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Integrated Management Techniques Used For Cogongrass Control

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INTEGRATED MANAGEMENT TECHNIQUES USED FOR COGONGRASS CONTROL

By

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Invasive weeds are becoming a greater problem throughout the southeastern United States, which calls for drastic means of location, classification, and management in order to halt these undesirable invasions. Three experiments were initiated in 2005 and 2006, two of which were to examine the effects of additives, NIS, Dyne-a-Pak, AMS, and Valor, and a ropewick applicator used in cogongrass control. Through these experiments, it was found that Dyne-a-Pak can provide greater enhancement in cogongrass control compared to non ionic surfactant, and that imazapyr can provide greater control than glyphosate when applied to cogongrass. The ropewick applicator was found to be an effective application technique for selectively controlling cogongrass.

A fourth experiment was initiated in 2005 to evaluate the application of classification techniques in classifying cogongrass from other vegetations along

Mississippi highway rights-of-ways. Results from this study indicate that supervised and unsupervised classification techniques can successfully identify cogongrass along highway rights-of-ways.

DEDICATION

I dedicate this work to my father (Gary Chesser), mother (Linda Chesser), and brother (Daniel Chesser). Your encouragement and support is the only reason I made it this far. I only hope that I have made you as proud of me as I am to be your son and brother. Your faith in me to finish this endeavor has meant more to me than you will ever know. I will always be indebted to you for the opportunities that you have made available to me. I could never thank you enough.

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I would like to express my gratitude and appreciation to Dr. John Byrd for giving me the opportunity to further my academic career. I thank you for your patience and faithfulness in me to accomplish this goal, even after the rocky beginning. I guess some people just need a jump start. I would also like to thank my minor professor, Dr. Rocky Lemus and committee member Dr. David Shaw. I would also like to extend a special thanks to my committee member Dr. Alfred Rankins, who sparked my endeavor through a student worker position in weed science.

Thanks to Matt Myers, Brian Burns, Nick Ivy, Scott Wright, Jim Taylor, and Stanley Self, who have all contributed to my research in some form or another. I also want to express a great appreciation to Matt Myers and Nick Ivy who were there every time we had to go to the field in the heat of the summer. We should all be experts on travel time when hauling a gooseneck trailer with tractor and four different implements, as well as how to not step on a cotton mouth in cogongrass.

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CHAPTER I

INTRODUCTION

Cogongrass [*Imperata cylindrica* (L.) Beauv.] is an invasive perennial grass, which spreads by seed and rhizome, and outcompetes most native vegetation. Hypotheses have been made that some plant species are invasive due to the ability to access and outcompete native plants for available resources (Davis et al., 2000). Once established, cogongrass displaces other vegetation in forests and rangelands, as well as on reclaimed mining sites and other disturbed areas (Shilling and Gaffney, 1995). It ranks as the seventh most troublesome weed worldwide (Holm et al., 1977). Cogongrass is a native of Southeast Asia and covers millions of acres of plantation and agriculture land (Colvin et al., 1994). It was accidentally introduced into Alabama in 1911 as packaging material in shipments from Japan (Tabor, 1952). Other selections from the Philippines were shipped to an Experiment Station in McNeil, Mississippi to be tested for forage use around 1920 (Patterson et al., 1981). It was introduced into Gainesville and Brooksville Florida in the 1940's as a potential forage crop and as potential soil stabilization plant material (Coile and Shilling, 1993). Currently cogongrass is reported in Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina, and as far north as Virginia (Bryson and Carter, 1993). Several thousand acres are infested with cogongrass in the southeastern United States and more than 1.2 billion acres worldwide (Holm et al., 1977). Cogongrass has been reported to be used as livestock feed at juvenile stages, paper making material, thatching and soil binder, and as mulching material where it is known to suppress weed growth (Tominaga et al., 1991; Tominaga and Watanabe, 1997). The invasiveness of cogongrass lies within its massive rhizome system, which provides reproductive capacity and allelotoxin production (Koger et al., 2004).

Cogongrass, genus Imperata, is in the Poaceae family; subfamily Panicoideae, tribe Andropogoneae, and subtribe Saccharine (Gabel, 1982; Dozier et al., 1998; Burnell, 2005). The *Imperata* genus has nine species worldwide, *cylindrica* species having six recognized varieties, *major* being the most common and widely spread variety in the United States (Gabel, 1982). While two of the *Imperata* species, cogongrass and Brazilian satintail (*Imperata brasilienis* Trin.), are the most prominent in the United States, cogongrass comprises most of the recorded infestation and is thought to be the most invasive (Bryson and Carter, 1993; Shilling et al., 1995). Cogongrass grows in loose to compact tufts with leaves that are flat, slightly corrugated, smooth to hairy at the base with sharply scabrid margins, and up to 1.5 m in length and 4-10 mm wide (Bryson and Carter, 1993). It is yellowish green in color, usually growing in patches of circular shape when total infestation has not occurred. Cogongrass reproduces sexually by seed (Bryson and Carter, 1993), with normal flowering in Mississippi at the beginning of the growing season in March immediately after transition, and grows actively until September. Flowering may also occur following frost, fire, mowing, tillage, or other disturbances. The inflorescence of cogongrass is branched but compacted into a white fluffy plume from 3-60 cm long (Holm et al., 1991), and it can contain up to 460 individual spikelets (Shilling et al., 1997). Each plant can produce up to 3,000 viable seeds (Holm et al., 1977), which are small and attached to the white plume of long hairs that facilitate wind dispersal (Hubbard, 1944). These aerodynamic seeding structures can easily be distributed over areas of up to 24 km (Hubbard, 1944), although generally movement is around 15 m (Holm et al., 1991). Shilling et al. (1997) reported the germination rate of these seeds to be as high as 98%, with no dormancy mechanism. Once germinated, seedlings initiate rhizome production within 30 to 40 days (Patterson et al., 1981). Prolific production of wind dispersed seeds contributes to the invasive nature of this grass and also contributes to long distant spread.

Being a perennial C_4, cogongrass develops a fibrous root system which forms dense mats, which excludes most other vegetation, and can also reproduce from rhizome propagules (Dozier et al., 1998). Tominaga (2003) states that colonization begins with wind dispersed seeds and after establishment spreads vegetatively through its rhizomes. These rhizomes not only have the ability to outcompete native plants for nutrients and water, they also can withstand extreme fluctuations of soil temperatures, soil moisture, and fertility. Studies show that cogongrass plants derived from rhizome propagules can produce up to 168 new rhizomes over an 87 day period, 350 shoots in 6 weeks, and can cover 4 m^2 in 11 weeks (Patterson et al., 1981; Dozier et al., 1998; Eussen, 1980). Rhizomes can comprise over 60% of the total plant biomass, and this low shoot-to-root ratio contributes to its rapid regrowth after burning or cutting (Sajise, 1976). Early rhizome development is vertical growth during the third and fourth leaf stage; by the fifth leaf stage rhizome growth is horizontal, and by the sixth leaf stage the rhizome tips begin to grow upward to produce new shoots (Dozier et al., 1998). The rhizomes are the means of its short distance spread and some long distance spread due to contamination of equipment with propagules.

Cogongrass is not only invasive, but it's presence causes greater potential for fire damage as higher temperatures have been measured when foliage is burned (Lippincott, 2000). This can elevate mortality rates of preferred vegetation, such as juvenile longleaf pine. Stunted growth of trees has also been reported, which was attributed to allelotoxins produced in *I. cylindrica* infestations (Holm et al., 1991). For these reasons, a cost share program for this problematic invasive weed was established in Mississippi in 2002. Dozier et al. (1998) stated that the key to long term control of cogongrass must include death of the rhizome system. Willard et al. (1997) concluded that sequential applications were needed to kill or deplete these rhizomes. Many herbicides have been evaluated in the attempt to control cogongrass, as well as many application techniques. Willard et al. (1997) also stated that dalapon, glyphosate, and imazapyr exhibited the best activity with the fewest adverse affects in cogongrass control. Since that discovery, dalapon registration with the Environmental Protection Agency (EPA) has been dropped by the manufacturer. Only glyphosate and imazapyr remain active labels, and neither herbicide can be selectively applied to longleaf pine at rates needed for cogongrass control.

The ropewick applicator is a device that has enabled applications of nonselective herbicides in sensitive crops to weeds that extended above the crop canopy (Dale, 1979). Introduced in the late 1970's, the ropewick was a variation of technology that originally started in 1909 and was expanded to include herbicide impregnated into bars of wax in the late 1960's (Derting, 1987). The ropewick applicator proved to be an effective way to selectively apply herbicides where crop safety was a concern. It was also environmentally friendly as herbicide application rates were significantly lower than with conventional application methods. Moomaw and Martin (1985) found the ropewick to be a durable and effective tool for applications of picloram to leafy spurge, which lowered the application amount. Ropewick herbicide applications have been documented to control various weeds, including cogongrass, in pastures and rangelands, cereal crops, vegetables, and cotton (Moomaw and Martin, 1990; Ralphs et al., 1991; Townson and Butler, 1990; Willard et al., 1997). Ropewick applications have been used with chemicals such as glyphosate and imazapyr for cogongrass and johnsongrass control. Keeyley et al. (1984) found that ropewick applications in cotton resulted in 83% fewer live johnsongrass shoots than with cultivation, and corresponded with 81% more seed cotton yield. Willard et al. (1997) found that a 50% imazapyr solution applied twice through a ropewick resulted in better cogongrass control than did than a 33% solution or either concentration of glyphosate at either one or two passes.

Along with the herbicides and techniques attempted, various additives have been investigated to enhance herbicide efficacy. Adjuvants have the ability to increase herbicide efficacy through processes such as spreading the herbicide solution onto foliage, and better wetting of leaf surfaces. These additives also enhance penetration of plant waxes, cuticles, and membranes which improve efficacy, and reduce application rates and lower application costs (Harker,1995). Postemergence herbicide additives can alter spray solution pH, droplet surface tension, buffering capacity, solute potential, viscosity, droplet size distribution, and other parameters (Beckett et al., 1992). Fielding and Stoller (1990) concluded that additives can improve environmental safety and lower herbicide use rates, which in turn lowers crop production costs and improve control of large weeds.

Kudsk et al. (1987) stated that one of the purposes of using additives with herbicides is to change the physio-chemical properties of the spray solution. Nonionic surfactants (NIS) are traditional additives used to reduce droplet surface tension, improve foliar coverage, and increase the rate of absorption through the leaf cuticle. Surfactants increase absorption and electrolyte leakage, as well as decrease carbohydrate translocation to roots when used with glyphosate on giant burreed (Leif et al., 1990). Surfactants also significantly increased control of Brazil pusley when applied with glyphosate (Sharma and Singh, 2001). Dyne-a-Pak® is a recently released product which is labeled as a patented blend of deposition agents, nonionic surfactants, and activators designed to provide the spray adjuvant functions of both crop oil concentrate and NIS to enhance herbicide activity. While surfactants are labeled for use with imazapyr and in certain formulations of glyphosate, which are two herbicides used for cogongrass management, Dyne-a-Pak® may provide an alternative additive for herbicide applications.

Ammonium sulfate (AMS) has been tested for the enhancement of several herbicides including glyphosate, imazethapyr, quizalofop, sethoxodim, aryloxyphenoxypropanoate (APP) herbicides, and cyclohexanedione (CHD) herbicides as well as many others (Beckett et al., 1992; Fielding and Stoller, 1990; Harker, 1995; Kent et al., 1991; Leaper and Holloway, 2000; Salisbury et al., 1991). Salisbury et al. (1991) reported that AMS at 3.3 kg ha^{-1} added to glyphosate at 0.42 kg ha^{-1} showed similar control of johnsongrass as glyphosate applied at 0.84 kg ha^{-1}. Ammonium-based fertilizers such as AMS may prove to be a viable additive in cogongrass control due to the increase in grass weed control when added to postemergence herbicides (Beckett et al., 1992).

Tank mixtures of herbicides can also improve control of certain weed spectrums, as well as improve control of certain weed species. Lich et al. (1997) stated that glyphosate tank-mixed with reduced rates of a selective herbicide could potentially provide an economical postemergence herbicide program that controls a broad spectrum of weeds. However, interactions may occur when additional herbicides are added as tank mix partners that may not result in enhanced weed control. Weed response of tank-mixed herbicides could be antagonistic, synergistic, or additive. If control observed with the mixture is greater than predicted, it is considered synergistic; if it is less than predicted, it is antagonistic, and if it is equivalent, it is additive (Lich et al., 1997). Valor® (flumioxazin) is a herbicide labeled to mix with glyphosate to increase burndown activity and broaden control of broadleaf and grass weeds. This mix may provide superior control of cogongrass compared to glyphosate or imazapyr applied alone.

