread of cogongrass after a treatment in 2000 is due to patches remaining from initial control rather than regrowth from dormant rhizomes. This is because rhizomes were only found where there were foliar patches. Overall, results of studies related to natural recruitment in different soil types suggest that there are no significant long-term effects on native plant recruitment due to imazapyr residues in the soil. After 2 years, there is no significant difference in native species growth in two soil types for all levels of imazapyr. These data are helpful in understanding how native species react to a post-imazapyr treated area for further cogongrass suppression.

APPENDIX
STANDARD CURVES FOR CORN ROOT BIOASSAY

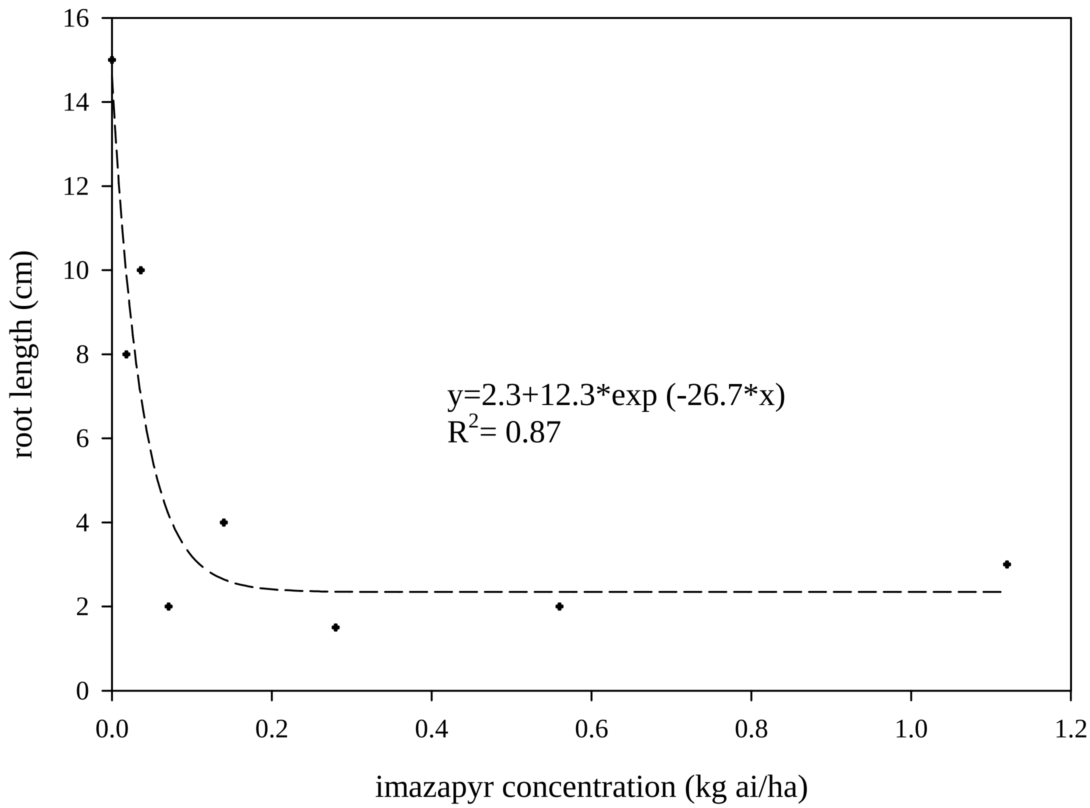

Figure A-1. The effect of imazapyr concentration on corn root length in a sand tailings soil type in Polk County, FL. Regression analysis used to determine unknown imazapyr concentrations in sand tailings soil 0 Months After Treatment (MAT). Values shown in Table 3.1.

