SMUTGRASS (*SPOROBOLUS INDICUS* VAR. *INDICUS)* CONTROL AND INDENTIFICATION IN PERENNIAL PASTURE IN TEXAS

A Thesis

by

ZACHARY STEVEN HOWARD

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Chair of Committee,	Scott A. Nolte
Co-Chair of Committee,	Brent Sellers
Committee Member,	Morgan Treadwell
Head of Department,	David D. Baltensperger

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ABSTRACT

Smutgrass (*Sporobolus indicus*) is a non-native perennial weed that is problematic due to its poor palatability to cattle and its difficulty to control once established. Currently there is limited literature on the effectiveness of labeled herbicide options, other than hexazinone, on smutgrass and injury to forages. The first objective of this research was to evaluate labeled options for controlling smutgrass, and to observe the most effective options over seasonal applications. The second objective was to evaluate pre-emergent herbicides and hexazinone for the control of smutgrass germinating from seed. Lastly, the third objective was to evaluate the use of UAV mounted RGB and NIR spectroscopy for the identification and biomass estimation of smutgrass. Applications of hexazinone, nicosulfuron + metsulfuron-methyl, and glyphosate + imazapic were the most effective treatments, while quinclorac had very little activity on smutgrass. Common bermudagrass (Cynodon dactylon) forage in all treatments recovered fully by 3 months after application. Hexazinone, nicosulfuron + metsulfuron methyl, glyphosate and imazapic were observed over spring, summer, and fall applications. Summer applications of hexazinone resulted in the highest level of control, while spring treatments provided the least control. Treatments of hexazinone and glyphosate applied in the summer incurred the greatest amount of smutgrass control, while fall applications sustained the least forage injury. Results from the pre-emergent study indicate that treatments of indaziflam and hexazinone provide adequate control of germinating smutgrass seedlings in the greenhouse at 0.25, 0.5, and 0.75X rates of the lowest recommended labeled rate for grass seedling control. Indaziflam treatments did not allow for any visible tissue to germinate, hexazinone fully controlled the germinating seedlings by 21 DAT, while pendimethalin significantly reduced seedling numbers at the 0.50 and 0.75X rates. Smutgrass was successfully identified in a bermudagrass pasture in imagery captured by a UAV equipped with consumer grade cameras. OBIA and SfM technique image analysis using a RGB and NIR imagery couple with CHM were used to delineate areas containing smutgrass. Furthermore, regression analysis indicated a relatively poor relationship (R^2 =0 .38) of pixel coverage to smutgrass biomass.

DEDICATION

This thesis is dedicated to my mother, Janet Howard.

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NOMENCLATURE

DAT	Days after treatment
g	gram
ha	hectare
kg	kilograms
L	liter
LSD	Fisher’s protected least significant difference
MAA	Months after A
MAB	Months after B
MAC	Months after C
MAT	Months after treatment
NIR	Near-infrared
RGB	Red, green and blue
WAB	Weeks after B
UAV	Unmanned aerial vehicle

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Weed Control and Smutgrass in Pastures

Control of invasive non-native plants in pastures can be costly and challenging. A variety of options involving both chemical and cultural weed control practices can quickly overwhelm a farmer or rancher. Cultural control practices are often labor intensive, time consuming, and may do more harm than good if not done properly. Herbicide applications can vary in number depending upon the goals of the producer and the needs of the livestock that are inhabiting the land. Additionally, a number of environmental parameters can influence the effectiveness of any given application. Furthermore, timing of these applications are subject to erratic factors that encompass weather conditions, soil properties, target and non-target species growth stage, as well as local and federal regulations.

Highly productive forages within pastures are essential for producers to maintain adequate profits. Invasive plants pose a problem to pastures as they compete for light, nutrients, and water, and may further inhibit forage growth through allelopathic properties. The increasing displacement of desired forage may lead to decreases in animal weight gain, stocking rates, and ultimately profit. Losses associated with non-native weeds are an estimated $1 billion in pastures alone (Pimentel, et al., 2000), where approximately $10 billion of forage crops are grown year to year (Pimentel, et al., 2005).

Smutgrass (*Sporobolus indicus*) is one such non-native weed that infests pastures and rangelands. It is thought to have originated from Southeast Asia (Mears, et al., 1996). It was in Florida that smutgrass was recognized as a potential threat to forages in the 1950’s (McCaleb, et al., 1963). Since then the threat to productive pastures of Florida has been realized. By about

1980 small smutgrass (*Sporobolus indicus* var. *indicus*) had invaded approximately 75% of improved central Florida pastures (Mislevy & Martin, 1985). Giant smutgrass (*Sporobolus indicus* var. *pyramidalis*) displaced small smutgrass and has been the most prevalent smutgrass species since the 1990's (Sellers, Rana, et al., 2012). Rana, Wilder, et al. (2017) demonstrated that giant smutgrass can germinate under conditions where small smutgrass may not, perhaps leading to the displacement of small smutgrass by its larger counterpart. Since the introduction of small smutgrass to Florida it has been detected in 23 states (McCaleb & Hodges, 1971).

Within East Texas, smutgrass inhabits many acres of pastures, rangelands, rights-of- way, and roadsides (Turner, et al., 2003). Smutgrass is not readily consumed by cattle past 2 to 3 weeks of growth, displaces desirable grasses, and poses a threat to the native landscape if left unmanaged. Smutgrass seedlings are difficult to identify and are often confused with other grasses at a young stage. Initial smutgrass stands may go unnoticed until 5 to 10 years later and if not attended to can become a threat to the pastures they inhabit (Valle, 1977). Research is needed to distinguish smutgrass in a grass swards and to further chemical control options for a preventing establishment and eliminating established smutgrass.

Review of Literature

Smutgrass Biology

Smutgrass (*Sporobolus indicus*) is a problematic, tuft forming perennial grass that affects many native and improved pastures in the southeastern and south-central United States. Currently there are two varieties of smutgrass present in the United States, giant smutgrass (*Sporobolus indicus* (L.) R. Br. var. *pyramidalis* (Beauv.) Veldkamp) and small smutgrass (*Sporobolus indicus* (L.) R. Br. var. *indicus*.). However, only small smutgrass is present in Texas (Shaw, 2012).

Bryson and DeFelice (2009) describe smutgrass as being a dark-green, tufted, erect plant that inhabits fields, pastures, roadsides, railroad beds, and waste sites. A Bipolaris species fungus is often present on the seedhead and, less so, the foliage of mature smutgrass plants. The perennial clump grass grows to 1.1-meters tall. Mature clumps produce stems 0.3 to 1.1-m tall, and foliage 15 to 48-centimeters long by 1 to 5-millimeters wide. Leaves are usually partially folded but can be found flat or rolled. It has smooth sheaths and a tiny membranous ligule. The inflorescence is 9 to 41-cm long, interrupted and spike-like, with obtuse unequal glumes reaching about half the length of the spikelet. Lemma is pointed and somewhat longer than the blunt palea. Panicles are compact, some have ascending branches. Giant smutgrass can be differentiated by the larger spreading panicles, larger plants base (30 to 46 cm), and taller size (1.2 to 1.5 m)

Seed production is continuous and prolific, most often occurring April to December (Currey, et al., 1973). Flowering, immature seed, mature seed, and shattering can occur all on one inflorescence (Mislevy & Currey, 1980). Thus, introductions to the soil seed bank may occur throughout the growing season if conditions are conducive. A single smutgrass plant has the capability to produce approximately 45,000 seeds; approximately 1,400 seeds are produced on a given panicle (Currey, et al., 1973). Testing completed by Currey, et al. (1973) indicated that germination in the field ranged from 1 to 9%, and scarification improved germination up to 98%. Seed can remain viable in the soil seed bank for approximately 2 years (Currey, et al., 1973) until favorable environmental conditions are met (Rana, Wilder, et al., 2017). Smutgrass has been shown to have no dormancy, allowing for concentration on management practices that focus on controlling seedlings pre and post-emergence (Rana, et al., 2017).