Remote sensing has recently exploded in the agricultural arena with image analysis, weed detection, and site specific spraying. Applications seem to be limitless and agriculture has now become precision agriculture. Hyperspectral images of the

Earth's surface is being acquired from a variety of aerial platforms, including low altitude fix wing aircraft as well as high altitude satellites (Erives and Fitzgerald, 2005). These images can potentially be analyzed and used to assess the identity, characteristics, and growth potential of various kinds of vegetative matter. Because many multispectral remote sensing devices operate in the green, red, and near infrared regions of the electromagnetic spectrum, they can discriminate light absorption and reflectance of vegetation. These reflectance patterns can be used to pinpoint the spectral characteristics of a specific type of vegetation to map infested areas and possible control measures for that species. High spectral-resolution imagery, also called image spectroscopy or hyperspectral remote sensing, may be the most appropriate data to map individual plant species with accuracy and precision (Clark et al., 1995). Parker and Hunt (2004) state that when flowering, leafy spurge has conspicuous yellow-green bracts which are spectrally distinct from other vegetation and may be distinguished with hyperspectral remote sensing. These scientists also took ground reference data and determined a 95% accuracy of classification of leafy spurge. Cogongrass also has a distinct green-yellow tinge most of the growing season which, like leafy spurge, may be spectrally distinct from other vegetation.

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CHAPTER II

ROPEWICK APPLICATIONS FOR THE CONTROL OF COGONGRASS [*Imperata cylindrica* (L.) Beauve] IN JUVENILE LONGLEAF PINE STANDS

Abstract

Field experiments were conducted in 2005 and 2006 in George and Hancock counties to evaluate the effects of chemical (glyphosate and imazapyr), concentration (33 and 50%), and number of passes (1 and 2 passes) on the control of cogongrass in juvenile longleaf pine stands when applied through a ropewick applicator. Eleven treatments, including 1 untreated check were applied to established cogongrass and replicated 4 times in a randomized complete block design at both locations. Treatments also included broadcast applications of clethodim and fluazifop at 0.70 and 1.40 L/ha respectively. Visual ratings were taken 30, 60, 120, and 360 days after treatment (DAT) in both years to evaluate percent control, and shoot biomass samples were collected and measured 360 DAT in both years to evaluate percent change in cogongrass compared to the untreated check. Treatments that contained glyphosate exhibited higher efficacy at 30 DAT (58 %); however, by 60 and 120 DAT, imazapyr ropewick treatments began to show greater control at 67% and 69%, respectively. The concentration of neither glyphosate nor imazapyr was not significant. Two passes with the ropewick provided greater control 30 DAT, but after 60 DAT was not significant. Neither broadcast applications of clethodim

nor fluazifop provided more than 36% control. However, both graminicides exhibited excellent seedhead suppression of cogongrass the next season.

Nomenclature: imazapyr; *Imperata cylindrica* (L.) Beauv.# IMPCY[1].

Abbreviations: DAT, days after treatment.

[1] Letters followed by this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available only on computer disk form WSSA, 810 East 10th Street, Lawrence, KS 66044-8897

Introduction

The longleaf pine (*Pinus palustris* P. Mill.) ecosystem once dominated the southeastern coastal plains and could be found from southeastern Virginia to eastern Texas (Tucker and Hill, 2003; Van Lear et al., 2005). Longleaf pine has previously covered as much as 37.2 million hectares along the southeastern United States, while today fewer than 2 million hectares remain (Sayer and Haywood, 2006). This drastic loss of longleaf pine forest ranks third among the most endangered ecosystem in the United States (Van Lear et al., 2005). The degradation of the longleaf pine ecosystem began after European colonization due to the exploitation of forest products, fire suppression, and conversion to agricultural lands (Tucker and Hill, 2003; Croker, 1979; Frost, 1993; Simberloff, 1993). Most of the reduction in longleaf pine forests over the last 30 years can be attributed to landowner preference for faster growing, more economical species such as loblolly pine and slash pine (Hedman et al., 2000). Incentive programs developed by The Longleaf Alliance, Partners for Fish and Wildlife program of the U.S. Fish and Wildlife Service, National Fish and Wildlife Foundation, Georgia Forestry Commission, and the Southern Company have been initiated to encourage independent land owners to restore longleaf pine ecosystem (Van Lear et al., 2005).

As cogongrass [*Imperata cylindrica* (L.) Beauv.] populations expand, it becomes a greater problem every year in the southeastern United States. Since 1979, populations of cogongrass in Mississippi have increased from 19 to 54 counties in 2006 (Patterson et al., 1981; John Byrd, personal communications). This increase is associated with reduced biodiversity, altered fire regimes, and a more competitive environment for commercially important vegetation (Brewer and Cralle, 2003). A large percentage of these infested sites in Mississippi counties are occupied by pine plantations, the majority of which are loblolly pine stands. Although these stands are affected by the invasion of this tropical grass, longleaf pine stands are more susceptible to damage from herbicide applications at the rates needed to control the invasive than are other pines. A minimum of 0.15 kg ae/ha imazapyr is the label recommendation for cogongrass control, whereas imazapyr applied over the top of longleaf pine is limited to 0.025-0.10 kg ae/ha (Arsenal® AC Specimen Label, BASF). Longleaf pine restoration is a primary goal of many landowners throughout the southeastern United States. However, seedlings can remain stemless for over ten years, and site preparation and prescribed burnings are two of the only management techniques for weed control in longleaf pine production (Knapp et al., 2006). Longleaf pine seedlings are adapted to fire because of the thick bark which protects the vascular cambium from excessive heat (Sayer and Haywood, 2006). Cogongrass poses a potential fire threat to the already endangered pine species causing greater fine-fuel loads, higher burn temperatures, and increased flame heights (Lippincott, 2000).

Lippincott (2000) postulated that ideal weeds regrow rapidly after burning, grazing, or mowing, they can resprout from vegetative fragments, and they are highly competitive under a variety of environmental conditions. Cogongrass is almost exactly described by this statement. Cogongrass is a perennial C_4 which reproduces by both seed and rhizomes. Once established, it displaces other vegetation in forests and rangelands, as well as on reclaimed mining sites or other disturbed areas (Shilling and Gaffney, 1995). Cogongrass is a native of Southeast Asia and covers millions of acres of plantation and agricultural land (Colvin et al., 1994). It was introduced into Alabama in 1911 as packaging material in shipments from Japan (Tabor, 1952) and tested for forage use in Mississippi approximately ten years later (Patterson et al., 1981). It was introduced into Gainesville and Brooksville Florida in the 1940's as a potential forage crop and as potential soil stabilization plant material (Coile et al., 1993). Currently cogongrass is reported in Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina, and as far north as Virginia (Bryson and Carter, 1993). Several thousand acres are infested with cogongrass in the southeastern United States and more than 1.2 billion acres worldwide (Holm et al., 1977).

Cogongrass grows in loose to compact tufts with blades that are flat, slightly corrugated, smooth to hairy at the base, with sharply scabrid margins, and reaches up to 1.5m in length and 4-10 mm wide (Bryson and Carter, 1993). Each plant can produce up to 3,000 highly germinating seeds (Holm et al., 1977), which are small and attached to the white plume of long hairs that facilitate wind dispersal (Hubbard, 1944). Once germinated, seedlings initiate rhizome production within 30 to 40 days (Patterson et al. 1981). Cogongrass also develops a fibrous root system which forms dense mats and excludes most other vegetation, and it can also reproduce from rhizomes (Dozier et al., 1998). Rhizomes can comprise over 60% of the total plant biomass, and this low shoot-to-root ratio contributes to its rapid regrowth after burning or cutting (Sajise, 1976).

Control of this invasive species has proven to be difficult with many herbicides and application techniques being attempted and only few proven somewhat successful.

Long-term control has yet to be achieved; although repeat applications are needed to deplete the rhizome system which is essential for control (Willard et al., 1997). These scientists also stated that of the herbicides and herbicide combinations evaluated for cogongrass efficacy, dalapon, glyphosate, and imazapyr exhibited the best activity with the fewest adverse affects. None of the herbicides used in cogongrass control can be selectively applied to longleaf pine stands with rates needed for control. Techniques such as herbicide spraying, cutting, burning, or chopping frequently eliminates more desirable non-target vegetation, therefore an alternative method should be used for control (Kay, 1995).

The ropewick applicator can be a cost effective way to selectively apply herbicides by reducing the amount of herbicide applied per hectare and applying only to target vegetation (Moomaw and Martin, 1990). Since the first design in 1979, the ropewick applicator has been used to control many weeds growing in and above crop canopies (Moomaw and Martin, 1985; Keeyley et al., 1984). Millions of hectares of cotton, soybean, and other crops were treated with glyphosate by ropewick applicators from 1979 to 1982 (McWhorter, 1989). Crop selectivity with phenoxy compounds was the primary concern with early herbicide research using wiper applications; however, there has been new interest in the wiper after the development of nonselective herbicides such as glyphosate (Derting, 1987). Successful selective control of Canada thistle in birdsfoot trefoil stands was demonstrated in 1988 using a ropewick applicator (Boerboom and Wyse, 1988). Willard et al. (1997) applied glyphosate and imazapyr using a ropewick applicator, resulting in over 60% inhibition of cogongrass and stated that multiple ropewick applications may be a viable alternative for cogongrass control in situations where broadcast applications are not desirable. Rhizome johnsongrass control was found using a 33% solution of glyphosate, with best control found using two applications in the opposite direction made on the same day (Derting, 1987). Wiper applications allow for reductions in cost of weed control, reduced equipment cost, reduction in drift potential, reduced environmental hazards, and reduced operator exposure (Derting, 1987). For these reasons it may prove to be a viable application method for selectively controlling cogongrass in juvenile longleaf pine. The objective of this study is to evaluate the ropewick applicator for selective applictation of glyphosate and imazapyr to established cogongrass in stands of jouvenile longleaf pine.

Materials and Methods

A field trial was conducted in the summers of 2005 and 2006 to evaluate the effects of glyphosate and imazapyr applied with a rope wick applicator in juvenile longleaf pine stands for cogongrass control. The experiment was initiated on separate sites in George County, MS in 2005 and Hancock County, MS in 2006. Soils at George and Hancock County were a Benndale fine sandy loam (coarse-loamy, siliceous, semiactive, thermic Typic Paleudults)[2] and a Poarch sandy loam (coarse-loamy, siliceous, thermic Plinthic Paleudults)[3] complex, respectively. Ropewick applications were made in July of 2005 in George County and in August of 2006 in Hancock County

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[2]Soil survey of George County, MS from November 1981. USDA Soil Conservation Service in Cooperation with MAES.

[3] Soil survey of Hancock County, MS from November 1981. USDA Soil Conservation Service in Cooperation with MAES.

of glyphosate[4] or imazapyr[5] plus non-ionic surfactant (NIS) 0.5% v/v[6] at 33 and/or 50% v/v solutions. They were applied once or twice (in opposite directions) in 1.5 m by 12.2 m plots to approximately 0.5 m tall established cogongrass within juvenile longleaf pine stands. The ropewick apparatus used was a 1.5 m long String Wing[7] ropewick applicator with a reservoir capacity of 7 L. The ropewick applicator consisted of one row of ropes which were inserted from top to bottom and spanned from end to end of a PVC reservoir. This apparatus used rubber bushings in screw-cap compression fittings to prevent leakage, and utilized a vent rope on top for proper wicking action. This gave a consistently wetted wick that covered the entire 1.5 m of PVC pipe length. Two sets of ropewicks were constructed, one for each herbicide and rate. Applications were made with the ropewick mounted to a tractor mounted front end loader for height control, which traveled 4.0 km/h with the wick surface held horizontal to the ground at approximately 15-25 cm from the ground. The young pines were planted 2.44 m apart in 2.74 m row spacings, and applications were made in between rows with no contact of trees. Conventional applications were also made of clethodim[8] at 0.05 kg/ha with 2.3 L/ha crop oil concentrate[9] (COC), and fluazifop-P-butyl[10] at 0.1 kg/ha with 2.3 L/ha COC using a tractor mounted sprayer. Applications were made at a speed of 6 km/hr which delivered 187 L/ha to established cogongrass in juvenile longleaf pine stands. The

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[4] Roundup Pro ® Herbicide, © 2003 Monsanto Company, St. Louis, Missouri 63167 U.S.A.
[5] Arsenal ® AC herbicide, BASF Corporation, 26 Davis Drive, Research Triangle Park, NC 27709.
[6] Red River 90, Red River Specialties, Inc., Rigeland, MS 39158.
[7] 2006 ©Green Leaf ®, Incorporated, 11144 Toney Rd, Fontanet, IN 47851.
[8] Select® 2EC Herbicide, © 2005 Valent U.S.A. Corporation.
[9] AgriDex®, ©2006 Helena Chemical Company, 225 Schilling Blvd., Collierville, TN 38017.
[10] Fusilade® DX Herbicide, Syngenta Crop Protection, Inc., Greensboro, NC 27409.

ropewick treatments were applied in between rows Visual ratings were taken 30, 60, 120, and 360 days after treatment (DAT) on a scale of 0 (no control) to 100 (complete control) of aboveground foliar biomass. Stem counts (SC) were also taken 360 DAT both years from a 125 cm^2 area sampling grid at three random locations within the respective plot, and values were averaged for a mean to determine stand density (SD).