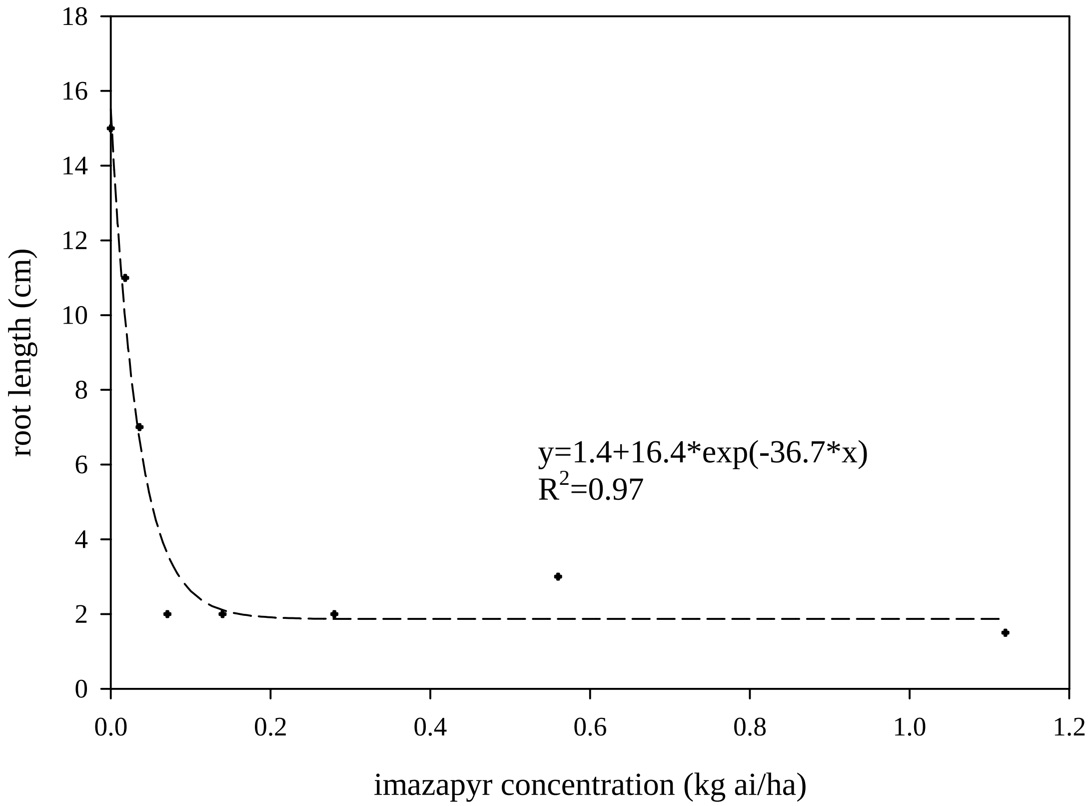

Figure A-2. The effect of imazapyr concentration on corn root length in a sand tailings soil type in Polk County, FL. Regression analysis used to determine unknown imazapyr concentrations in sand tailings soil 1 Month After Treatment (MAT). Values shown in Table 3.1.