Rana, et al. (2017) observed that temperatures of 25 to 35-C °, favorable moisture levels, and soil surface placement are the drivers for successful seed germination. Light and pH have little influence on germination. Findings from Rana, et al. (2017) are pivotal in understanding the specific conditions that influence germination of smutgrass seeds. This information will be utilized to explore the effectiveness of various herbicides with pre-emergent seedling activity labeled for use on perennial grass pastures.

Seed Dispersal

Although cattle do not readily consume mature smutgrass (Simon & Jacobs, 1999), seeds can be dispersed through the digestive tract of cattle (Andrews, 1995). It was suggested that smutgrass is being ingested by way of the seeds sticking to forage being consumed, and/or by ingestion through licking of seed infested hair. Research completed by Andrews (1995) demonstrated that about 19% of smutgrass seeds were viable after ingestion by cattle. It was reported that by 7 days 100% of the seed had been excreted. Seeds remaining in the manure exposed to natural conditions were found to not be viable. Andrews (1995) concluded that manure, unless spread by way of heavy rainfall or cleaning the area, is not a medium suitable for the growing of smutgrass and that the seeds that adhere to and later brush off from cattle and equipment are of greater concern.

Smutgrass in Pastures

Smutgrass can be problematic in pastures and to forage producers. Texas is home to more than 5 million acres of land grown for forages (USDA, 2017) where smutgrass inhabits 54 counties primarily in the southeast portion of the state. (USDA, 2018). As smutgrass densities increase, desirable forage availability and stock rates of these acres decrease (Ferrell, et al., 2006). Therefore, quality forage of these potentially productive hectares is at risk of severe decline due to smutgrass infestations.

Though not generally grazed by cattle there are circumstances where smutgrass is consumed. Durham and Kothmann (1977) demonstrated during winter months that smutgrass is grazed out of preference for green forage and the lack of other desirable forages. In situations of intense grazing, Mullahey (2000) reported that smutgrass provides a forage quality and weight gain similar to that of bahiagrass (*Paspalum notatum*), and that cattle will consume the tender regrowth of smutgrass in an intense rotational grazing system. Likewise, cattle will also graze the new regrowth resulting from mowing or burning (Mullahey, 2000). The lack of palatability beyond this fresh regrowth is thought to be the result of low digestibility associated with the high neutral detergent fiber of mature smutgrass (Persad, 1976).

Ferrell, et al. (2006) reported that bahiagrass yields were significantly reduced when subjected to low (<20% groundcover) as well as medium (20% to 70% groundcover) and high (>70% groundcover) densities of giant smutgrass. As giant smutgrass densities increased from low to medium, bahiagrass yields were reduced to 49% (Ferrell, et al., 2006). When smutgrass densities were high, bahiagrass yields were reduced by 87% compared to low densities.

Similarly, Rana, Sellers, et al. (2017a) found that giant smutgrass would outcompete bahiagrass at pH levels ranging from 4.5 to 6.5. Because of the competitive nature of giant smutgrass compared to bahiagrass, an increase in infestations will likely occur. At that point, extra feed will need to be supplemented or lower calving percentages and/or a decrease in calf weaning weights will take place in a pasture setting (Ferrell, et al., 2006). Conversely, bahiagrass was found to out-compete small smutgrass at 4.5 and 5.5 pH under optimal growing conditions (Rana, Sellers, et al., 2017).

Bermudagrass production is also adversely affected by the increases in plant size and density of smutgrass (Smith, et al., 1974). Forage quality has been shown to improve when smutgrass is removed from bermudagrass (Smith, et al., 1974). To date, no research has been conducted on yield returns associated with controlling smutgrass in bermudagrass stands.

Costs of smutgrass infestations due to decreased stocking rates can be staggering as can the cost of control. When considering smutgrass management options, the cost of control should not exceed the cost of the infestation’s impact on cattle production. Hexazinone is an herbicide that can be effective in the management of smutgrass and is often the standard control method used. Though it is effective, it is also expensive. The use of hexazinone on smutgrass stands of low density in bahiagrass has shown to not be cost effective (Ferrell, et al., 2006). Controlling low infestations using 1.1 kg ha^{-1} hexazinone resulted in a net loss of \$11.30 ha^{-1}, while controlling medium and high density infestations resulted in a net gain of \$26 and \$47 ha^{-1} respectively, in a cow-calf operation. However, the cost of high-density smutgrass stands is also expensive. Dependent upon calf values, medium to high densities cost of smutgrass infestations were found to be \$92.52 ± 10 and \$114.15 ± 14 ha^{-1} respectively, when left uncontrolled.

Cultural Control Methods

Although effective on a variety of problematic pasture weeds, controlling smutgrass through cultural methods provides many challenges. Many techniques used to control smutgrass have been found to only reduce plant size (McCaleb, et al., 1963), facilitate seed dispersal (McCaleb, et al., 1971; McCaleb, et al., 1963), or allow for seeds to emerge when the seed bank is disturbed (McCaleb, et al., 1971).

Cultivation, in general, is variable and often an unsatisfactory control method that can lead to germination of seed in the soil. During cultivation, new seedlings emerged from the soil and smutgrass plants were not eliminated (McCaleb, et al., 1963). Because small smutgrass will only germinate at the surface, and giant smutgrass will germinate 3 cm deep and up to the soil surface, deep tillage is advisable as the seed must remain covered sufficiently (Wilder, 2009).

McCaleb, et al. (1963) mowed smutgrass once every week for 4 consecutive weeks at a 3-inch height to study the effects of rotary mowing. They found the smutgrass responded with a reduced plant size that soon recovered to its original size once mowing ceased. In spite of dispersing seeds, mowing does allow for fresh regrowth for grazing.

Intense rotational grazing followed burning and mowing treatments were found to be effective in Florida by Walter, et al. (2013). Head fires utilized for burning, and the smutgrass was mowed to 20-cm height in November. They found that grazing alone did not decrease the number of smutgrass plants and that burning followed by grazing increased the plant population by 25% three years after treatment. Burning followed by intense high-density rotational stocking did, however, reduced the size of the smutgrass plants, slowed the invasion rate, and reduced the area occupied by smutgrass. This allowed for desirable species to become more competitive and fill the bare spots left behind (Walter, et al., 2013). It was concluded that after 3-years of defoliation and grazing, burning may need to be implemented to continue control of smutgrass (Walter, et al., 2013).

Andrade (1979) tried grazing smutgrass sprayed with molasses and found that ground cover from smutgrass was not reduced. It was also discovered by Valle (1977) that, when covered with molasses, the percentage of ground covered by smutgrass was not affected by the length of the rotation cycle. With supplementation, *Sporobolus* sp. could be used as a feed when incorporated in hay or silage as a part of a weed control program (Mears, et al., 1996). However, cultural practices that relocate smutgrass can facilitate the spread of seed (Valle, 1977), and there is a potential danger of cattle sickness associated with the presence of the Bipolaris fungus often found on the inflorescence (Hemckmeier, et al., 2018).

By itself, the burning of smutgrass infested pastures for smutgrass control has also proven to deliver unsatisfactory results. However, burning is an effective measure for seed destruction. Most smutgrass seed is found in the top 5 to 10-mm of soil (Andrews, 1995), leaving it exposed to the high temperature set forth by fire. The viability of giant smutgrass seed is reduced to zero when exposed to 125℃ for longer than 15-seconds (Vogler, et al., 1998). Consequently, significant reductions in the soil seed bank can be made resulting in reduced smutgrass emergence. Burning may also trigger germination, allowing for subsequent pre- or post-herbicide control following emergence (Ditomaso, et al., 2006). Little information is available about the efficacy of pre-emergent herbicide options for smutgrass control.

Chemical Control Methods

Since many of the cultural practices commonly utilized for smutgrass control produce such variable or unsatisfactory results, chemical control options can be used and are an effective and efficient option. Traditionally one of the most generally effective herbicide control options was dalapon. Dalapon applied at varying rates reduced plant size and/or provided adequate control but significantly injured desirable forages (Brecke, 1981; Meyer & Baur, 1979; Mislevy & Currey, 1980; Smith, 1982). When followed by mowing or roller chopping, a lower rate of dalapon was effective in smutgrass control (Mislevy, et al., 1980). When fertilizer was applied post herbicide application, forage ground cover was increased (Mislevy, et al., 1980). However, dalapon is no longer registered in the United States (Mislevy, Curry, et al., 1980).