Due to homogeneity of data, locations were pooled and used as additional replications, and nontransformed data were used for analysis and presentation. All data were analyzed using PROC MIXED in SAS 9.1 (SAS 2004)[11], to test main effects and interactions between herbicides, herbicide concentrations, and number of ropewick passes. After data from SC were averaged, they were converted to percent reduction of the check and analyzed by Repeated Measures techniques with PROC MIXED in SAS 9.1 (SAS 2004). Fisher's protected LSD at the 0.05 level of significance was used to separate appropriate treatment means.

Results and Discussion

Of the eight ropewick treatments evaluated in this study, the 50% glyphosate solution applied with 2 passes provided the greatest level of control 30 DAT at 58 %. This level of control was significantly greater than any imazapyr ropewick treatment at this rating date. No treatments of imazapyr resulted in control above 50 % 30 DAT (Figure 2.1); however, imazapyr can begin to inhibit leaf elongation within one day of and acquire maximum translocation within 4 days of application (Shaner, 1988;

[11] Statistical Analysis Systems (SAS) software, Version 9.1. SAS Institute, Inc., Box 8000, SAS Circle, Cary, NC 27513, USA.

MacDonald et al., 2002). Glyphosate in a 33% solution with two passes and 50% solution with one pass provided similar results 30 DAT at 53 and 49%, respectively, to that of glyphosate in a 50% solution with two passes (Figure 2.1). There was no difference 30 DAT among the 33 and 50 % concentrations of neither glyphosate nor imazapyr; however, the ropewick applications utilizing two passes provided greater results at 50% cogongrass control overall compared to 42% observed with one pass. These results do not support the observations of Willard et al. (1997) who reported that two passes of a ropewick applicator provided significantly greater cogongrass control than a single pass. Fluazifop provided 36% control of cogongrass 30 DAT, which was similar to that of the 50% glyphosate solution with one pass. The poorest cogongrass control was observed with clethodim which provided only 6%.

Imazapyr applied with the ropewick provided the highest range of control 60 DAT from 58 to 67 % (Figure 2.2). There were no differences between concentrations or number of passes from any imazapyr treatments, which was also contradictory to the findings of Willard et al. (1997). At this evaluation, the initial levels of control seen from glyphosate ropewick treatments had fallen an overall 23 % (Figure 2.2). Fluazifop treatments remained at 36 %, which were equivalent to the level of control provided by glyphosate ropewick treatments, regardless of concentration or number of passes (Figure 2.2). Clethodim treatments provided the lowest level of control and continued to do so for the remainder of the rating period. These findings support Mask et al. (2000) who found that neither clethodim nor sethoxydim of the cyclohexanedione family showed much activity on cogongrass. Fluazifop-butyl has been noted to give in-season suppression of cogongrass growth, but no long-term control in the U.S. (MacDonald et al., 2002). However, cogongrass seedhead suppression was observed at the later rating dates for both fluazifop and clethodim treatments. This is consistent with Burnell (2005) who reported that clethodim at 0.15 and 0.29 kg/ha, applied immediately prior to seedhead emergence, provided 84 to 94% seedhead control in cogongrass.

Imazapyr remained the superior ropewick treatment for cogongrass control 120 DAT, which ranged from 46 to 69% (Figure 2.3). The highest level of control at 69% occurred with the high concentration (50%) using imazapry applied with one pass. However, there was no difference between 33 or 50% solutions of imazapyr applied with two passes. There was also no difference among number of passes. At this time, glyphosate treatments provided greater control than that of fluazifop and clethodim, however, all were under 34% (Figure 2.3).

Shortly after the 120 DAT rating period, the plot area burned due to wildfire. Cogongrass regrowth appeared before the 360 DAT rating period, but the trends of control were similar to those observed at 120 DAT. Imazapyr was the superior treatment regardless of concentrations or number of passes. There was minimal regrowth in the imazapyr ropewick plots after the fire, and control ranged between 65 to 78% (Figure 2.4). Cogongrass in all other treatment plots had regrown to the point that those treatments produced below 16 % cogongrass control. The highest level of control seen was 78% using imazapyr in a 50% solution with 2 passes, but there was no difference from imazapyr in a 33% solution with 2 passes at 69%. There also was no interaction among concentrations or number of passes (Figure 2.4). These findings are consistent with Willard et al. (1997) who found imazapyr in a 50% solution with 2 passes to provide the greatest amount of cogongrass control when using a ropewick applicator.

All treatments decreased SD 32 to 74% compared to the check. There were no differences among concentrations or number of passes, although comparisons among herbicides were consistent with visual control ratings. Imazapyr ropewick treatments provided superior control, from 63 to 74% reduction in SD 360 DAT (Figure 2.5), to that of glyphosate. Clethodim and fluazifop treatments provided 47 and 42% reductions, respectively, but there was no difference from the glyphosate ropewick treatments ranging from 32 to 37% (Figure 2.5).

Conclusions

The findings of this study reveal that the ropewick applicator can be a viable alternative to cogongrass control in juvenile longleaf pine. Imazapyr at 33 or 50% solution applied one or two directions can achieve acceptable levels of control 360 DAT. While glyphosate ropewick treatments did not provide acceptable levels of control for cogongrass, Willard et al. (1997) speculated that glyphosate absorption and translocation is more sensitive to higher concentrations than imazapyr. Conversely, Leif and Oelke 1990) stated that as glyphosate concentration increased from 5 to 30% control increased. However, Willard et al. (1977) concluded that the use of concentrations of more than 33% glyphosate would be economically unsound and that lower concentrations may provide as much, if not more, control of cogongrass. Due to a drop in glyphosate prices since 1977, higher concentration glyphosate treatments have become more economical.

This research indicates that in longleaf pine production, where prescribed burnings are the preferred weed control method, the ropewick could be used to apply imazapyr to alleviate the dangers posed by increased fire heights, temperatures, and competition induced by cogongrass infestation.

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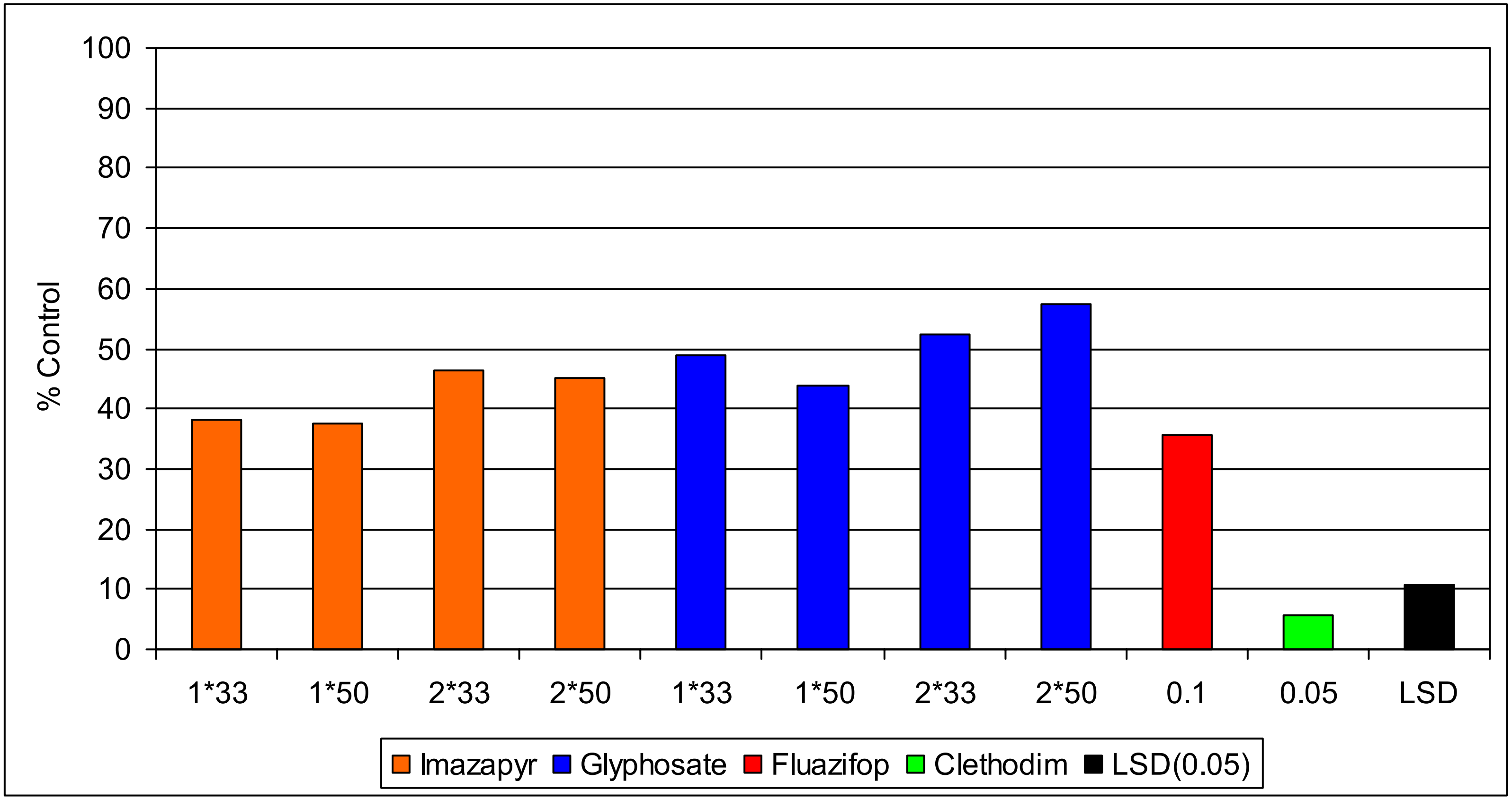

Figure 2.1: Percent control of cogongrass 30 days after treatment (DAT) using imazapyr or glyphosate in ropewick applications of pass (1 or 2) * concentration (33% or 50%), and broadcast application of fluazifop-P-butyl and clethodim in kg/ha.

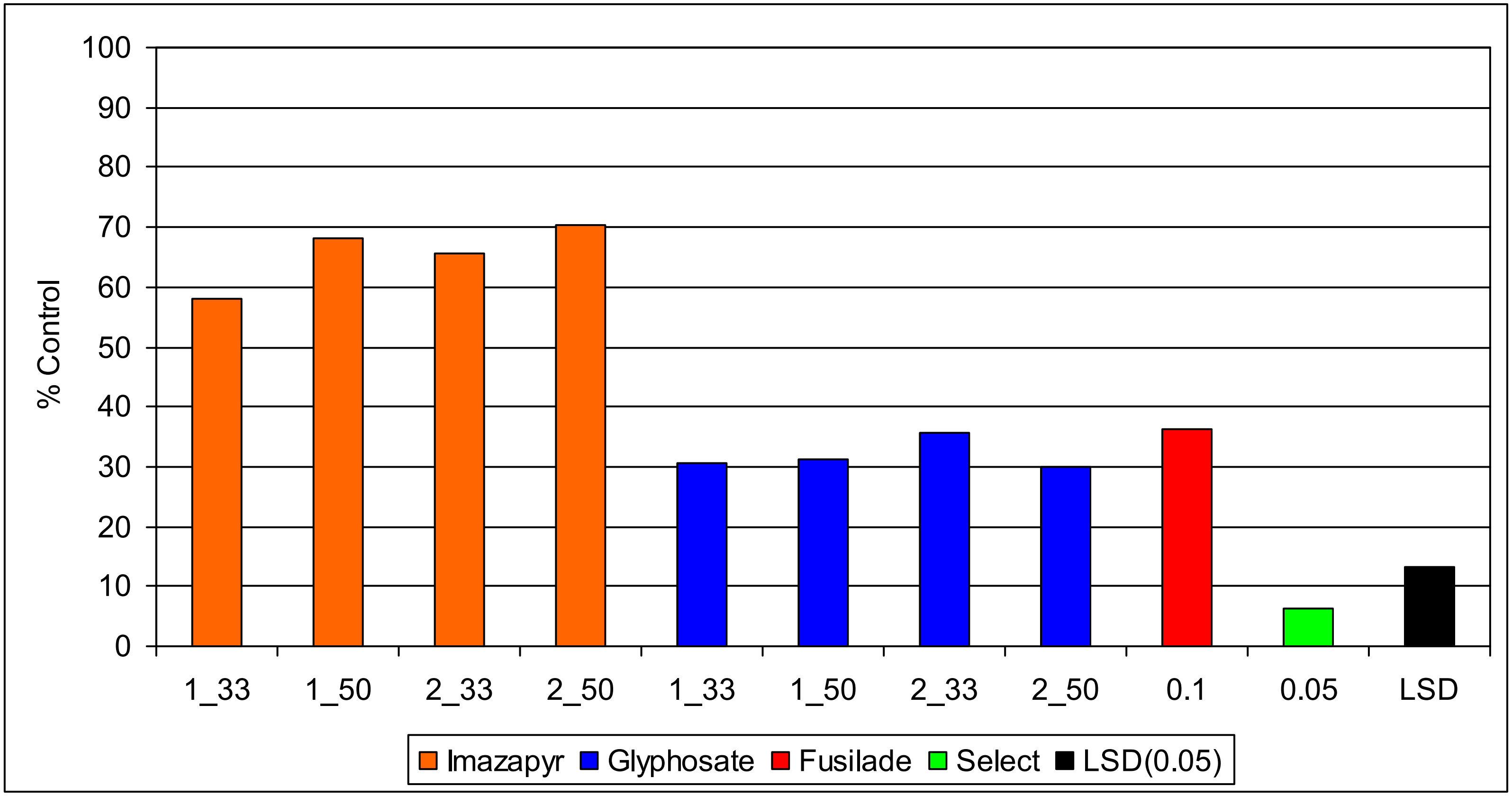

Figure 2.2: Percent control of cogongrass 60 DAT using imazapyr or glyphosate ropewick applications of pass (1 or 2) * concentration (33% or 50%), and broadcast application of fluazifop-P-butyl and clethodim in kg/ha.