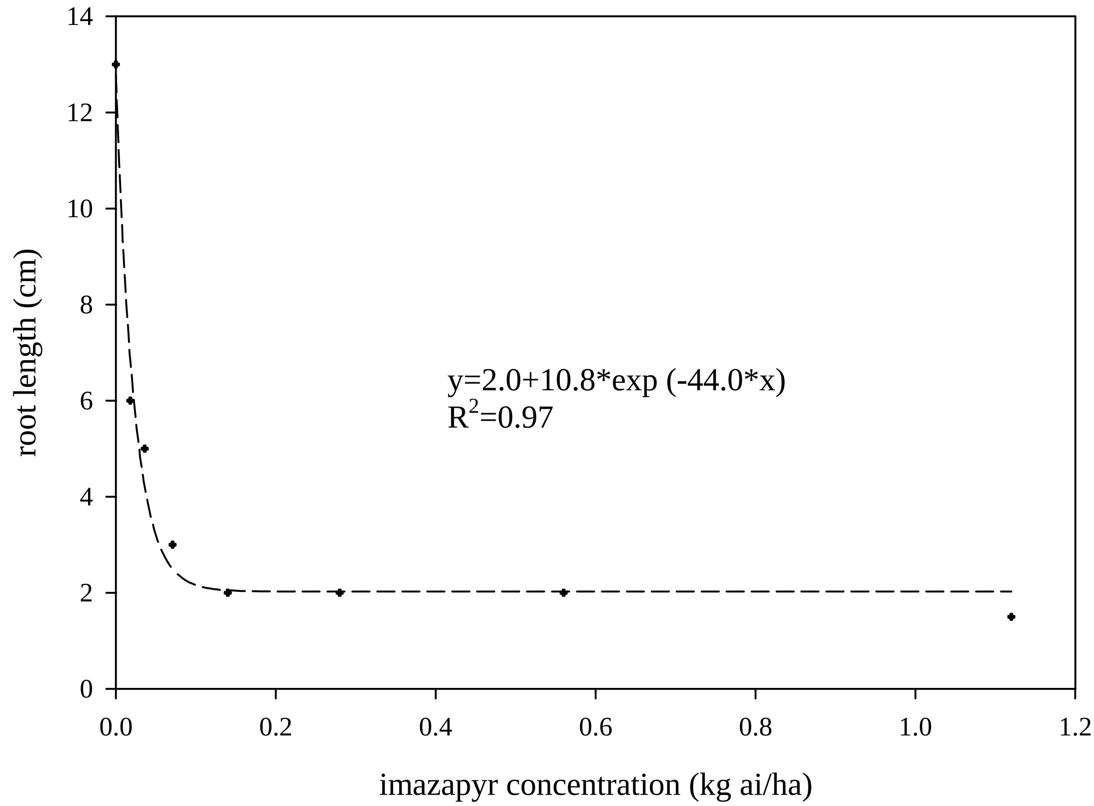

Figure A-3. The effect of imazapyr concentration on corn root length in a sand tailings soil type in Polk County, FL. Regression analysis used to determine unknown imazapyr concentrations in sand tailings soil 3 Months After Treatment (MAT). Values shown in Table 3.1.

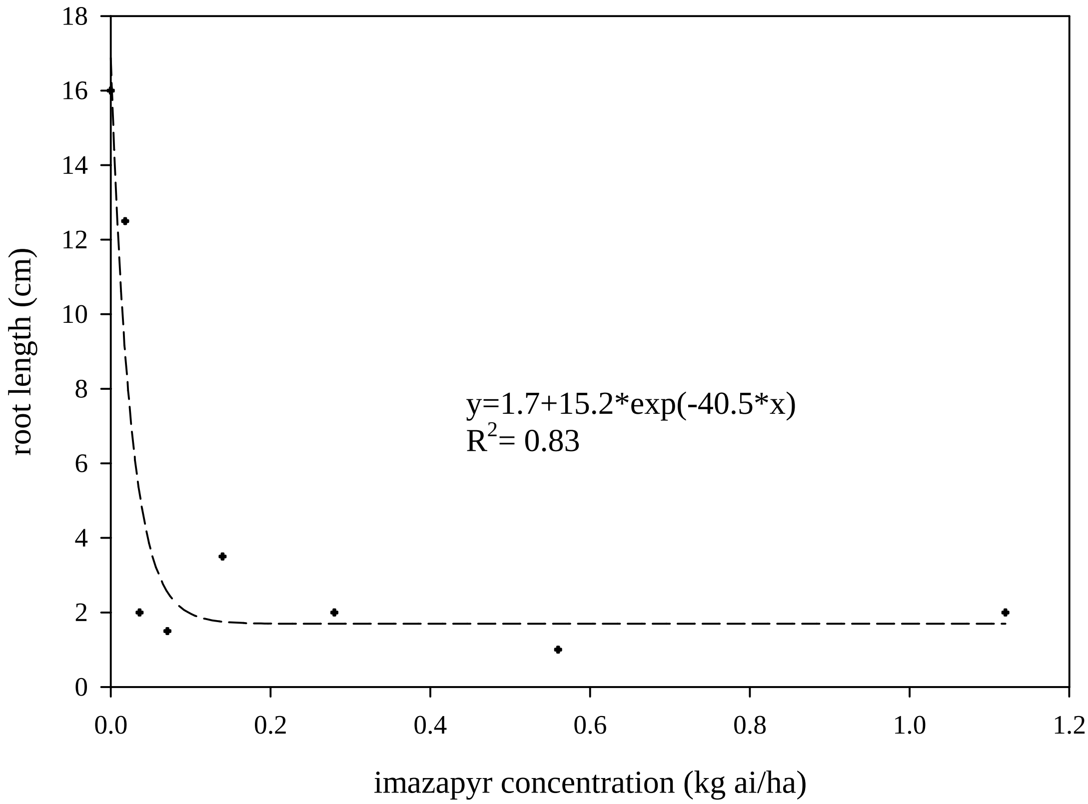

Figure A-4. The effect of imazapyr concentration on corn root length in a clay soil type in Polk County, FL. Regression analysis used to determine unknown imazapyr concentrations in clay soil 0 Months After Treatment (MAT). Values shown in Table 3.2.