In 1989 a federal label for hexazinone use in pastures was granted. Hexazinone has since often been the standard chemical control measure used. Early tests indicated that 1.7, 2.2 and 3.4 kg ha^{-1} rates of hexazinone provided effective control of smutgrass (Brecke, 1981). More recent research suggests that rates of 0.56, 0.84, 1.05 and 1.12 kg ha^{-1} provide adequate control of smutgrass (Ferrell, et al., 2006; Mislevy, et al., 2002; Mislevy, et al., 1999; Wilder, et al., 2011). However, control with the lower application rates is highly variable (Wilder et al., 2011).

Brecke (1981) discovered that higher rates (2.2, 3.4 kg ha^{-1}) of hexazinone damaged bahiagrass. Meyer, et al. (1979) found confounding results when utilizing 1.1 and 2.2 kg ha^{-1} rates wherein coastal bermudagrass cover generally increased during the 1975 and 1976 treatments. Wilder, et al. (2008) observed an inverse relationship 4-weeks after treatment between hexazinone application rate and forage yield of hybrid bermudagrass. Research from Ferrell, et al. (2006) indicated that at low and medium densities of smutgrass in bahiagrass hexazinone applied at 1.12 kg ai ha^{-1} reduced bahiagrass biomass significantly. The same rate applied to high densities of smutgrass resulted in an increase of bahiagrass biomass, having reduced the competition to the bahiagrass. While not only targeting smutgrass, hexazinone can be effective in controlling other grass species such as annual bluegrass (*Poa annua*), barnyardgrass (*Echinochloa crus-galli*), and Lolium species (Bayer, 2020), all common weedy grasses of pastures within Texas where smutgrass is present.

No recent research has been conducted on the use of broadcast applied glyphosate. Riewe, et al. (1975) found that 1.12 kg ha^{-1} of glyphosate would provide significant smutgrass control. More recent research indicates the use of glyphosate in a roller wiper application can provide exceptional control. Bidirectional wiping of smutgrass with a 50% volume/volume glyphosate solution resulted in 90% control and no damage to the (Lemus, et al., 2013). In the same study, bermudagrass was also observed colonizing the spot once occupied by smutgrass 11 months after application. Further research is needed to determine effective rates of glyphosate, as well as other effective herbicides on smutgrass.

Attempts at influencing the level of control from herbicides through various methods have been made. Mislevy, et al. (1999) clipped mature smutgrass plants ranging from 50 to 70-cm tall to a height of 7.5-cm. After 15 to 30-cm of fresh growth materialized, they were sprayed with hexazinone to assess the effects concerning season of application, growth stage, and hexazinone rate. Evaluation one year after treatment determined that mowing smutgrass resulted in no significant increase in control. Mislevy, et al. (2002) found similar results regarding mowing before hexazinone application. Midsummer and fall application dates resulted in better control than did the late-spring application (Mislevy, et al., 1999). Wilder (2009) found that adjuvants, in general, were of no benefit to increasing smutgrass control by use of hexazinone.

Utilizing the 2012 price of $1000 ha^{-1} for pasture renovation Rana, Sellers, et al. (2017b) advised that it may be impractical to renovate before 50% smutgrass infestation. They also advised that sequential herbicide applications may need to follow the renovation given the germination of seeds that McCaleb, et al. (1971) demonstrated are viable for a minimum of two years. To prevent the reestablishment of smutgrass, a residual herbicide or other means of germination control would be practical for the subsequent two years. There are no herbicides currently labeled for residual control of smutgrass within the United States. However, it has been demonstrated by Vogler (2010) that two weedy Sporobolus species in Australia are susceptible to commonly used pre-emergent herbicides. It would also be beneficial to know if applications of commonly used herbicides for smutgrass control are influencing incoming populations germinating from seed. Therefore, pre-emergent grass herbicides need to be evaluated for effective control of germinating smutgrass seeds. Other means of controlling smutgrass seed germination have been demonstrated by Phyllanthus tenellusMacêdo, et al. (2020), wherein the bioactivity of alcoholic extracts of *P. tenellus*, *R. communis*, and *C. papaya* were successful. This work demonstrates the potential success of alternative methods to prevent smutgrass re-infestations.

Weed Species Identification and Biomass Estimation Utilizing Spectroscopy

As an invasive, undesired species, it would be beneficial to the producer to know where and to what extent smutgrass is present. This aids in management decisions and interventions, especially when using weed threshold values for implementing control measures, as is often a strategy employed in pasture management. These parameters are often sampled spatially by ground observation and expressed as percent weed coverage. Traditionally this is a labor-intensive process and assessment accuracy is dependent upon the experience of the observer and the extent to which the field is observed.

At present, no research has been accomplished to measure the biomass or identify patches or individual smutgrass plants by way of imaging technology. Spectral features of the grass can be used for identification and mapping. The height differentiation between the smutgrass and common bermudagrass, a commonly grown forage in Texas, can be used for further quantification of the smutgrass' location and biomass. This information will allow producers to target problematic areas with effective herbicides while sparing injury to the desired forage.

Spectral imaging by way of Unmanned Aerial Vehicle (UAV) is a way to discriminate species within many acres. Species discrimination can be accomplished by the use of multi and hyperspectral cameras. Reflectance spectra are collected across a large number of contiguous spectral bands within each pixel. Typical multispectral data include red, green and blue (RGB) and near infrared (NIR), whereas hyperspectral data obtains tens to hundreds of colors. Objects can be characterized with greater accuracy with hyperspectral imagery due to the vast number of spectral values over their multispectral counterparts (Cushnahan, et al., 2016), though not without fault or the need for increased processing time and power (Bowyer & Danson, 2004; Filippi & Jensen, 2006; Price, 1994).

The use of spectroscopy to identify or discriminate weed species has been accomplished on numerous occasions in both row crop and rangeland settings (Gomez-Casero, et al., 2010; Lass, et al., 2005; Mirik, et al., 2013). It has been documented that utilizing spectra provides its difficulties when distinguishing species, especially when attempting to match spectra to a known library (Price, 1994). However, numerous techniques have been developed for spectral data analysis. Singh, et al. (2019) provide an overview of techniques used today.

Object based image analysis (OBIA) segmentation is an imagery analysis method that has grown from the use of multiple-parameter analysis techniques that have been used for decades. OBIA also applies radiometric information and the science of geographic information to create a more robust analysis of high resolution imagery (Blaschke, 2010). Within this analysis technique objects are created from pixels of similar information, in this instance, spectrally (Blaschke, 2010). This method can be applied to vegetation level (Laliberte, 2010) and species level identification (Husson, et al., 2016). Through image classification of RGB imagery, Laliberte (2010) were able to successfully classify grass/forb, shrubs, and bare ground by OBIA. They concluded that including multispectral imagery could bolster the potential for specific species mapping.

Morphological differences of the target weed and forages present can be exploited for accurate location, identification and biomass estimation. A canopy height model (CHM) derived from a digital elevation model (DTM) and/or digital surface model (DSM) can provide biomass estimations, mapping, and classification for a variety of vegetation in agricultural settings (De Castro, et al., 2018; Diaz-Varela, et al., 2014; Matese, et al., 2017; Näsi, et al., 2017; Persson, et al., 2012).

When spectral and elevation data are utilized together, classification of ecosystems and agricultural terraces have seen improvement over elevation data alone (Diaz-Varela, et al., 2014; Treitz & Howarth, 2000). Within pasture settings little work has been done to accomplish mapping and biomass estimation of weeds by utilizing CHM and spectral imagery. A coupling of spectral imagery with elevation data that exploits the height of smutgrass can aid in identification. This can be further merged into management systems that utilize biomass estimations for weed thresholds values and weed mapping for site specific weed management.