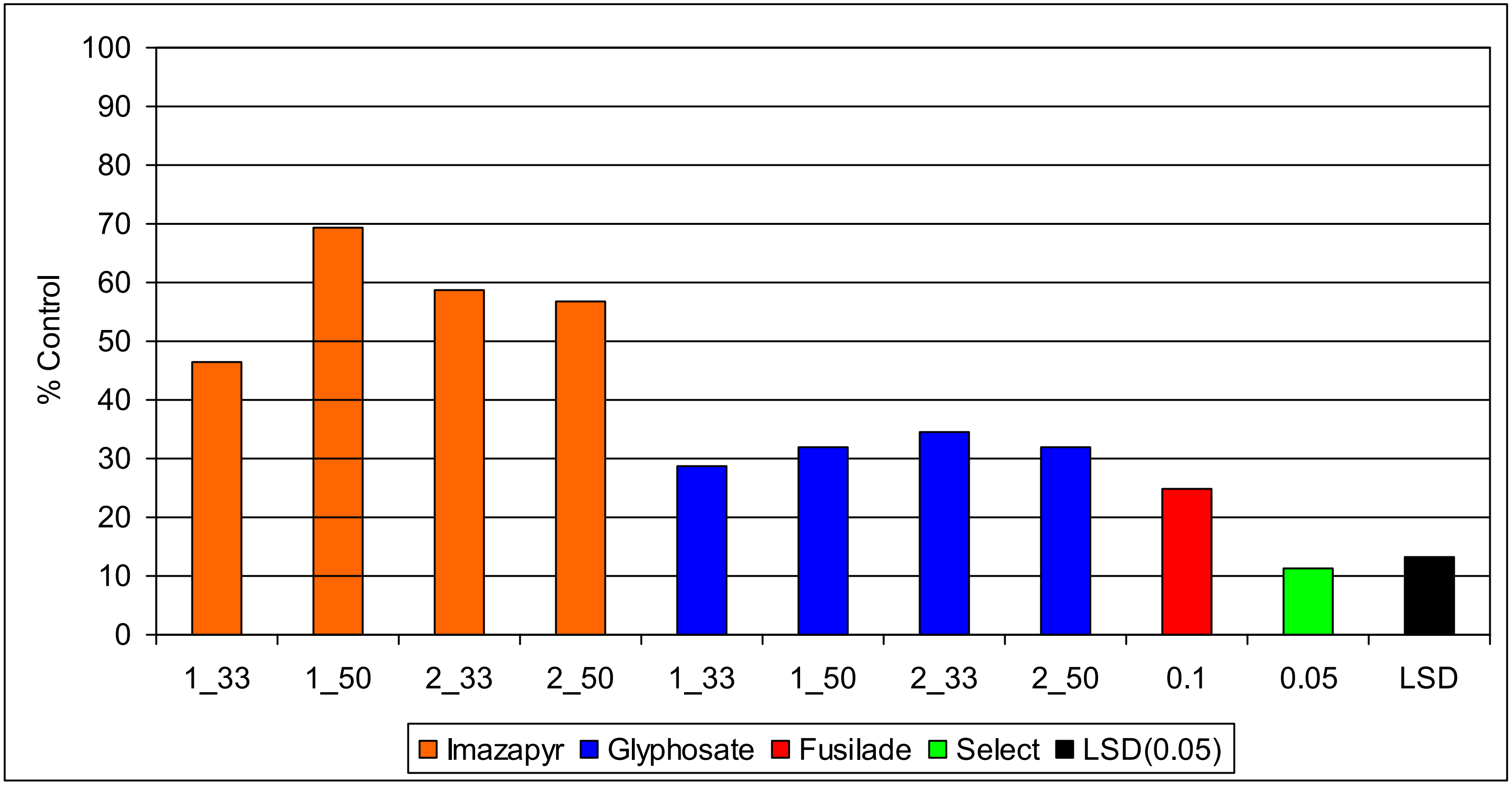

Figure 2.3: Percent control cogongrass 120 DAT using imazapyr or glyphosate in ropewick applications of pass (1 or 2) * concentration (33% or 50%), and broadcast application of fluazifop-P-butyl and clethodim in kg/ha.

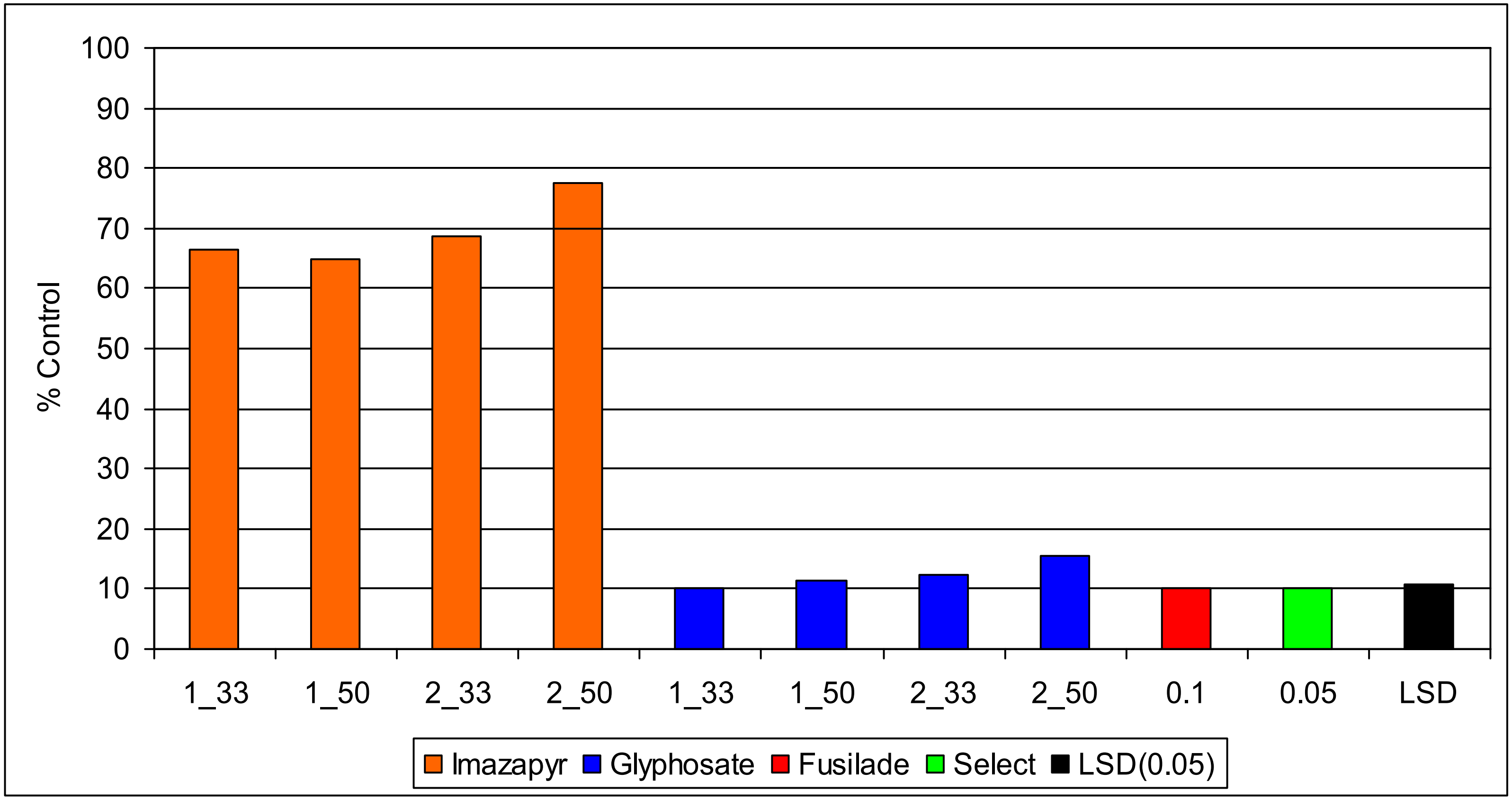

Figure 2.4: Percent control cogongrass 360 DAT using imazapyr or glyphosate in ropewick applications of pass (1 or 2) * concentration (33% or 50%), and broadcast application of fluazifop-P-butyl and clethodim in kg/ha.

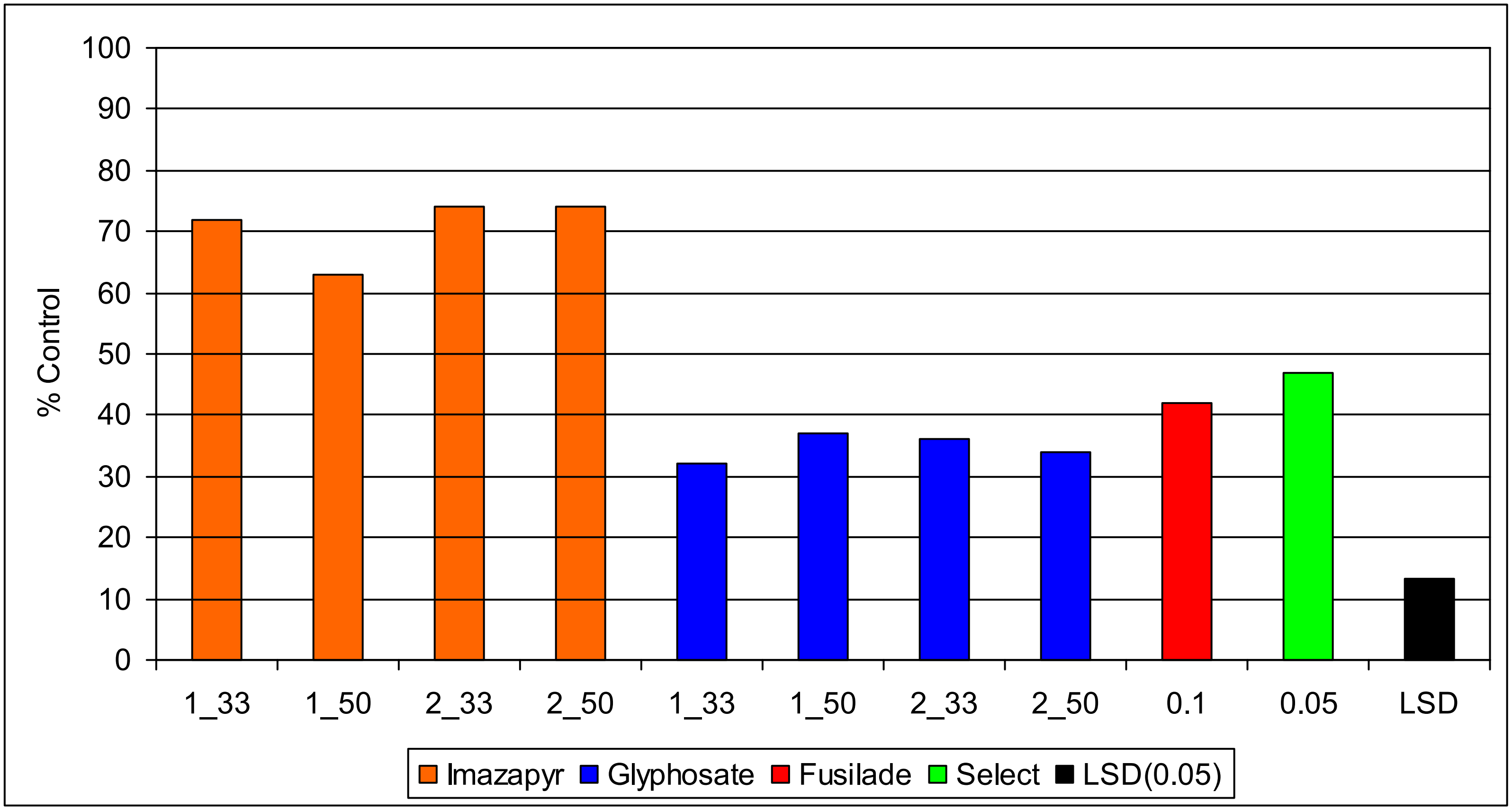

Figure 2.5: Percent reduction from the check of cogongrass shoots 360 DAT using imazapyr or glyphosate in ropewick applications of pass (1 or 2) * concentration (33% or 50%), and broadcast applications of fluazifop-P-butyl and clethodim in kg/ha.