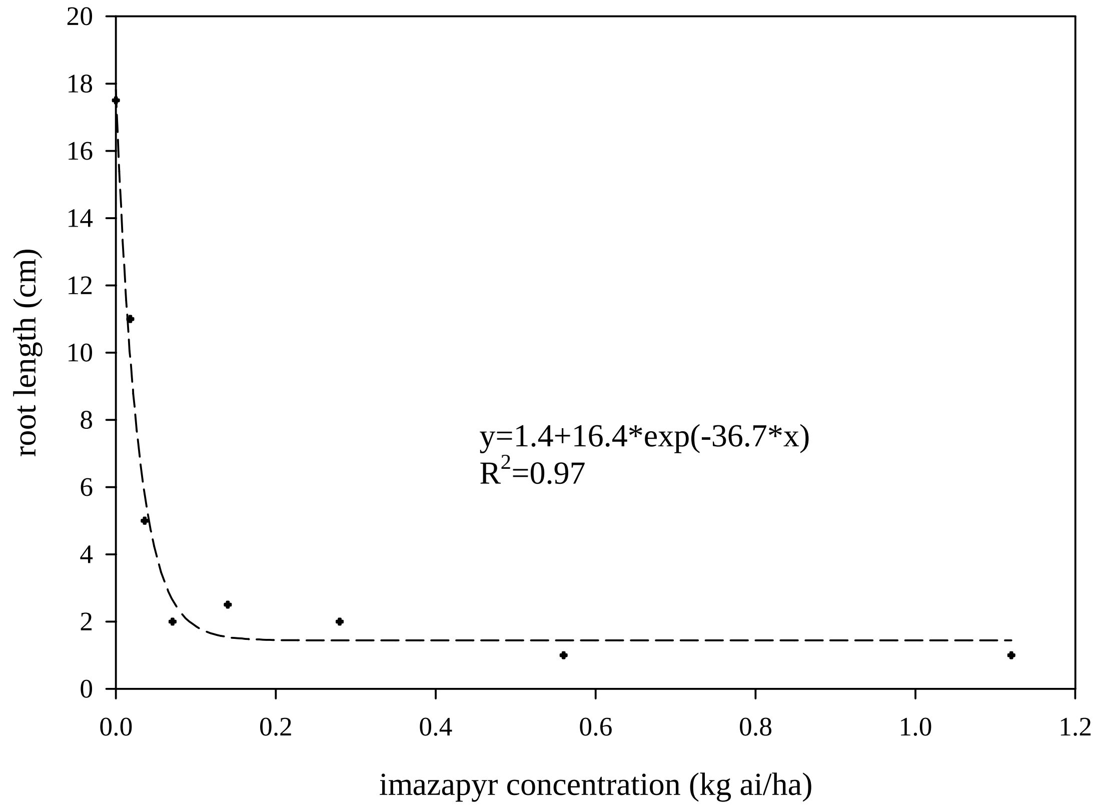

Figure A-5. The effect of imazapyr concentration on corn root length in a clay soil type in Polk County, FL. Regression analysis used to determine unknown imazapyr concentrations in clay soil 1 Month After Treatment (MAT). Values shown in Table 3.2.