CHAPTER II

EVALUATION OF CHEMICAL CONTROL AND SEASONAL APPLICATION OPTIONS FOR SMUTGRASS (*Sporobolus indicus* var. *indicus*)

Introduction

Sporobolus indicus (smutgrass) is a perennial, tuft forming grassy weed that infests a significant portion of hectares in East Texas (Turner, et al., 2003). Smutgrass can primarily be found in the southeastern portion of the United States (USDA, 2018), where there are two varieties of smutgrass: giant smutgrass (*Sporobolus indicus* (L.) R. Br. var. *pyramidalis* (Beauv.) Veldkamp), and small smutgrass (*Sporobolus indicus* (L.) R. Br. var. *indicus*). Small smutgrass has been detected in 23 states since its introduction in Florida (McCaleb, et al., 1971), and is the only smutgrass variety found in Texas (Shaw, 2012). Smutgrass typically infests right-of-way and roadside areas and is particularly problematic in forage and hay producing fields due to its lack of preference by cattle and displacement of desirable forages.

Texas is home to the most cattle of any state in the United States with a market value of more than $8.6 billion (USDA, 2019b), and is supported by forage produced on approximately 5 million acres of land (USDA, 2019a). Smutgrass inhabits 54 counties of the state (USDA, 2018), and adversely affects the production and quality of bermudagrass (*Cynodon dactylon*) (Smith, et al., 1974), a common forage of east Texas. Forage yields and optimum stocking rates on otherwise potentially productive acreage in Texas are at risk due to smutgrass infestations.

Traditionally, controlling smutgrass has been difficult by means of cultural and chemical control. Cultural practices including cultivation, mowing, and burning have been observed to encourage germination of seeds (McCaleb, et al., 1971), reduce plant size (McCaleb, et al., 1963), and spread seed (McCaleb, et al., 1971; McCaleb, et al., 1963). However, intense rotational grazing followed by burning treatments reduced the total area occupied by the smutgrass, and desirable species were observed filling in the areas left behind by the controlled or partially control weed (Walter, et al., 2013). Moreover, similar results were observed by Dias (2019) when burning was followed by intense rotational stocking with and without hexazinone treatment.

The most effective method for controlling smutgrass has traditionally been chemically, through the use of dalapon. Dalapon is an herbicide used to control annual and perennial grasses on a variety of fruit and vegetable crops, forested areas, and sugarcane. When applied at varying rates it was found to reduce plant size and/or provide adequate control of smutgrass (Brecke, 1981; Meyer, et al., 1979; Mislevy & Currey, 1980; Smith, 1982). Dalapon was however deregistered and is no longer available for use within the United States (Mislevy, et al., 1999).

Hexazinone has since been the primary control choice for smutgrass management in perennial grass pastures. Research suggests that rates of 0.56, 0.84, 1.05 and 1.12 kg ha^{-1} have the potential to provide adequate control, though lower application rates are highly variable (Wilder, et al., 2011). However, Dias (2019) more recently concluded that a rate of 1.12 kg ha^{-1} should be recommended. It was also observed that highest hexazinone activity resulted from applications mades from mid-June to mid-August in Florida.

Meyer, et al. (1979) found that ‘Coastal’ bermudagrass cover had increased at one year after treatment when rates of 1.1 and 2.2 kg ha^{-1} were use. They concluded that without deferred grazing post treatment, desirable grasses may be overgrazed inhibiting them from filling in the bare spots left by the dead smutgrass. Other research observed an inverse relationship between hexazinone rate and forage yield of ‘Tifton-85’ bermudagrass at four weeks after treatment (WAT) (Wilder, et al., 2008). However, by 6 WAT bermudagrass had resumed normal growth when treated with the optimum rate for smutgrass control, 1.1 kg ha^{-1}. This may explain why an increased in bermudagrass cover was observed one year after treatment by Meyer, et al. (1979). In bahiagrass, Ferrell, et al. (2006) observed a yield reduction at low and medium smutgrass infestations, but a yield increase in high smutgrass infestations within the year following hexazinone applications. This was attributed to the smutgrass competition exceeding the hexazinone injury imposed on the bahiagrass, leading to a yield increase. However, they discovered numerical increases in bahiagrass yield production from low, medium and high smutgrass densities, and observed statistical differences for the medium and high infestations one year after treatment. Results from these studies indicate that hexazinone will reduce the yield of commonly grazed forages within the year following hexazinone application, but, provided the success of smutgrass control, will result in a forage yield increase at least one year after treatment.

The lack and variability of control following hexazinone applications has often left ranchers to manage for smutgrass infestations, rather than being able to fully control the weed. Therefore, the objectives of this research were to i) evaluate the efficacy of broadcast herbicides labeled for smutgrass control or suppression (hexazinone, nicosulfuron + metsulfuron methyl, glyphosate + imazapic) plus an herbicide recently receiving registration for use in forage and hay pastures (quinclorac), and ii) to evaluate the impact of herbicides (hexazinone, nicosulfuron + metsulfuron methyl, imazapic, and glyphosate) applied in three different seasons (spring, summer, and fall).

Materials and Methods

Site Descriptions

Two locations where chosen for the experiments. Experiment one was conducted near Richards, Texas (30.512417 ºN, -95.815667 ºW), in 2018 and repeated in 2019 at the same field site. Experiment two was conducted in 2019 at the Richards, Texas location described above, and near Belleville, Texas (29.969167 ºN, -96.186250 ºW). The soil type at the Richards location was Kaman clay (very-fine, smectitic, thermic Oxyaquic Halpuderts) with a soil pH of 5.9, and a Katy fine sandy loam (fine-loamy, siliceous, semiactive, hyperthermic Typic Paleudalfs) with a soil pH of 5.1 at the Belleville location. At both locations the pastures primarily consisted of common bermudagrass, while Pensacola bahiagrass and common carpetgrass (*Axonopus fissifolius* (Raddi) Kuhlm) were sparsely present at the Richards location, and Pensacola bahiagrass was present at the Belleville location. At both locations no regular fertilizing maintenance had been performed, and both locations were lightly stocked (one animal unit per 3 to 5 acres). For both experiments, the experimental design was a randomized complete block with 3 replications, including an untreated control in each replication. All herbicide treatments were applied utilizing a backpack compressed air sprayer with 8003 drift guard flat-fan nozzles calibrated to deliver 187 L/ha^{-1}.

Experiment 1

The objective of this experiment was to evaluate the efficacy of herbicide options labeled for the use of control or suppression of smutgrass. Herbicide treatments included hexazinone at 0.84 kg ha^{-1}, nicosulfuron at 56.1 g ha^{-1} + metsulfuron methyl at 15.8 g ha^{-1}, nicosulfuron at 56.1 g ha-$^{-1}$ + metsulfuron methyl at 15.8 g ha^{-1} followed by nicosulfuron at 39.4 g ha^{-1} + metsulfuron methyl at 10.5 g ha^{-1}, imazapic at 0.21 kg ha^{-1} + glyphosate at 0.52 kg ha^{-1}, and quinclorac at 0.42 kg ha^{-1}. Hexazinone treatment was applied twice; once in the spring (A application) and once in the summer (B application). The low rate follow up treatment (C application) of nicosulfuron + metsulfuron methyl was made in late summer one month after the initial high rate treatment (B application). All other treatments were made in the summer (B application). Visual estimates of % weed control were made using a scale of 0 as no control and 100 as total control, and % injury as a combination of stunting and chlorosis using a scale of 0 as no injury and 100 as plant death. Smutgrass control was visually estimated at 5, 10, and 18 weeks after application, and bermudagrass injury was recorded at 5, 10, and 18-weeks after application.

Experiment 2

The objective of this experiment was to evaluate labeled smutgrass control or suppression options across three seasons. The experimental design was a randomized complete block with 3 replications, including an untreated control in each replication. Herbicide treatments included hexazinone at 1.26 kg ha^{-1}, nicosulfuron at 56.1 g ha^{-1} + metsulfuron methyl at 15.8 g ha^{-1}, glyphosate at 0.52 kg ha^{-1}, and imazapic at 0.21 kg ha^{-1}. Treatments were applied in spring, summer, and fall. Visual estimates of % weed control were made using a scale of 0 as no control and 100 as total control. Spring and summer applications were visually estimated for smutgrass control at one and three months after application, while fall applications were visually estimated for smutgrass control at one month after application due to dormancy at three months after application. All treatments were evaluated in the following spring after green-up had occurred.