CHAPTER III

EVALUATION OF THE EFFECTS OF ADDITIVES ON THE CONTROL OF COGONGRASS USED WITH GLYPHOSATE AND IMAZAPYR

Abstract

Field studies were conducted in 2005 and 2006 in George County, MS to evaluate the additive effects of 1) Dyne-a-Pak® (DP) and non ionic surfactant (NIS) used with imazapyr, and 2) flumioxazin and ammonium sulfate (AMS) used with glyphosate and imazapyr for cogongrass control. Twelve treatments, including 2 untreated checks, were replicated 4 times in a randomized complete block design for both experiments at two locations and applied to established cogongrass. Treatments for study 1 consisted of imazapyr at 0.14, 0.28, 0.42, 0.56, and 0.84 kg ae/ha applied with 0.25% V/V NIS or 1% V/V DP. Treatments for study 2 consisted of 10 combinations of glyphosate at 1.7 kg ae/ha or imazapyr at 0.84 kg ai/ha mixed with AMS at 0.46 kg/ha, flumioxazin at 0, 0.07, 0.14, or 0.28 kg ai/ha, or a combination of flumioxazin plus AMS. Visual ratings were taken 60, 90, and 360 days after treatment (DAT) in both years for both studies to evaluate percent control, and rhizome biomass samples were taken 360 DAT in both years for study 1 to evaluate percent reduction of the rhizome system. In study 1, imazapyr at 0.84 kg/ha applied with DP resulted in the highest control over 96% at 90 and 360 DAT. A reduced rate of imazapyr, 0.28 kg/ha, applied with DP provided the

same level of control (75 %) as imazapyr at 0.84 kg/ha applied with NIS at 90 and 360 DAT. Flumioxazin and AMS provided no additive effect when applied at these rates with glyphosate and imazapyr. Treatments which contained imazapyr in study 2 provided greater control (>86 %) than treatments with glyphosate (< 54 %) 90 DAT in both years.

Nomenclature: nonionic surfactant; imazapyr; flumioxazin; ammonium sulfate; glyphosate; *Imperata cylindrica* (L.) Beauv.# IMPCY[12].

Abbreviations: DAT, days after treatment; NIS, nonionic surfactant; DP, Dyne-a-Pak; AMS, ammonium sulfate

[12] Letters followed by this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available only on computer disk form WSSA, 810 East 10th Street, Lawrence, KS 66044-8897

Introduction

Control of cogongrass is difficult, and only a few herbicides have proven to be effective. Although cogongrass has been controlled in agriculture fields by deep plowing, stands in forests and open ranges are best controlled with herbicide applications (Hartley, 1949; Tanner et al., 1992). In most situations, long-term control has yet to be achieved from a single application; therefore, multiple applications and application timings are recommended for rhizome depletion and long-term control (Shilling et al., 1997; Peyton, 2005). Tanner et al. (1992) reported that in cogongrass treatments that resulted in 91% mortality rates, sequential applications would be needed to eliminate the grass completely. A recent increase in the use of translocated herbicides for cogongrass control has occurred due to the ability to destroy viable rhizome buds and prevent regrowth (Townson and Price, 1987). Many herbicides and herbicide combinations have been used, but the majority of herbicide applications used for cogongrass control revolve around glyphosate and imazapyr. Glyphoste and imazapyr are broad-spectrum, systemic herbicides that provide good control of cogongrass for one year and are the standard recommended treatments (Peyton, 2005; Miller, 2000; Dozier et al., 1998). Imazapyr can provide greater control of cogongrass than glyphosate with soil residual activity. While glyphosate has no soil residual activity, it could offer greater application timing flexibility as well as lack of residual activity for revegetation (Gaffney and Shilling, 1996). Glyphosate and imazapyr absorption and movement within target vegetation are both greatly enhanced by additives.

Additives have been used as early as the 1890's to enhance the activity of pesticides (Kent et al., 1991). The use of adjuvants has also been seen since 1935 with the increase in herbicidal activity of sulfuric acid used with surfactants (Green and Bailey, 1987). Due to the enhancement of herbicide performance, it is now commonplace for adjuvants to be used with glyphosate and imazapyr (Leaper and Holloway, 2000). Leaper and Holloway (2000) revealed that glyphosate absorption is greatly increased by the physiochemical properties of the adjuvant, especially its degree of surface activity, hygroscopicity, and intrinsic uptake behavior. Although adjuvants differ in their effectiveness, an indication of the appropriate adjuvant for a specific herbicide is required for maximum effect (Dodds et al., 2006; Nalewaja et al., 1986; Wanamarta et al., 1989). The function of herbicide additives is to enhance herbicidal movement to target sites. There are many types of additives: nonionic surfactants (NIS), crop oil concentrates (COC), fertilizers such as ammonium sulfate (AMS), blending agents, spreader stickers, deposition agents, drift retardants, etc. Many additives, such as surfactants, are used to enhance performance of herbicide applications, but their total cumulative effects may not be fully understood (Sharma and Singh, 2001). As with foliar applications of systemic herbicides, such as glyphosate, activity is influenced by the efficiency of cuticle retention and penetration, tissue absorption, and phloem translocation (Leaper and Holloway, 2000). Kudsk et al. (1987) speculated that additives such as NIS alter the physico-chemical properties of the spray solutions, which may alter the phytotoxicity of the herbicide by increased spreading, retention, and penetration of the herbicide on target vegetation foliage. Additives also have the potential to reduce application costs and herbicide use rates. Kudsk et al. (1987) revealed, in a study with allyoxydim-sodium, that three times as much herbicide without additive was needed to provide the same results as when additives were used. Some scientists think additives such as AMS enhance herbicide penetration due to an effect on membrane permeability of aqueous solutions (Kent et al., 1991). Dodds et al. (2006) found that the use of urea ammonium nitrate (UAN) with bispyribac-sodium for the control of barnyardgrass yielded the highest absorption rate of over 74% compared to other tank mixed additives.

Nonionic surfactants (NIS) reduce spray droplet surface tension, thus improve foliar coverage and increase the rate of absorption through the leaf cuticle. Surfactants have also been found to increase absorption and electrolyte leakage, as well as decrease translocation of carbohydrates to roots when used with glyphosate on giant burreed (Leif and Oelke, 1990). Surfactants also significantly increased control of Brazil pusley when applied with glyphosate (Sharma and Singh, 2001). Dyne-a-Pak® is a relatively new product which is a proprietary blend of UAN and methylated seed oil (MSO), and it is designed to provide the spray adjuvant functions of both crop oil concentrates and NIS in enhancing herbicide applications. Recent studies show that similar blends of UAN and NIS or petroleum oil adjuvants increased foliar absorption of ^{14}C-nicosulfuron and ^{14}C-primisulfuron in quackgrass (Bruce et al., 1993). Dodds et al. (2006) iterated that the inclusion of UAN to NIS or MSO adjuvants increased adsorption up to 47-80% compared to without UAN. This combination of NIS and UAN could provide a better alternative to NIS alone.

Ammonium sulfate (AMS) has been tested for the enhancement of several herbicides: glyphosate, imazethapyr, quizalofop, and sethoxodim, as well as many others(Beckett et al., 1992; Harker, 1995; Leaper and Holloway 2000). Kent et al. (1991) found that the addition of AMS to imazethapyr increased translocation 40%. Hatzios and Penner (1985) showed that glyphosate mixed with AMS has a synergistic effect on the perennial weed *Agropyron repens*. Kent et al. (1991) also theorized that AMS added to herbicide applications could increase efficacy and the spectrum of weeds controlled, lower herbicide use rates and ultimately the amount of herbicide in the environment (Kent et al., 1991). Beckett et al. (1992) revealed that additions of ammonium-containing fertilizers, such as AMS, to postemergent herbicides increased grass weed control. The addition of AMS to ^{14}C-sethoxodim has proven to increase absorption into large crabgrass, and has been found to have an additive effect when mixed with imazapyr (Kent et al., 1991; Jordan et al., 1989). Beckett et al. (1992) stated that spray solution pH affects ionization of acid herbicides, which affects absorption into the plant. Although the effects of fertilizer additives is relatively unknown, the increase in absorption shown by ammonium-based fertilizers may be due to some change in herbicide solution pH and may prove to be an effective additive for cogongrass control.

Herbicide tank-mix combinations can also be considered additives in herbicide applications. However, interactions may occur when additional herbicides are added as tank- mix partners that may not result in enhanced weed control. Weed response of tank-mixed herbicides could be antagonistic (less), synergistic (greater), and additive (equivalent). Agricultural chemicals applied in mixtures can interact at different sites: in the solution, at the plant surface, in the soil, within the tissues, or at the cellular site of action (Green and Bailey 1987). Tank-mixes often result in better control of target weed species than any of the constituents alone (Horsley, 1990). Kent et al. (1991) found that the addition of imazapyr to imazethapyr increased translocation of the herbicide compared to imazethapyr alone. With the rise in occurrence of resistant weeds, tank-mixing herbicides can be an alternative tactic for control as well as prevention.

Flumioxazin (Valor®) is a soil applied herbicide that is an effective inhibitor of protoporphyrinogen IX oxidase (protox), which is an important enzyme involved in chlorophyll and heme biosynthesis (Saladin and Clement, 2003). This pre-emergent herbicide has been shown to provide good control of common waterhemp, prickly sida, and several other broadleaf weeds (Niekamp et al., 1999). Flumioxazin has also been shown to be a good tank-mix candidate with herbicides such as chlorimuron and imazaquin, and is labeled for tank-mixing with glyphosate for burndown applications (Niekamp et al., 1999). With most cogongrass herbicide application, selectivity is not a concern. Therefore, the addition of flumioxazin may be a viable tank-mix partner for glyphosate and imazapyr for cogongrass control. The objectives of these studies are to evaluate imazapyr used with NIS and DP, and glyphosate and imazapyr used with combinations of AMS and flumioxazin as additives in cogongrass control.

Materials and Methods

Two field experiments were conducted in the summers of 2005 and 2006 to evaluate the effects of Dyne-a-Pak®[13] compared to nonionic surfactant[14] (NIS) used with imazapyr in study 1 and a second study (study 2) to evaluate flumioxazin[15] and ammonium sulfate[16] (AMS) used with glyphosate[17] and imazapyr[18] for cogongrass control. Both experiments, consisting of 12 treatments replicated four times, were conducted at the same site and replicated at separate sites within George County, MS. Site 1, located in northern George County, contained a Benndale fine sandy loam (coarse-loamy, siliceous, semiactive, thermic Typic Paleudults)[19] , and site 2 in central George County had a Lucedale sandy loam (fine-loamy, siliceous, thermic Rhodic Paleudults)[20]. Treatments in study 1 consisted of imazapyr applied at 0.14, 0.28, 0.42, 0.56, or 0.84 kg/ha with either 1% V/V Dyne-a-Pak® or 0.25% V/V NIS. Treatments in study 2 consisted of 0.84 kg/ha imazapyr or 1.7 kg/ha glyphosate applied with 0.46 kg/ha AMS and 0, 0.07, 0.14, or 0.28 kg ai/ha flumioxazin. Both glyphosate and imazapyr were also applied with 0.14 kg/ha flumioxazin, but without AMS. Two untreated checks were also

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[13] Nonionic Spray Adjuvant and Deposition Aid, ©2006 Helena Chemical Company, 225 Schilling Blvd., Collierville, TN 38017

[14] Red River 90, Red River Specialties, Inc., Rigeland, MS 39158.

[15] Valor SX Herbicide, ©2007 Valent U.S.A. Corporation.

[16] AMS Complete, Universal Crop Protection Alliance®, LLC, Eagan, MN 55121.

[17] Roundup Pro ® Herbicide, © 2003 Monsanto Company, St. Louis, Missouri 63167 U.S.A.

[18] Arsenal ® AC herbicide, BASF Corporation, 26 Davis Drive, Research Triangle Park, NC 27709.

[19] Soil survey of George County, MS from November 1981. USDA Soil Conservation Service in Cooperation with MAES.

[20] Soil survey of George County, MS from November 1981. USDA Soil Conservation Service in Cooperation with MAES.

included as treatments. Nonionic surfactant at 0.25% (v/v) was added to all imazapyr treatments. Both experiments were designed as randomized complete blocks with 4 replications consisting of 10 treatments and 2 nontreated controls per replication. Treatments were applied to 2.4 m by 4.6 m plots in cogongrass-infested, noncropped fields with a CO_2 pressurized backpack sprayer that delivered 234 L/ha through a four nozzle hand-held boom equipped with Teejet 8002VS standard flat fan nozzles. Both experiments were treated June 2005 and June 2006 to approximately 0.5 m tall foliage. Visual evaluation of aboveground foliar biomass, and stand health were taken 60, 90, and 360 days after treatment (DAT) based on a scale of 0 (no control) to 100% (complete control). Belowground rhizome biomass (RB) samples were collected May 2006 and May 2007 from each plot of study 1 with a 1.24 cm^3 soil probe, washed free of soil, dried for 24 hours in a 70º C forced-draft oven, and weighed to evaluate rhizome biomass.