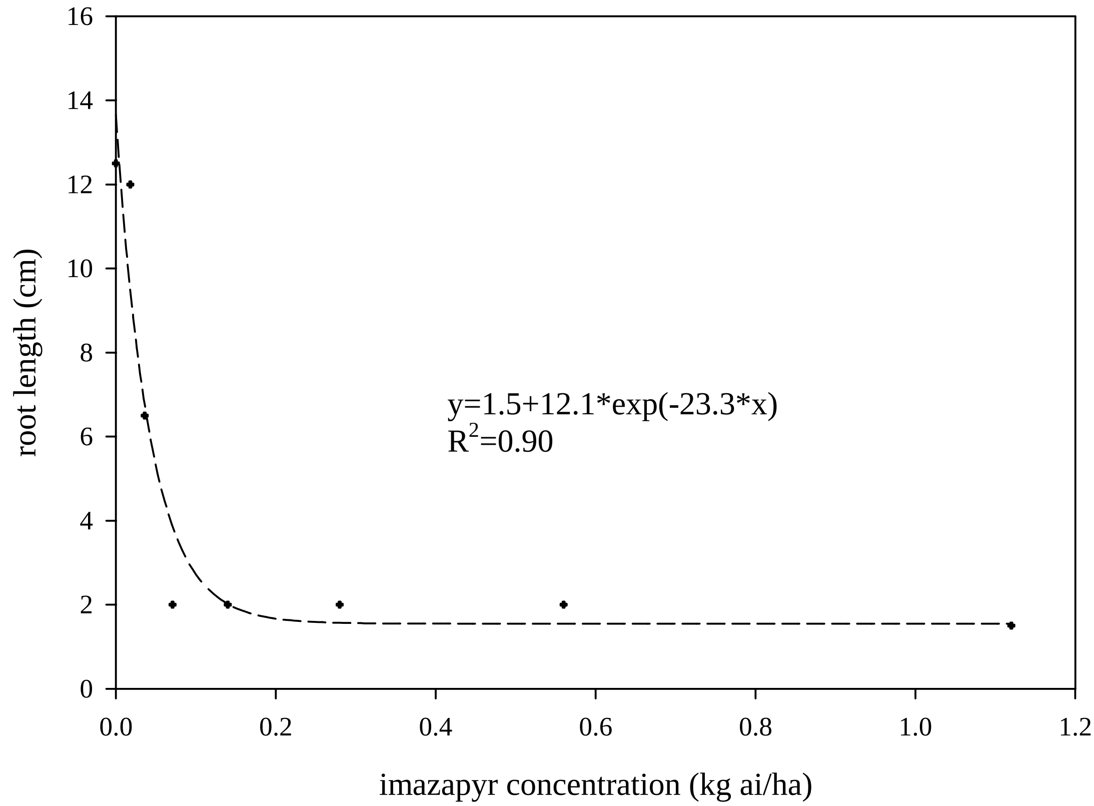

Figure A-6. The effect of imazapyr concentration on corn root length in a clay soil type in Polk County, FL. Regression analysis used to determine unknown imazapyr concentrations in clay soil 3 Months After Treatment (MAT). Values shown in Table 3.2.

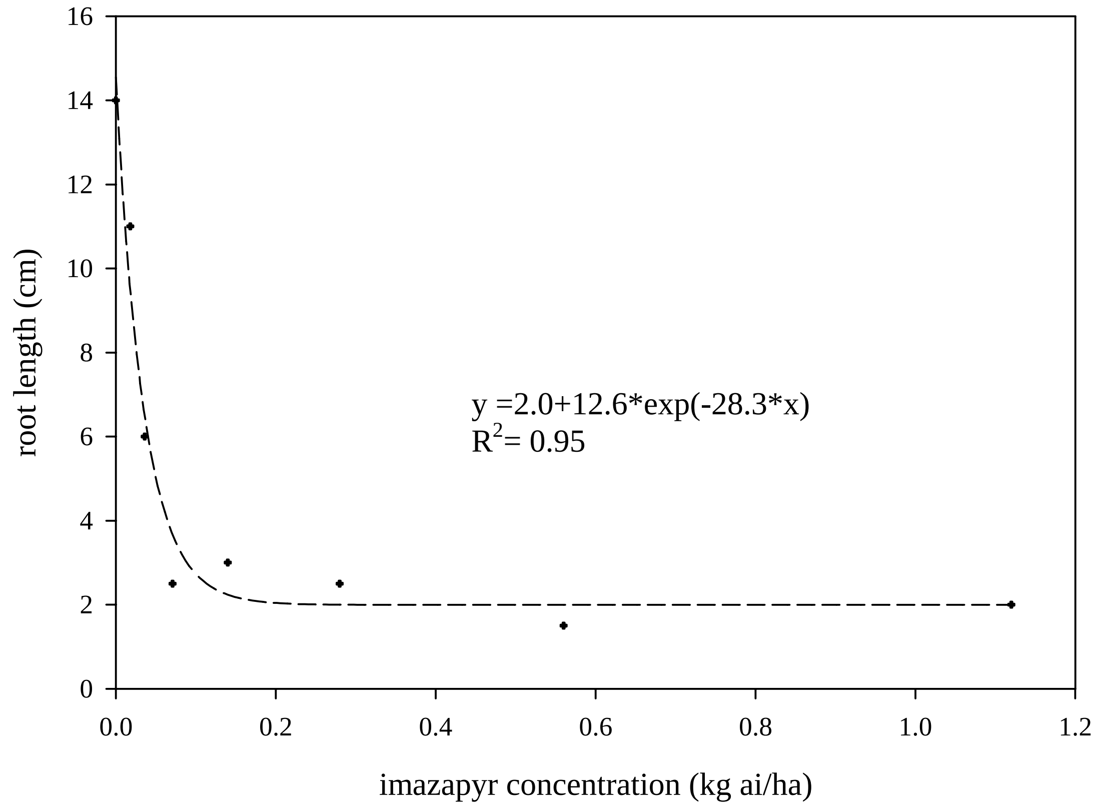

Figure A-7. The effect of imazapyr concentration on corn root length in an overburden soil type in Polk County, FL. Regression analysis used to determine unknown imazapyr concentrations in overburden soil 0 Months After Treatment (MAT). Values shown in Table 3.3.