Data from both experiments were analyzed separately, and a similar procedure was used for both. All data were visually observed for normality and variance homogeneity. Transformed data were subject to ANOVA using R (R Core Team, 2019), and were analyzed for treatment by year interaction in experiment one, and treatment by location in experiment two. Means were separated using the LSD.test function under the 'multcomp' package in R written by Hothorn, et al. (2008).

Results and Discussion

Experiment 1

There was a significant (P = 0.023) treatment by year interaction for 5 WAB smutgrass control rating, however no significant (P < 0.05) interaction was observed for 18 and 40 WAB smutgrass control ratings (Table II-1). Consequently, data were analyzed separately by year for 5 WAB, and combined by year for 10 and 18 WAB control ratings. There were significant differences in smutgrass control between different treatments for all rating timings (Table II-2). At 5 WAB in both 2018 and 2019, imazapic + glyphosate treatments provided the highest level of control at 62% and 83%, respectively. Spring applied hexazinone and quinclorac treatments performed the worst in both years, providing no more than 9% and 10% control, respectively. B application of hexazinone provided higher levels of control in 2019 (68%) than in 2018 (23%). Nicosulfuron + metsulfuron methyl, with and without follow up applications provided similar results (48% to 58% across years) (Table II-2); however, sequential applications resulted in a reduction in seed heads at 18 WAB.

Results of hexazinone treatments, in this study, confirm the findings of previous studies. Wilder (2009) also saw relatively poor control of smutgrass when using a 0.81 kg ha^{-1} rate of hexazinone applied in the summer. Brecke (1981) observed variable control (90% and 79%) in separate locations when using a 0.8 kg ha^{-1} rate of hexazinone. Interestingly, Mislevy, et al. (1999) found that a rate of 0.56 kg ha^{-1} hexazinone provided 65% control in one year, but 89% control of smutgrass the next. These variable results could be from the impact of rainfall post application. Recent work by Dias (2019) demonstrated that 10 to 75-mm of rainfall within 7 days following hexazinone treatment provided the best opportunity for giant smutgrass control. Also confirming Wilder (2009) findings, Dias (2019) concluded that 1.12 kg ha^{-1} rate of hexazinone should be used for the most consistent control. In our study, the 2018 spring treatment of hexazinone received 12 and 71-mm of rainfall within 7 and 14 DAT, respectively (Table II-3). No rainfall occurred within 7 DAT of summer applied hexazinone, and only 1-mm total rainfall occurred within 14 DAT. In 2019, 2-mm rainfall fell within 7-days following the spring treatment of hexazinone; however, 21-mm of rainfall occurred in the 14-days follow the application. Summer applications received 31-mm of rainfall within 7-days, and a total of 62-mm by 14 DAT. The higher efficacy of summer applied hexazinone in 2019 may be attributed to adequate rainfall immediately following application. However, the overall inadequate control (< 90%) of all applications may be attributed to lack of seasonal activity for spring applications (Mislevy, et al., 1999), and overall variable control for the 0.84 kg ha^{-1} rate of hexazinone (Brecke, 1981; Wilder, 2009). It is also suggested that timing and intensity of the rainfall events may impact control results when using hexazinone (Dias, 2019). Our study indicates that applications of hexazinone should be made when forecasted rainfall is within the targeted range set forth by Dias (2019) and the 0.84 kg ha^{-1} rate is not advised due to its substantial variability for smutgrass control.

Treatments of nicosulfuron + metsulfuron methyl on smutgrass performed similar to other studies when applied on tufted grassy perennial weeds. Grichar and Foster (2019) observed no greater than 45% control with sequential applications to King Ranch (KR) bluestem *(Bothriochloa ischemum* var. *songarica)*. Vaseygrass *(Paspalum urvillei)* incurred ground cover reductions when nicosulfuron + metsulfuron methyl was applied. It was concluded, however, that inputs across multiple years would be needed for complete control (Jeffries, et al., 2017). Nicosulfuron + metsulfuron methyl should not be used for smutgrass control, although, it may assist in slowing the infestation when used to target other weeds when smutgrass is present. Objective measurements such as biomass yields need to be evaluated following this combination of herbicides for confirmation.

Imazapic + glyphosate performed the best across all treatments in both years. This combination of herbicides is seldom seen in literature for the use of perennial grass control, but rather is often used as a tool for removal of annual species in range and grasslands. Using imazapic + glyphosate to control downy brome, Morris, et al. (2016) found that treatments reduced perennial grass cover in the first year after application, experiencing recovery in the following year. Others (Nyamai, et al., 2011; Priest & Epstein, 2011) have demonstrated this combinations utility in assisting the establishment of native perennial grasses. Although possibly effective for the use of controlling smutgrass, this pre-mix herbicide combination is expensive, where-as by itself glyphosate is significantly cheaper than imazapic. Experiment two involves treatments of glyphosate and imazapic individually to observe their efficacy.

Quinclorac provided the least amount of control over the entirety of the experiment. Traditionally used in rice, this herbicide has gained recent registration for use in pasture and rangeland systems. With proper timing it will provide control of annual grasses, however it will not control plants growing from rhizomes (Rector, et al., 2018). On switchgrass, a perennial warm season bunch grass, quinclorac caused injury at establishment but plants recovered by 8-weeks after treatment (Curran, et al., 2011). Our data and these previous findings indicate that quinclorac is not suitable for the control of smutgrass.

There was a significant treatment by year interaction for 5 ($P < 0.0001$) and 10 ($P < 0.0001$) WAB injury ratings, therefore data were analyzed separately by year, and separately by rating timings (5 WAB and 10 WAB). For the 2018 trial, data indicate that injury to bermudagrass from treatments of spring (A) applied hexazinone and imazapic + glyphosate were no more than 20% at 5 WAB, and no more than 15% at 10 WAB for imazapic + glyphosate (Table II-4). Spring (A)-applied treatment of hexazinone had recovered by 10 WAB (Table II-4), while treatment of imazapic + glyphosate had fully recovered by 18 WAB (data not shown). In 2019, all treatments except quinclorac resulted in higher injury to bermudagrass than 2018 treatments (Table II-4). At 5 WAB, summer (B) applied hexazinone gave the highest injury (67%), and at 10 WAB imazapic + glyphosate gave the highest injury (28%). All treated plots with injured bermudagrass recovered by 18 WAB.

2018 results show similarities to results from Wilder, et al. (2008). They showed that treatments of 0.25, 0.5, and 1.0 kg ha^{-1} of hexazinone applied to Tifton-85 hybrid bermudagrass had recovered to normal growth by 6-weeks after treatment. Meyer, et al. (1979) saw a general increase in coastal bermudagrass ground cover when treatments of hexazinone at 1.1 kg ha^{-1} were applied. Our 2019 results show significant injury from hexazinone when applied at the B application, but also saw an increase in smutgrass control over 2018. As with the higher smutgrass control, this may be due to more rainfall within 7 days following B application. Lack of rainfall and considerable cloud coverage five weeks following summer (B) application in 2018 probably led to a decrease in hexazinone activity compared to the 2019 summer (B) application. These conditions may explain the increase in bermudagrass injury to all treatments except quinclorac in 2019 compared to 2018.

Though hexazinone and glyphosate + imazapic gave the greatest initial control of the smutgrass, they, along with nicosulfuron + metsulfuron methyl, were also among the most injurious to the forage. Furthermore, lack of control at 40 WAT, regardless of treatment or application timing, is disconcerting especially when considering the high cost of the herbicides and their application. While higher rainfall may have had an impact on the higher initial efficacy following the summer hexazinone application in 2019, a higher rate may help provide longer term results. Imazapic + glyphosate may be a potential option for smutgrass control, but further studies should be conducted to deduce the proper rate for adequate smutgrass control and the impact on bermudagrass yield. The individual active ingredients are examined in experiment 2 to determine the impact of them alone on smutgrass control and bermudagrass injury. Sequential applications of nicosulfuron + metsulfuron methyl appear to provide no additional long-term efficacy, however, single applications should be, and are further investigated in experiment two as this is an herbicide commonly used for bermudagrass pasture weed control.