All data were analyzed with the Repeated Measures technique of PROC MIXED in SAS 9.1[21], to test main effects and interactions among additives for study 1, and chemicals and additives for study 2. Fisher's protected LSD at the 0.05 level of significance was used to separate appropriate treatment means for both studies.

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[21] Statistical Analysis Systems (SAS) software, Version 9.1. SAS Institute, Inc., Box 8000, SAS Circle, Cary, NC 27513, USA.

Results and Discussion

Study 1

Due to homogeneity of data, years and locations were pooled and used as additional replications and nontransformed data were used for analysis and presentation. Cogongrass control did not exceed 50% at any evaluation period when the lowest imazapyr rate (0.14 kg/ha) was used (Table 3.2). No differences in cogongrass control were detected between imazapyr applied with NIS or DP at that rate. Greater cogongrass control was detected at every evaluation period as the rate of imazapyr was increased to 0.28 or 0.42 kg/ha. Imazapyr applied at 0.28 kg/ha used with DP produced between 22 and 33% higher control than the same rate applied with NIS across the 3 evaluation periods. The margin of difference in control when using DP or NIS with 0.42 kg/ha imazapyr were not as substantial as with the lower rates. Imazapyr applied at 0.42 kg/ha with DP was at least 18% higher than the same rate applied with NIS. As the imazapyr rate was increased to 0.56 kg/ha overall cogongrass control increased from the lower rate, but no difference between DP and NIS was detected. The maximum imazapyr rate evaluated was 0.84 kg/ha. At this rate differences in control were detected between NIS and DP at the initial evaluation made 60 DAT. However, as additional evaluations were made 90 and 360 DAT, no differences in control of cogongrass were found with 0.84 kg/ha imazapyr applied with DP or NIS. These findings are supported by Dodds et al. (2006), who found that the proprietary blend of DP increased the burndown activity of bristly starbur and increased the absorption of bispyribac-sodium in barnyardgrass 87% compared to MSO or NIS.

Aside from the differences seen among additives, there were significant differences in control when imazapyr rates were compared. Generally when used with NIS, as imazapyr rate increased cogongrass control increased with the exception of the lowest and highest rates (Table 3.1). It is interesting to note that cogongrass control with imazapyr applied with DP did not increase with increased imazapyr rates, except the lowest and highest rate applied (Table 3.1). At all three evaluation dates with the DP treatments, cogongrass control increased as the rate increased from 0.14 to 0.28 kg/ha, but there was no increase in control until the rate increased from 0.56to 0.84 kg/ha, except at 90 DAT (Table 3.1). However, only 0.84 kg/ha provided acceptable control of 92% at 360 DAT. That was not the case with all NIS treatments. In general there was no difference in cogongrass control with 0.14 or 0.28 kg/ha imazapyr with NIS at any evaluation date. Control of cogongrass did not exceed 55% with either of these rates. There was also no difference in control observed with the two highest rates of imazapyr applied with NIS. By 360 DAT, control was only slightly above 80% from 0.84 kg/ha imazapyr applied with NIS (Table 3.1). Overall the visual evaluation data seemed to indicate cogongrass control with imazapyr mixed with DP was more consistent compared to mixtures with standard NIS. The differences seen from the high rate and the lower rates of imazapyr demonstrate the need for the higher rates to acquire acceptable cogongrass control. Therefore, these data should not be misused as justification to apply lower imazapyr rates for cogongrass treatments as the best treatment provided only 92% at 360 DAT.

Percent reduction (PR) of the underground biomass provided supporting evidence to aboveground visual control. Rhizome biomass of cogongrass decreased as imazapyr rate increased, regardless of whether NIS or DP was added (Table 3.2). All treatments reduced rhizome biomass compared to the untreated control and as imazapyr rate increased rhizome biomass decreased (Table 3.2). Unfortunately, there were few differences among treatments, which may be due to the high degree of variability in this weedy species. Imazapyr applied with DP tended to have lower rhizome biomass than the same imazapyr rate applied with NIS. Imazapyr at 0.14 kg/ha mixed with NIS reduced rhizome biomass compared to the untreated check. No difference was detected as imazapyr rate increased from 0.14 to 0.56 kg/ha, although they represent 29 to 43% reduction in biomass compared to the untreated control. This may be due to overall variability of rhizome biomass in cogongrass. Bryson and Carter (1993) state that based on soil type, rhizome biomass of cogongrass can accumulate within the top 0.15 to 0.4 m of the soil surface which can have differences in amounts of underground biomass.

There was a difference in rhizome biomass when imazapyr was applied at 0.84 kg/ha with NIS compared to the lowest rate as the biomass was only 4.9 g/l or was reduced 57% compared to the untreated control. When imazapyr was applied with DP, the lowest imazapyr rate applied did not reduce cogongrass rhizome biomass compared to the untreated control. However, at 0.28 kg/ha or higher rates, rhizome biomass was significantly reduced. Rhizome biomass weights ranged from 7 to 5 g/l as the imazapyr rate increased from 0.28 to 0.84 kg/ha. Each of these rates mixed with DP reduced cogongrass rhizome biomass 50 to 64% compared to the untreated control.

Study 2

There were no interactions or trends found with neither flumioxazin nor AMS to suggest enhanced nor decreased activity when applied with either imazapyr or glyphosate. Beckett et al. (1992) found that fertilizers, such as AMS, had little effect on giant foxtail control with quizalofop. They stated that any benefits from the fertilizer may have been masked by the excellent enhancement of control provided by NIS and petroleum oil concentrate, which may be the case for both additives in this study (Beckett et al., 1992). However, Hatzios and Penner (1985) reported that ammonium salts have important synergistic effects, which can be direct or indirect, on the toxicity of several foliarly applied herbicides on perennial weeds. Although, reduced performance with triazine herbicides mixed with ammonium nitrate has been shown, which was attributed to the acidification of the soil from the fertilizer which enhanced the adsorption of the herbicide to soil particles (Betts and Morrison 1979; Burt and Schnappinger 1978). While no interaction among additives was seen, significant interaction among herbicides was evident. Imazapyr provided superior cogongrass control from 81 to 86% at 60 DAT with or without the addition of flumoxiazin or AMS (Figure 3.1). By comparison, the glyphosate treatments were 59% or less. Peyton et al. (2005) found that imazapyr provided greater than 75% cogongrass control compared to only 65% when glyphosate was used.

The only difference among additives detected in the entire data set, in addition to any treatment compared to the untreated control, was glyphosate mixed with 0.14 kg/ha flumioxazin without AMS which was superior to any glyphosate plus AMS or plus AMS and flumioxazin. Bond et al. (2005) found control of Persian clover and California burclover to be greater when flumioxazin was applied with glyphosate than when used alone. However, an increase in flumioxazin rate to 0.14 kg ai/ha or adding COC to the flumioxazin and glyphosate mix did not improve control of broadleaf weed species over flumioxazin at 0.07 kg ai/ha plus Glyphosate (Bond et al., 2005). At other rating dates in this study all treatments were better than the untreated, and all imazapyr treatments were superior to glyphosate treatments. By 90 DAT, cogongrass control with imazapyr treatments were higher, while the glyphosate treatments were lower than that observed at 60 DAT (Figure 3.1). There were no differences among treatments at 90 DAT except all treatments compared to the untreated control. Treatments that contained imazapyr ranged between 90 and 95% control, while those treatments that contained glyphosate ranged between 40 and 45% cogongrass control. Ezell (2006) found that imazapyr mixed with flumioxazin provided excellent control of herbaceous weeds in loblolly pine plantations. Conversely, Nandula et al. (2005) revealed that the addition of flumioxazin noticeably reduced control of horseweed by glyphosate, although added a residual effect seen weeks after treatment. Similarly, imazapyr provided excellent control in this study although no improvement due to flumioxazin or AMS was observed. Control decreased with both imazapyr and glyphosate treatments by 360 DAT (Figure 3.1). However, all imazapyr treatments still provided between 88 and 93% control of cogongrass and all glyphosate treatments provided between 25 and 33% control. While all treatments that contained herbicide were significantly different than the untreated, there were no differences within imazapyr or glyphosate treatments that revealed enhanced control from the addition of AMS or flumioxazin.

Conclusions

Both studies support earlier research that has shown that glyphosate and imazapyr can be used for cogongrass control. However, additives have the potential to enhance cogongrass control both with imazapyr and glyphosate. Results from study 1 indicate that either NIS or DP used with imazapyr can provide excellent cogongrass control and deplete rhizome biomass. Rhizome biomass was lower when imazapyr at 0.84 kg/ha was applied with DP than imazapyr at 0.42 kg/ha and lower was applied with NIS. Importantly enough, only 0.1 g of rhizome is needed for reproduction, and only one piece of rhizome can produce up to 350 shoots and cover 4 m^2 in as little as 11 weeks (Eussen 1980, Soerjani 1969). This makes it of particular importance to deplete as much of the rhizome system as possible. Although a reduction in herbicide rate seemed to be a possibility with DP, the higher rates still need to be applied to insure optimal cogongrass control. While AMS and flumioxazin, or both enhanced cogongrass control compared to the untreated control, flumioxazin did not enhance control compared over AMS in study 2 at 90 or 360 DAT. The literature shows mixed conclusions with fertilizer additives. Salisbury et al. (1991) found AMS to enhance the effects of glyphosate for johnsongrass control; but Harker (1995) showed no improvement with AMS mixed with fluazifop on wild oat or barley. Even though results from this study indicate that flumioxazin does not enhance glyphosate or imazapyr activity on cogongrass, it is labeled as an additive burndown herbicide for use with glyphosate. The lack of effects seen from AMS and flumioxazin may be due to the masked effectiveness from high performance of NIS explained by Beckett et al (1992). Through study 2 we found that imazapyr, regaurdless of additive, produces greater cogongrass control than glyphosate. Similarly, Ketterer et al. (2006) found glyphosate to produce a much lower level of control than imazapyr when applied to cogongrass. These studies prove that additives such as DP could be a good alternative to traditional NIS. However, both provide good addition in control. Higher rates of imazapyr and glyphosate are needed for greater management of this invasive. While glyphosate remains less costly, the long term control provided by imazapyr may outway the multiple applications needed with glyphosate for cogongrass control.

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Table 3.1 Visual cogongrass control with imazapyr as influenced by nonionic surfactant (NIS) 0.25% (v/v) or Dyne-a-Pak (DP) 1% (v/v).

Imazapyr (kg ae/ha)	60DAT		90DAT		360DAT	
	NIS	DP	NIS	DP	NIS	DP
	---------------	---------------	--------------- %	---------------	---------------	---------------
0.14	44c	47c	43e	54de	33e	49cd
0.28	45c	70b	53de	75bc	41de	74b
0.42	53c	74b	64cd	82b	58c	79b
0.56	65b	76b	77b	86ab	74b	71b
0.84	75b	89a	86ab	96a	82ab	92a
LSD $_{(0.05)}$	11.6		11.6		11.6	

Table 3.2 Cogongrass rhizome biomass as influenced by imazapyr rate with nonionic surfactant (NIS) 0.25% (v/v) or Dyne-a-Pak (DP) 1% (v/v).