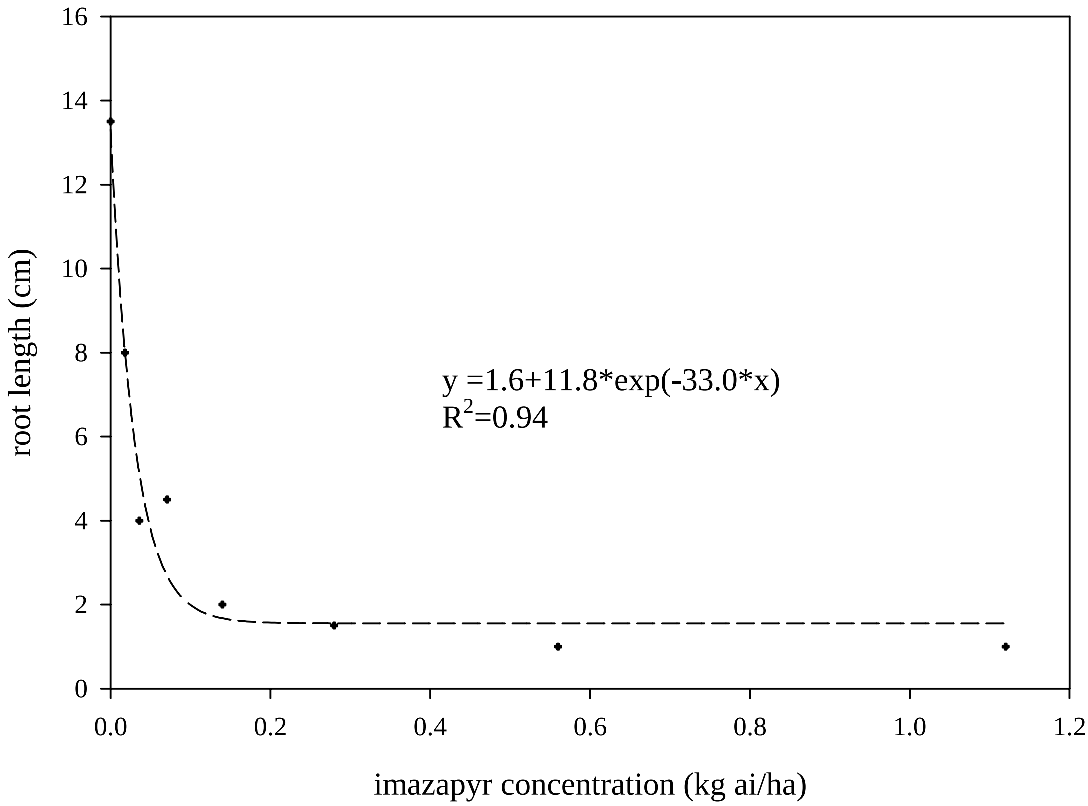

Figure A-8. The effect of imazapyr concentration on corn root length in an overburden soil type in Polk County, FL. Regression analysis used to determine unknown imazapyr concentrations in overburden soil 1 Month After Treatment (MAT). Values shown in Table 3.3.