Experiment 2

Treatments were evaluated for % smutgrass control following spring green up in 2020. A significant (P <0.001) (Table II-5) treatment by location interaction was observed for spring, summer, and fall applications and were therefore analyzed separately by location. No treatment differences were detected for spring (A) application at the Belleville location, and the smutgrass had recovered except for treatments of hexazinone. No treatment at the Richards location provided over 40% control (Table II-6), and only hexazinone and nicosulfuron + metsulfuron methyl provided any control at 2020 spring green-up. For summer (B) applications, hexazinone provided the highest level control at Richards (70%) and Bellville (55%). While smutgrass control from fall (C) applications was lower with hexazinone at both locations, imazapic resulted in the highest level of control of any treatment at Richards (57%) and Belleville (25%).

For bermudagrass injury, there was a significant treatment by location interaction for 3 months after spring (A) application (P <0.001) and 3-months after summer (B) application (P = 0.0346), therefore data were analyzed by location (Tables II-5). No application injured the bermudagrass more than 17% (glyphosate) at Richards following the spring (A) application, while imazapic injured bermudagrass the most at Bellville (43%) (Table II-7). No other treatments resulted in higher than 12% injury. At 3 MAB, bermudagrass had recovered at the Richards location, while nicosulfuron + metsulfuron methyl had 10% injury at Bellville.

A significant difference in treatments was detected for bahiagrass injury. All treatments except hexazinone injured the bahiagrass following the spring (A) and summer (B) applications, with nicosulfuron + metsulfuron methyl showing the highest injury (90%) 3 months after the spring (A) application, and glyphosate showing the highest injury (68%) 3 months after the summer (B) application. Visual estimations indicated that all forage present had recovered by the following spring (data not shown).

These results were not surprising for some treatments and confounding for others. The differences in hexazinone performance at locations is not uncommon (Brecke, 1981; Mislevy, et al., 1999), as mentioned above, but it is also important to note this is not always the case (Dias, 2019). The difference in smutgrass control by hexazinone for spring and summer results are similar to those found by Mislevy, et al. (1999), yet drastically different when comparing fall applications. Most of these differences may be explained by total rainfall received 7 and 14 DAA (Table II-2).

Spring applications of hexazinone did better at the Richards location having received adequate rainfall (21 mm) for herbicide incorporation by 14 DAA, even while lacking adequate rainfall (2 mm) 7 DAA. This is significant as the spring application of 0.84 kg ha^{-1} hexazinone at the same location, receiving the same rainfall, performed poorly in experiment one. This demonstrates an increase in efficacy, and reduction in variability when higher application rates are used. The 1.12 kg ha^{-1} application at Belleville did poor, having received inadequate rainfall (6 mm) within 14 DAA. The summer treatment of hexazinone fared better, perhaps due to adequate rainfall occurring within 7 DAA (31-mm) at Richards, and 14 DAA (27) at Bellville. Fall applications of hexazinone performed as expected due to lack of adequate rainfall at the Richards location, and the excessive rainfall at the Belleville location 7 and 14 DAC (Table II-8).

These results agree with the rainfall requirements Dias (2019) deemed to be necessary for hexazinone activity on smutgrass, though results in our study demonstrate lower overall performance, indicating that other factors may be at play. Overall, results from this experiment support that adequate rainfall amounts received post application are important for achieving higher hexazinone activity.

It is interesting to see that hexazinone caused very little to no injury regardless of the forage or season of application. Our results differ from that of Ferrell, et al. (2006) who saw a general reduction in bahiagrass biomass when hexazinone was applied to low and medium densities of smutgrass at 1.12 kg ha^{-1}. However, our results are similar to that of Wilder, et al. (2008), who at 3 MAT saw only a slight decrease in Tifton-85 hybrid - bermudagrass yield. In our study, common bermudagrass was rated and most prevalent within the plots and is a common grazing forage throughout the eastern portion of Texas. Though it is generally considered to be more vigorous in the face of herbicide applications compared to hybrid bermudagrass, it would be beneficial to further understand the impact of hexazinone on common bermudagrass.

Drastic differences in smutgrass control from glyphosate and imazapic treatments across the different seasons are interesting as well. Treatments during the spring and summer failed, however at Richards showed promise when applied in the fall (Table II-6). Fall applied treatment failure at the Belleville site may be due to two reasons resulting in poor growing conditions. Firstly, drought conditions were present at the Bellville location for 8-weeks leading up to the fall application, not only leading to overall poor growing conditions, but also the opportunity for the smutgrass to develop a thicker cuticle, leading to reduced herbicide absorption. Secondly, an excessive amount of rainfall fell within 14 DAA (Table II-8). Due to the overcast that the excessive rainfall brought along with the saturated soils, poor growing conditions were also had following application. Glyphosate and imazapic also resulted in the highest, yet tolerable, injury 3-months following the spring application (14 and 24%, respectively). Common bermudagrass injury is to be expected following an application of glyphosate.

Overall performance of nicosulfuron + metsulfuron methyl was poor and variable regardless of season of application or location (Table II-6). This is not surprising as others (Grichar, et al., 2019; Jeffries, et al., 2017) have observed similar activity on grass perennial weeds. Furthermore, this combination of herbicides is typically applied with the target of annual broadleaves and grasses. At Bellville, bahiagrass injury did not occur from hexazinone treatments 3 MAA or 3 MAB. At 3 MAA, nicosulfuron + metsulfuron methyl injury (90%) was the highest regardless of treatment or season but resulted in only 33% injury three months after the summer application (Table II-7). This is interesting, as metsulfuron methyl is commonly recommended for bahiagrass control at the rates applied in this study (Corriher-Olson, 2017; Sellers & Ferrell, 2012).

Our findings indicate that hexazinone at 1.12 kg ha^{-1} applied in the summertime is the most preferable rate. This is important as this herbicide is most commonly recommended for the selective control of smutgrass and will cause the least desirable injury while still allowing for grazing. We saw overall variable and unsatisfactory control with hexazinone in the spring following applications. Follow up applications the year following the initial application are warranted for further control. While combinations of glyphosate + imazapic showed overall better performance than their individual components alone or hexazinone, it is an expensive pre-mix and glyphosate applications showed similar control when applied in proper growing conditions in the fall. For this reason, coupled with low cost of glyphosate over imazapic and the glyphosate + imazapic pre-mix, glyphosate should be further investigated in a forage setting to determine if there is a rate that provides adequate smutgrass control and no more than transient common bermudagrass injury.

Table II-1 Analysis of variance table for experiment 1.

Effect	Control		Injury	
	df	*P* value	df	*P* value
	5 WAB[a]			
Year	1	0.0238	1	<0.001
Treatment	5	<0.001	5	<0.001
Year X Treatment	5	0.023	5	<0.001
	18 WAB		10 WAB	
Year	1	0.38	1	<0.001
Treatment	5	<0.001	5	<0.001
Year X Treatment	5	0.181	5	<0.001
	40 WAB			
Year	1	0.429		
Treatment	5	<0.001		
Year X Treatment	5	0.626		

[a] Abbreviation: WAB, weeks after B application.

Table II-2 Control of smutgrass 5, 18 and 40 WAB, by herbicide treatment.

Herbicide Treatment	Rate	Application	2018	2019	Combined	
			5 WAB[a]	5 WAB	18 WAB	40 WAB
	kg ha^{-1}		%			
Hexazinone	0.84	A	8c[b]	9d	0c	0c
Hexazinone	0.84	B	23b	68b	6bc	0c
Nicosulfuron + MSM[c]	56.1 15.8	B	47a	50c	2c	0c
Nicosulfuron + MSM	56.1, 15.8 39.5, 10.5	B,C	47a	58bc	12b	10b
Imazapic + Glyphosate	0.21 0.52	B	62a	83a	65a	52a
Quinclorac	0.42	B	5c	10d	0c	0c

[a] Abbreviation: WAB, weeks after B application.

[b] Means within the same column followed by the same letters are not significantly different at the 5% probability level.

[c] Abbreviation: MSM, metsulfuron methyl.

Table II-3 Herbicide application dates and rainfall amounts through 7 & 14 d after treatment, in 2018 and 2019 for experiment 1.