	360DAT	
	grams/liter	
Imazapyr kg ae/ha	NIS	DP
Untreated check	11.3a	11.3a
0.14	8.1bc	8.9ab
0.28	7.3bcd	5.7cde
0.42	7.3bcd	4.9de
0.56	6.5bcde	4.9de
0.84	4.9de	4.1e
LSD $_{(0.05)}$	3	

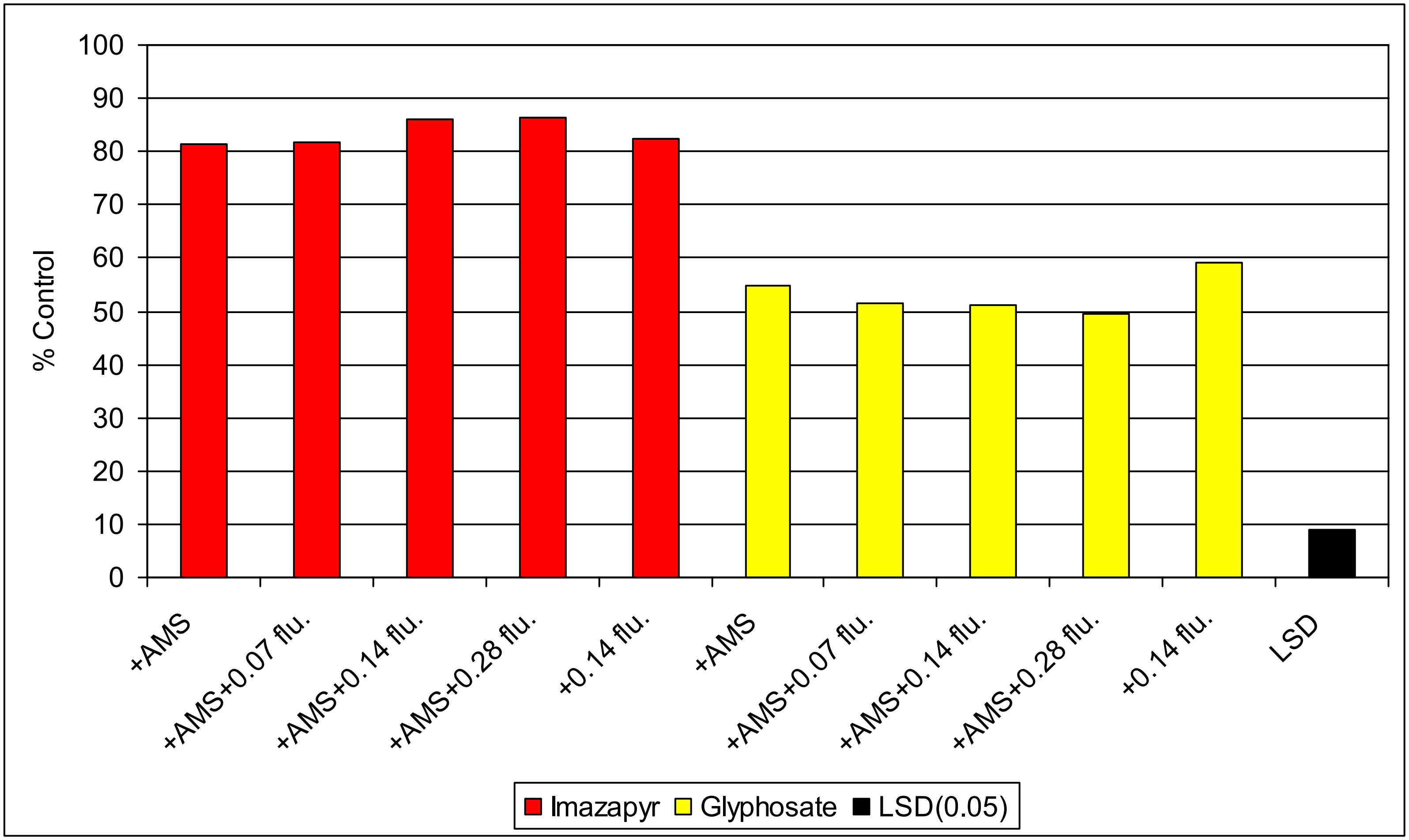

Figure 3.1: Cogongrass control using imazapyr 0.84 and glyphosate 1.7 kg ae/ha as influenced by additive ammonium sulfate (AMS) 0.46 kg ai/ha and flumioxazin (V) 0.07, 0.14, or 0.28 kg ai/ha 60days after treatment

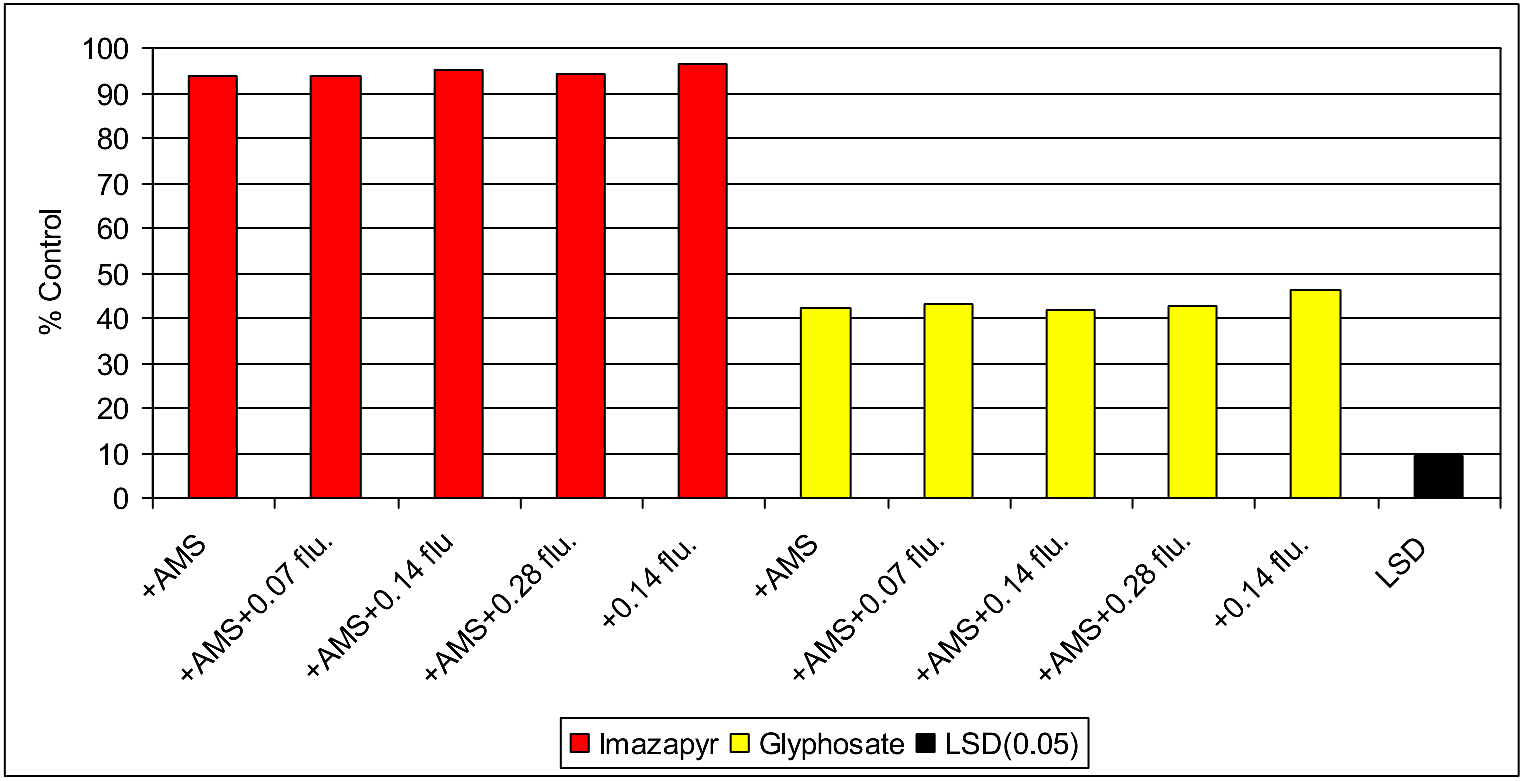

Figure 3.2: Cogongrass control using imazapyr 0.84 and glyphosate 1.7 kg ae/ha as influenced by additive ammonium sulfate (AMS) 0.46 kg ai/ha and flumioxazin (V) 0.07, 0.14, or 0.28 kg ai/ha 90 days after treatment.

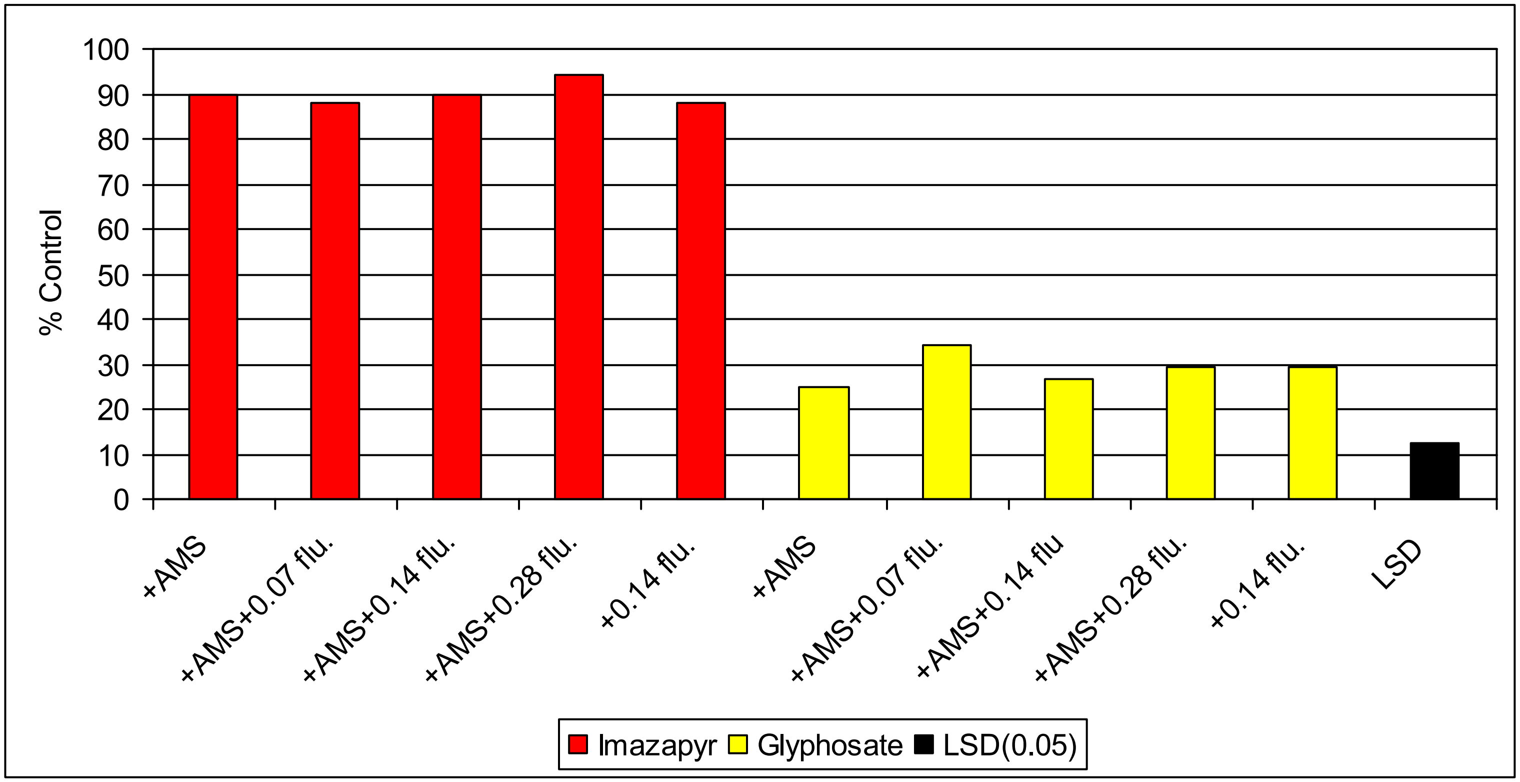

Figure 3.3: Cogongrass control using imazapyr 0.84 and glyphosate 1.7 kg ae/ha as influenced by additive ammonium sulfate (AMS) 0.46 kg ai/ha and flumioxazin (V) 0.07, 0.14, or 0.28 kg ai/ha 360 (DAT).

CHAPTER IV

CLASSIFICATION OF COGONGRASS ON HIGHWAY RIGHTS-OF-WAYS USING REMOTELY SENSED AERIAL IMAGERY

Abstract

A field study was conducted from 2005-2006 to test broad scale classification of cogongrass [*Imperata cylindrica* (L.) Beauv.] on Mississippi highway rights of ways with aerial imagery. Four mosaics of high resolution multispectral images of median and rights-of-way along Interstate 59 between Meridian and Laurel, Ms and rights-of-way along MS Hwy 528 between Bay Springs, MS and Interstate 59 were used for analysis and classification. The basis for this study was to test basic user classification methods on high resolution imagery for broad scale detection of cogongrass. The imagery was analyzed by supervised and unsupervised classification techniques based on a 5-class system including cogongrass, other roadside vegetation, road/bare soil, forest, and shadow/water. The unsupervised classification technique began with 100 classes which were narrowed down to the five classes of interest, whereas the supervised classification technique trained the system for the five classes of interest. Near infrared (NIR), red, green, and blue spectral reflectance values for each known class area within the images, along with spatial patterns and expert knowledge, were analyzed and used to train and recode the classified image. Areas of the images suspected to be the five classes of

interest were used to train the system for supervised classification and used to recode the unsupervised classification. A database of GPS points of known locations for each class within each image were used to test the accuracy of each classification. Overall accuracies for supervised classification of the images ranged from 85 to 95%, while unsupervised classification resulted in 75 to 90% accuracies. Producers' accuracies for the cogongrass class ranged from 54 to 71% with unsupervised techniques; however, supervised classification techniques resulted in 54-100% accuracy to depict cogongrass. Both classification techniques produced 100% cogongrass class user's accuracies for all images. All other classes produced lower user's accuracies. The results from this study show good results for cogongrass detection with basic knowledge classification techniques.

Nomenclature: Cogongrass, *Imperata cylindrica* (L.) Beauv.# IMPCY[1].