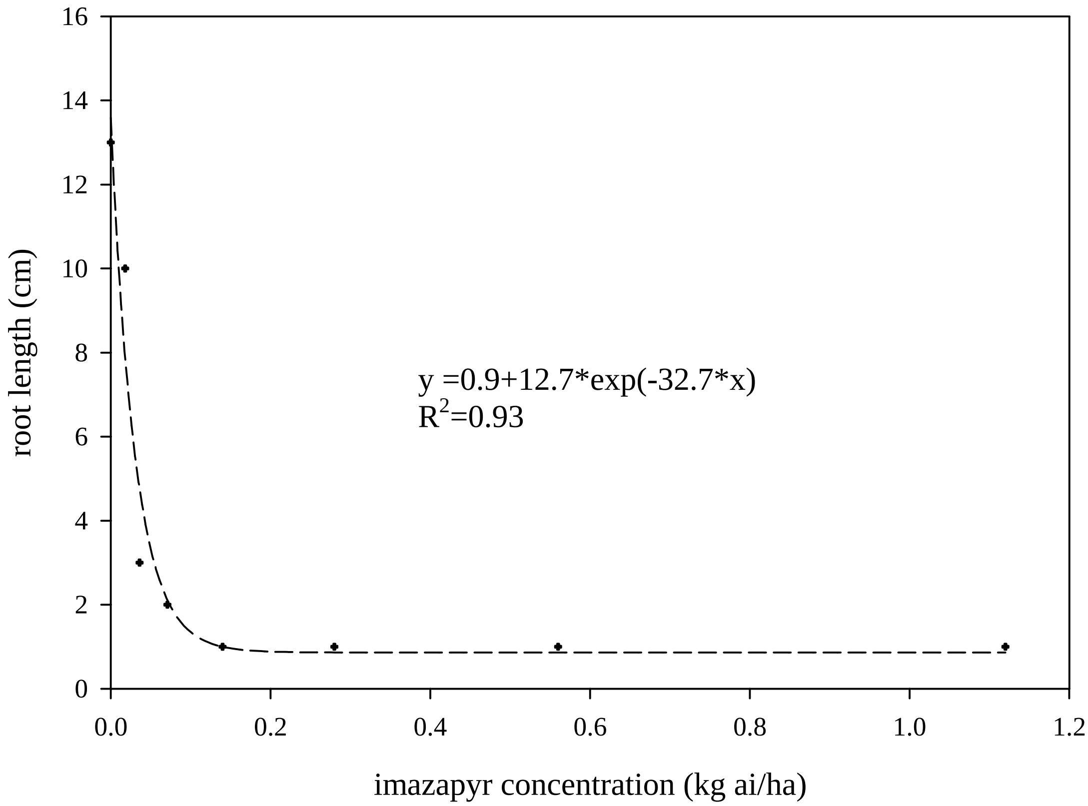

Figure A-9. The effect of imazapyr concentration on corn root length in an overburden soil type in Polk County, FL. Regression analysis used to determine unknown imazapyr concentrations in overburden soil 3 Months After Treatment (MAT). Values shown in Table 3.3.