	Application		Rainfall[a]	
Year	Code	Date	7DAT	14DAT
			mm	
2018	A	April 9	12	71
	B	May 23	0	1
	C	July 3	5	41
2019	A	April 16	2	21
	B	June 12	31	62
	C	July 30	13	13

[a] Rainfall amounts are cumulative total rainfall received from the date of application up through 7 and 14 d after treatment.

Table II-4 Injury of common bermudagrass for 5, 18, and 40 WAB by herbicide treatment.

Herbicide Treatment	Rate	Application	Rating Timing			
			2018		2019	
			5 WAB[a]	10 WAB	5 WAB	10 WAB
	kg ha^{-1}		%			
Hexazinone	0.84	A	3ab[b]	0b	18d	10b
Hexazinone	0.84	B	0b	0b	67a	22a
Nicosulfuron + MSM[c]	56.1 15.8	B	0b	0b	37c	12b
Nicosulfuron + MSM	56.1, 15.8 39.5, 10.5	B,C	0b	0b	45bc	23a
Imazapic + Glyphosate	0.21 0.52	B	17a	13a	55ab	28a
Quinclorac	0.42	B	0b	0b	0e	0c

[a] Abbreviation: WAB, weeks after B application.

[b] Means within the same column followed by the same letters are not significantly different at the 5% probability level.

[c] Abbreviation: MSM, metsulfuron methyl.

Table II-5 Analysis of variance table for experiment 2.

Effect	Control		Injury			
	Smutgrass		Bermudagrass		Bahiagrass	
	df	*P* value	df	*P* value	df	*P* value
			Spring			
Location	1	<0.001	1	0.382		
Treatment	3	<0.001	3	<0.001	3	<0.001
Location X Treatment	3	<0.001	3	<0.001		
			Summer			
Location	1	0.0887	1	0.0257		
Treatment	3	<0.001	3	0.0346	3	<0.001
Location X Treatment	3	<0.001	3	0.0346		
	Fall					
Location	1	<0.001				
Treatment	3	<0.001				
Location X Treatment	3	<0.001				

Table II-6 Control of smutgrass at 2020 spring green-up by application timing and herbicide treatment at Richards and Bellville, TX for experiment 2.

		Period applied					
		Spring		Summer		Fall	
Herbicide Treatment	Rate	Richards	Bellville	Richards	Bellville	Richards	Bellville
	kg ha^{-1}	%					
Hexazinone	1.26	40a[a]	3	70a	55a	23b	12b
Nicosulfuron + MSM[b]	56.1 15.8	28b	0	20b	0d	10c	17b
Glyphosate	0.52	0c	0	10c	37b	52a	15b
Imazapic	0.21	0c	0	12c	15c	57a	25a

[a] Means within the same column followed by the same letters are not significantly different at the 5% probability level.

[b] Abbreviation: MSM, metsulfuron methyl.

Table II-7 Injury to bermudagrass at both locations, and to bahiagrass at Bellville by herbicide treatment for spring (A) and summer (B) 2019 applications for experiment 2.

		Rating Timing					
		Bermudagrass				Bahiagrass	
		Grimes		Bellville		Bellville	
Herbicide Treatment	Rate	3 MAA[a]	3 MAB[b]	3 MAA	3 MAB	3 MAA	3 MAB
	kg ha^{-1}	%					
Hexazinone	1.26	7	0	0d[c]	0b	0d	0d
Nicosulfuron + MSM[d]	56.1 15.8	10	0	7c	10a	90a	33c
Glyphosate	0.52	17	0	12b	7ab	20c	68a
Imazapic	0.21	5	0	43a	3ab	52b	53b

[a] Abbreviation: MAA, months after A application.
[b] Abbreviation: MAB, months after B application.
[c] Means within the same column followed by the same letters are not significantly different at the 5% probability level.
[d] Abbreviation: MSM, metsulfuron methyl.

Table II-8 Herbicide application dates and rainfall amounts through 7 & 14 d after treatment at Richards and Bellville, TX locations for experiment 2.

	Application		Rainfall[a]	
Location	Code	Date	7DAT	14DAT
			mm	
	A	April 16	2	21
Richards	B	June 12	31	62
	C	October 23	1	2
	A	May 17	1	6
Bellville	B	July 22	4	27
	C	October 23	276	308

[a] Rainfall amounts are cumulative total rainfall received from the date of application up through 7 and 14 d after treatment.

CHAPTER III

IMPACT OF HEXAZINONE AND PREEMERGENT HERBICIDES ON SMUTGRASS (*Sporobolus indicus* var. *indicus*) SEEDS

Introduction

Smutgrass (*Sporobolus indicus*) is a non-native weed that infests a vast number of pastures and rangelands within East and South East Texas. Since its introduction in Florida, many pastures the southeastern United States have succumbed to the introduction and establishment of smutgrass. The result is a negative impact on the quantity and quality of forages commonly utilized for livestock grazing (Ferrell, et al., 2006; Smith, et al., 1974) .

Smutgrass is a prolific seed producer, generating approximately 1,400 seeds on a given panicle that may remain viable in the soil for approximately 2 years (Currey, et al., 1973) until favorable conditions are met for germination (Rana, Wilder, et al., 2017). Though field germination ranges from 1 to 9%, scarification of smutgrass seeds improves germination up to 98% (Currey, et al., 1973). These attributes indicate that, regardless of the successful control of mature seed producing plants, the soil seed bank is large and, therefore, must be depleted to see successful long-term control of smutgrass.

It has been shown that applications of hexazinone, sequentially or following pasture renovation significantly reduce smutgrass densities, but only for 12-months following the initial treatment (Rana, et al., 2015). Although hexazinone needs to be incorporated into the root zone for plant uptake, its low adsorption coefficient (Koc = 54 mL g^{-1}) and high solubility (33,000 mg L^{-1}) indicate that it can be readily leached. Hexazinone is also a relatively expensive herbicide for use in pasture, costing \$80.6 kg^{-1}.

These properties indicate that a different solution for controlling germinating seedlings is needed.

Pendimethalin is a pre-emergent herbicide available for use in forage systems with the intended purpose of controlling many annual and perennial broadleaf and grass weeds germinating from seed. Application rates vary from 0.47 to 1.81 kg ha^{-1} (BASF, 2020), has no grazing restrictions following application, and costs \$21.80 kg^{-1}. This herbicide is recommended for the control of field sandbur (*Cenchrus spinifex*) (Nolte, 2019). It has also demonstrated utility for controlling spiny amaranth when applied prior to emergence in a pasture setting (Edwards, 2010).

Indaziflam is a broad-spectrum pre-emergent herbicide used in a variety of perennial cropping systems that controls both grass and broadleaved weeds when germinating from seed. Currently, indaziflam is pending registration for use in bermudagrass forages (Sebastian, et al., 2017). This herbicide has shown to control weeds common to perennial pasture systems such as southern sandbur (Cenchrus echinatus L.) (Nolte, et al., 2020) smooth crabgrass (Digitaria ischaemum), and annual bluegrass (Poa annua) (Brosnan & Breeden, 2012). It has also been demonstrated to have increased activity on monocots at reduced concentrations, and controls invasive weeds significant to that of rangelands (Sebastian, et al., 2017).

Materials and Methods

A trial to test the efficacy of 2 soil residual herbicides and hexazinone on germinating smutgrass seeds was deployed in a randomized complete block design with four replications. Each replication included an unsprayed control for comparison. Smutgrass seeds were collected from the Brazos valley. Collected seeds were prepared by separating the chaff by differential airflow using an Oregon Seed Blower (Hoffmn Manufacturing), mechanically scarified by 400 grit sandpaper, and stored at 21°C during the experiments. A mixture of top soil and sand in a 2:1 v/v ratio was sterilized and placed into 10 cm pots. All pots were subsurface irrigated before seeding. Germination tests were performed to determine seeding rates (data not shown). Twelve seeds were placed on the soil surface following herbicide application. Natural light was supplemented with high pressure sodium lights in the greenhouse for a 12/12 – h day/night photoperiod. Greenhouse temperatures were 29/15°C day/night. Herbicide treatments were applied using a single-nozzle track sprayer (R & D Sprayers, Opelousas, LA) at 140 L ha^{-1} from an 8002 EVS flat fan nozzle traveling 4.83 km h^{-1}. A preliminary study was conducted to determine the herbicide rates. Three different rates were used for each herbicide (Table III-1). All treatments were surface watered initially for herbicide activation, as needed to prevent crusting, and subsurface irrigated weekly. All treatments were individually covered with clear plastic to retain soil moisture. The number of seedlings emerged per pot, as well as visual estimates of % chlorosis and % stunting, using a scale of 0% (no chlorosis or stunting) to 100% (complete plant death), were recorded every 7-days for 5-weeks. The study was repeated twice, with the first run established in October of 2019, and the second in February of 2020. During the second run, the sprayer was calibrated to 187 L ha^{-1}, resulting in a 33% overage in application. Thus, a third run is in process for publishable data. All data were analyzed by ANOVA using R (R Core Team, 2019), and transformed as needed. The number of seedlings germinated in the treatments were compared against the untreated control using the DunnettTest function under the 'DescTools' package in R written by Signorell, et al.