Abbreviations: NIR, Near infrared; GPS, Global Positioning System; GIS, Geographic Information System; NDVI, Normalized Difference Vegetative Indices;

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[1] Letters followed by this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available only on computer disk form WSSA, 810 East 10th Street, Lawrence, KS 66044-8897

Introduction

Cogongrass is a more widespread problematic weed each year. Control measures of this invasive weed have been widely investigated, but eradication has yet to be achieved. Therefore the spread of this grass into new areas is more of a concern. Some control can be obtained with glyphosate and imazapyr, but detection of current and new populations with remotely sensed data has found new interest (Johnson and Bruce, 2005). Because the invasion of cogongrass in Mississippi and throughout the southeastern United States is so widespread, detection and classification methods for broad-scale control seems to be a new frontier. One of the needs in weed management as a whole is adequate, large-scale, cost-effective methods to map and monitor plant populations long term (Williams and Hunt, 2004; Johnson, 1999; Anderson et al., 2003). Geographic Information Systems (GIS), Global Positioning Systems (GPS), and remote sensing are powerful tools used to acquire and study geographic data quickly and accurately, and may lead to easier ways to detect and control invasive weeds (Long and Srihann, 2004). Remote sensing is defined as obtaining information of a target through analysis of data acquired by a device with no physical contact to the target (Lillesand and Kiefer, 2000). Remote sensing technologies have been widely studied for many agricultural practices such as detection of disease, herbicide drift, and weed infestations (Danielsen and Munk, 2004; Buering, 2004; Koger et al., 2003). Satellite and aerial imagery have been studied, with some success, for the detection of cogongrass; however, aerial platforms may provide greater spectral and spatial resolution for the scale of the area that can be covered (Johnson and Bruce, 2005). Huang et al. (2001) hypothesize that automatic detection of cogongrass through remotely sensed data can efficiently provide precise information for the monitor of the spread of invasives.

Many remote sensing devices operate in the blue, green, red, and near infrared regions of the electromagnetic spectrum, and can discriminate radiation, absorption, and reflectance of vegetation. When multispectral imagery is used for invasive weed detection, the weed needs to have distinguishing characteristics for successful classification. These attributes can help pinpoint the spectral characteristics of a specific type of vegetation to map populations, which can be used for control measures of that species. Williams and Hunt (2004) stated that after flower emergence, the conspicuous yellow-green bracts of leafy spurge, which are spectrally distinct from other vegetation, can be used to distinguish populations with hyperspectral remotely sensed data. Cogongrass also has a distinct yellowish tinge most of the season of active growth and has been found to be distinguishable with hyperspectral remote sensing (Huang et al., 2001). Hunt et al. (2006) stated that hyperspectral imagery is difficult and requires expertise to process, and almost always exceeds budgetary constraints. This brings about concern for an efficient, user-friendly, and cost-effective manner to remotely sense invasive weeds. The yellowish tinge and circular growth patterns of cogongrass may prove to be a distinction which allows for detection and classification of high spatial resolution multispectral imagery with basic techniques.

The basic concept behind remote sensing is the assignment of variables into categories of useful information, commonly known as image classification (Williams and Hunt, 2004). Long and Srihann (2004) state that classification is a simple way to visualize major features of an image by identification of visual or data values for every pixel in the image. There are numerous methods to process and classify images, many of which can be complicated and require a great amount of time and remote sensing knowledge. If high spatial resolution multispectral imagery is used, the two basic remote sensing processes which are most effective for land cover and change detection are supervised and unsupervised. Classifications are preformed by the software based on the spectral analysis of an image for identification of terrestrial features (Long and Srihann, 2004). Spatial characteristics can also be observed to train and classify features within the image. These spatial features (size, shape, orientation) of objects are revealed by changes in average spectral properties that occur at boundaries (Ketting and Landgrebe, 1976). Gray (2005) found supervised classification techniques of high spatial resolution multispectral imagery to be a difficult, but effective, technique for detection of certain morningglory species in soybeans with 75% accuracies. Gibson et al. (2004) also found it difficult to distinguish between velvetleaf and giant foxtail with multispectral imagery. These studies, however, dealt with weed detection in agricultural crops and had relatively low weed stand density. In most instances along highway rights-of-ways, cogongrass is found in scattered stands which are almost a monoculture of the invasive. Weeds such as cogongrass, that have morphological characteristics that can be readily distinguished spectrally from other vegetation, can be good targets for lower spectral resolution imagery (Hunt et al., 2006). For this reason, classification of high spatial resolution imagery may result in higher classification accuracies than found in a crop system. The objective of this study was to evaluate simple classification techniques for the detection of cogongrass along highway rights-of-ways using high spatial resolution multispectral aerial imagery.

Materials and Methods

Aerial images were taken in 2005 and 2006 of Interstate 59 median and rights-of-way between Meridian and Laurel, MS and Highway 528 rights-of-way between Bay Springs, MS and Interstate 59 in March and May with the GeoVantage camera system. This camera system provided a 4 band multispectral image with the blue band centered at 450 nm, the green band centered at 550 nm, the red band centered at 650 nm, and the near-infrared band centered at 850 nm. It had a spectral resolution of 80 nm in the visible spectrum and 20 nm for the NIR band**.** The spatial resolution was +/– 1 m with a visible resolution of 0.25 m. Four image mosaics were used to distinguish cogongrass from other roadside vegetation, bare soils/roads, forests, and shadows/water on highway rights-of-ways. A database of field collected GPS points, which represented each class, was accumulated for image interpretation and accuracy assessment. Erdas imagine[2] and ArcGIS[3] software packages were used to perform image analysis and classifications. Unsupervised and supervised (maximum likelihood) classification techniques were used and evaluated for their effectiveness to detect cogongrass stands. The unsupervised classification technique began with 100 classes which were narrowed down to the five classes of interest, whereas the supervised classification technique trained the system for

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[2] ERDAS Imagine, Version 9.0, 2007 Leica Geosystems Geospatial Imaging, 5051 Peachtree Corners Circle, Suite 100 Norcross, Georgia, USA 30092.

[3] ArcGIS, Version 9.1, Environmental Sciences Research Institute, 380 New York St. Redlands, CA 92373-8100, USA.

the five classes of interest. Due to the size of the areas of observation, and limited ground truth data, training sites were created based on expert knowledge of spectral (NIR, red, blue, and green reflectance values) and spatial (size, shape, color, and orientation) patterns of each class. These training sites were used to train the supervised classifier and recode the unsupervised classifier. A 7x7 neighborhood filter was used for each output to remove "salt-and-pepper" misclassifications, which are speckles of misclassified pixels within a known class area. The classified images were applied to the ground truth data for accuracy assessments. The results of this analysis yielded Producer's and User's accuracies for each class, and an overall accuracy of the classifier. Producer's accuracy, which is known as the error of omission, is the probability that the ground truth data has been classified correctly. User's accuracy, also known as the error of commission, is the probability that the classes produced from the classifier actually match that class on the ground (ground truth data).

Results and Discussion

For this study, supervised and unsupervised classification methods were implemented in 5-class systems for detection of cogongrass along highway medians and rights-of-ways. Supervised classifiers allow the user to define signatures of spectral and spatial information for each class which are used to classify, while unsupervised classifiers allow the user to define the number of classes but require no training and are largely carried by the software (Long and Srihann 2004). The supervised classifier provided greater overall accuracies, up to 95% as shown in Table 4.1. This was to be expected since the training procedure is used in supervised classification. Only Image 4 provided greater overall accuracy for the unsupervised method; however, it produced the second lowest overall accuracies of 85 and 87% for the supervised and unsupervised methods, respectively. Although easier and less time is required, unsupervised classification relies solely on the software and spectral data, which can cause more misclassification than with a trained system. On average, the supervised classification method only provided 5% greater overall classification accuracy than the unsupervised method. This may be due to the recode process performed on the unsupervised images, which is based on user knowledge of the spatial and spectral features of the image. Because pixels of similar spectral characteristics are classified by the unsupervised system, some pixels classified alike are inseparable and result in misclassification regardless of recode. As represented in Table 4.1 either classification technique produced sufficient overall accuracies of 75 to 95%.

Although a 5-class system was used, the ultimate goal was to evaluate the system for cogongrass detection accuracies. The classifiers effectively identified cogongrass from the images. Tables 4.2, 4.3, 4.4, and 4.5 reveal higher user's than producer's accuracies for the cogongrass class regardless of image or classification method. The average user's accuracy, represented in Table 4.6, for the cogongrass class was 100% regardless of classification method. Only the shadow/water class with a supervised classifier produced an average user's accuracy of 100%. All other classes produced average user's accuracy between 80 and 96% and 75 and 90% with the supervised and unsupervised classifiers, respectively. This suggests a higher probability that cogongrass classified on the image will be cogongrass in the field. The roadside vegetation and forest classes in image 1 and roadside vegetation class in image 4 produced the lowest user's accuracies between 60 and 79%. These lower accuracies may be due to some confusion among forest, roadside vegetation, and cogongrass classes, and may have resulted in some under or over-classification of one or more of the classes. Each class provided acceptable user's accuracy for every image regardless of classification technique.

Producer's accuracy for cogongrass was lower with both classification methods. As represented in Table 4.3, the supervised classification method of image 2 provided a producer's accuracy of 100% for the cogongrass class, while all other images produced below 78%. All other classes provided higher producers accuracies than the cogongrass class. On average, the cogongrass class resulted in 72 and 62% producer's accuracies for the supervised and unsupervised classifiers, respectively. All other classes ranged between 77 and 100% with the supervised system, and from 79 to 98% with the unsupervised classifier. This suggests a lower probability that the cogongrass ground truth points were correctly identified by the system. In future research, more ground truth data are needed than were available in this study. Lack of knowledge and experience with the image analysis methods combined with costs of more accurate ground truth data collection equipment may have skewed the overall accuracy of classification of these images.

Conclusions

Results from this study show acceptable levels of classification accuracy from either a supervised and unsupervised classification method. Both the supervised and unsupervised classification techniques have the ability to distinguish between the cogongrass, roadside vegetation, road/bare, forest, and shadow/water classes when high spatial resolution multispectral aerial imagery are used. The cogongrass class received high user's accuracy in each image from either classification technique, however, on average all other classes provided greater producers accuracy. There were some misclassifications, which is to be expected with most remote sensing applications. Due to the lower classifications seen for the roadside vegetation, it is suspected that over-classification of the cogongrass class occurred. This over-classification of the cogongrass class is presumed to be the result of a confusion of it and the roadside vegetation class. However, as a beginning point of detection and estimation of the scope of an invasive weed problem, an over-classification is more desirable than an under-classification. The results from this study were acceptable for the ground truth data at hand. Future research may center its focus on a small area as a baseline classification with maximum ground reference, and then apply to the broad scale area.

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Table 4.1 Overall classification accuracies for classification technique generated from the May 2005 images.

Image	Supervised	Unsupervised
	------------------------------------ %	------------------------------------
1	85	75
2	95	90
3	95	88
4	85	87
Averaged	90	85

Table 4.2 Classification accuracies for classification technique generated from the May 2005 image 1.

Class	Supervised		Unsupervised	
	User's Accuracy	Producer's Accuracy	User's Accuracy	Producer's Accuracy
	------------------	------------------ %	------------------	------------------
Cogongrass	100	54	100	54
Roadside Vegetation	67	80	61	73
Road/Bare	100	100	100	100
Forest	79	100	60	55
Shadow/Water	100	100	73	100

Table 4.3 Classification accuracies for classification technique generated from the May 2005 image 2.

Class	Supervised		Unsupervised	
	User's Accuracy	Producer's Accuracy	User's Accuracy	Producer's Accuracy
	-- % --			
Cogongrass	100	100	100	71
Roadside Vegetation	100	93	82	93
Road/Bare	82	100	75	100
Forest	92	100	100	92
Shadow/Water	100	86	100	86

Table 4.4 Classification accuracies for classification technique generated from the May 2005 image 3.

Class	Supervised		Unsupervised	
	User's Accuracy	Producer's Accuracy	User's Accuracy	Producer's Accuracy
	-- % --			
Cogongrass	100	78	100	56
Roadside Vegetation	86	92	80	92
Road/Bare	100	100	92	100
Forest	92	100	90	82
Shadow/Water	100	100	85	100

Table 4.5 Classification accuracies for classification technique generated from the May 2005 image 4.

Class	Supervised		Unsupervised	
	User's Accuracy	Producer's Accuracy	User's Accuracy	Producer's Accuracy
	%			
Cogongrass	100	57	100	65
Roadside Vegetation	67	91	76	100
Road/Bare	100	100	92	92
Forest	82	100	100	86
Shadow/Water	100	93	88	100

Table 4.6 Averaged classification accuracies for classification techniques generated from the May 2005 images.

Class	Supervised		Unsupervised	
	User's Accuracy	Producer's Accuracy	User's Accuracy	Producer's Accuracy
	------------------------------------ % ------------------------------------			
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Cogongrass	100	72	100	62
Roadside Vegetation	80	77	75	90
Road/Bare	96	100	90	98
Forest	86	100	88	79
Shadow/Water	100	87	87	89