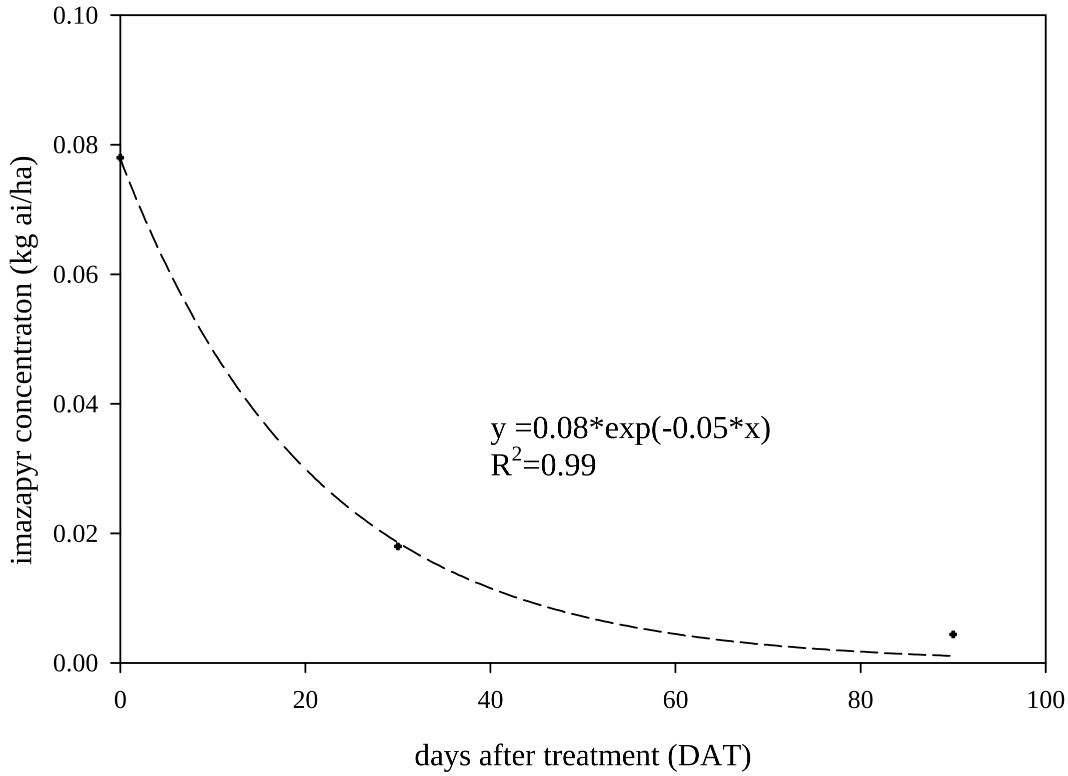

Figure A-10. Imazapyr concentration as a function of days after treatment (DAT) in a clay soil type in Polk County, FL. Regression analysis used to determine imazapyr concentrations over time after initial application of 0.84 kg ai/ha. Values shown in Table 3.4.

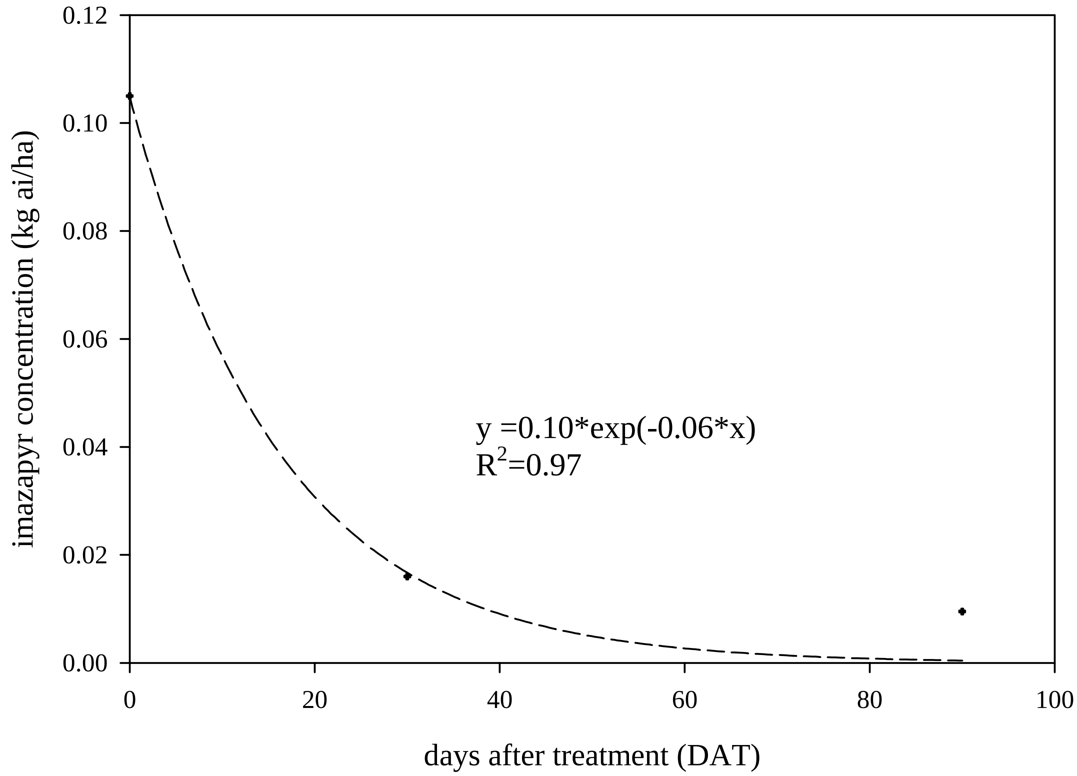

Figure A-11. Imazapyr concentration as a function of days after treatment (DAT) in an overburden soil type in Polk County, FL. Regression analysis used to determine imazapyr concentrations over time after initial application of 0.84 kg ai/ha. Values shown in Table 3.5.

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BIOGRAPHICAL SKETCH

Born on January 28, 1979, Melissa Carole Barron is the only child of Bryant and Carol Barron of Liberty, Mississippi. Born and raised in the small town of Liberty, Melissa was surrounded by nature and wildlife, which helped her to develop a strong interest in environmental sciences. After finishing at Franklin High School with honors in 1997, she went on to receive a Bachelor of Science degree in soil science from Mississippi State University in 2001. After completing her Master of Science degree in agronomy at the University of Florida in 2005, Melissa plans to pursue a career in environmental consulting.