(2019). For chlorosis and stunting observations, means were separated using the LSD.test function under the ‘multcomp’ package in R written by Hothorn, et al. (2008). A probability value of $P<0.05$ was used to determine significant differences.

Results and Discussion

Treatment differences were observed at all rating timings for changes in the number of smutgrass seedlings germinated (Table III-1). No smutgrass germinated from any of the pots sprayed with indaziflam. Hexazinone gave the quickest control (no live seedlings) of any treatments where germinated smutgrass was observed. No treatments of pendimethalin caused full control (no live seedlings), however, by 14 DAT less seedlings were observed at all rating timings with the exception of the 0.533 kg ha^{-1} rate. Stunting and chlorosis were present at most rating times (Tables III-2 and III-3). 1.07 and 1.6 kg ha^{-1} gave the highest initial stunting (>85%) of the pendimethalin treatments. Highest stunting and chlorosis were observed 28 DAT for all pendimethalin rates, with the exception of the highest stunting of the 0.533kg ha^{-1} rate occurring 35 DAT.

All treatments of hexazinone gave complete control by 21 DAT. At 7 DAT, no treatment gave significantly less seedlings than the control, however by 14 DAT all treatments gave at least partial control (≤17% of control). Stunting was present at all observations up until total control, and chlorosis was present at all observations except for the 0.21 kg ha^{-1} rate 7 DAT. The 0.63 kg ha^{-1} rate of hexazinone caused the least stunting, yet the quickest control.

Treatments of indaziflam saw no germination at any rate. This is not surprising due to the action of indaziflam within the germinating seed, and the rates selected.

Indaziflam belongs to the Weed Science Society of America’s Group 29, cellulose inhibiting herbicides. These herbicides directly interfere with the cellulose synthase processes needed for cell construction. Indaziflam belongs specifically to the alkylazine class of herbicides, which have significantly higher inhibitory activity compared to the benznitriles and benzamides. Indaziflam is a low use rate herbicide, however the highest rate selected for this study was the lowest recommended use rate by the current product label (Bayer, 2020). This could explain the lack of germination observed in these treatments, even at the lowest treatment rate. Also, the herbicide was applied to bare soil and kept in optimum conditions with ample moisture for herbicide activation. Nonetheless, indaziflam appears to be a candidate for the control of smutgrass from seedlings. Further research should be conducted to identify optimum rates for field use when targeting smutgrass seedlings.

Pendimethalin treatments were variable, causing significant chlorosis, stunting, and at the higher rates, reduced seedling survival. This is not uncommon, as Dear, et al. (2006) observed moderate to severe injury and reduced shoot and root weights from perennial seedlings treated with 0.6 kg ha^{-1} pendimethalin. Though the resulting efficacy from these rates was unsatisfactory, the injury caused may prove detrimental when competition from forages and/or other weeds are introduced. Furthermore, there appears to be no general trend of recovery between ratings from these treatments. As with indaziflam, the ideal greenhouse conditions help increase the efficacy of the herbicide. However, due to the promising injury inflicted by pendimethalin, higher rates should be observed to determine the optimum rates for its use.

Treatments of hexazinone proved fatal for germinating smutgrass at 7 DAT for the highest rate, and 14 DAT for all other rates. This could help explain Rana, et al. (2015) findings that treatments of hexazinone reduced smutgrass stands following pasture renovation. Wilder, et al. (2011) also suggested that younger plants may be more susceptible to hexazinone. If an application is not incorporated to the root zone for the control of mature plants, the application is perhaps not be totally lost. Germinating seedlings may still be affected by the herbicide. Though an expensive herbicide, hexazinone is still an adequate option for controlling germinating smutgrass.

Field trials evaluating indaziflam, pendimethalin, and hexazinone, will be a crucial part of future research. All three pre-emergent herbicides have potential for controlling germinating smutgrass. Following complete mature smutgrass control or pasture renovation, rates will need to be tested for control of germinating smutgrass. Information on length of residual activity, cost of optimum rates, and forage tolerance is needed to determine the best option for growers in the regions affected by smutgrass.

Table III-1 Smutgrass seedling emergence at 7, 14, 21, 28 and 35 d after treatment, as influenced by herbicide treatment.

Herbicide Treatment	Rate	Smutgrass seedling emergence 7 DAT[a]	14 DAT	21 DAT	28 DAT	35 DAT
	ai ha^{-1}	—% of untreated control —				
Pendimethalin	0.533 kg	93	83	81	79	79
Pendimethalin	1.07 kg	100	67*	47*	24*	24*
Pendimethalin	1.6 kg	93	67*	56*	50*	44*
Indaziflam	18.25 g	0*	0*	0*	0*	0*
Indaziflam	36.5 g	0*	0*	0*	0*	0*
Indaziflam	54.75 g	0*	0*	0*	0*	0*
Hexazinone	0.21 kg	90	17*	0*	0*	0*
Hexazinone	0.42 kg	87	3*	0*	0*	0*
Hexazinone	0.63 kg	107	0*	0*	0*	0*

[a] Abbreviation: DAT, days after treatment

* Significantly different from the untreated control according to Dunnett's test ($\alpha = 0.05$)

Table III-2 Chlorosis of emerged smutgrass seedlings at 7, 14, 21, 28 and 35 d after treatment, as influenced by herbicide treatment.

Herbicide Treatment	rate	Chlorosis [a]				
		7 DAT	14 DAT[b]	21 DAT[b]	28 DAT[b]	35 DAT[b]
	ai/ha^{-1}	%				
Pendimethalin	0.533 kg	4b	24	50	68	60
Pendimethalin	1.07 kg	6b	18	59	53	44
Pendimethalin	1.6 kg	0b	43	55	68	55
Hexazinone	0.21 kg	0b	39	-	-	-
Hexazinone	0.42 kg	66a	20	-	-	-
Hexazinone	0.63 kg	6b	-[c]	-	-	-

[a] Means followed by the same letter within a column are not significantly different at P > 0.05.

[b] No significant differences were detected when subject to ANOVA at P > 0.05.

[c] Values are absent where no seedlings were observed.

Table III-3 Stunting of emerged smutgrass seedlings at 7, 14, 21, 28 and 35 d after treatment, as influenced by herbicide treatment.

Herbicide Treatment	Rate	Stunting[a] 7 DAT	14 DAT	21 DAT	28 DAT[b]	35 DAT[b]
	ai/ha^{-1}	%				
Pendimethalin	0.533 kg	45b	55a	60b	59	60
Pendimethalin	1.07 kg	89a	84a	78a	56	54
Pendimethalin	1.6 kg	86a	88a	76a	75	73
Hexazinone	0.21 kg	18c	30b	-	-	-
Hexazinone	0.42 kg	73a	19b	-	-	-
Hexazinone	0.63 kg	20c	-[c]	-	-	-

[a] Means followed by the same letter within a column are not significantly different at P > 0.05.

[b] No significant differences were detected when subject to ANOVA at P > 0.05.

[c] Values are absent where no seedlings were observed.

CHAPTER IV

SPECTRAL IDENTIFICATION AND BIOMASS ESTIMATION OF SMUTGRASS (*Sporobolus indicus* var. *indicus*)

Introduction

Smutgrass (*Sporobolus indicus* var. *indicus*) is a tufted, non-native perennial grass that has invaded many acres of pastures, rangelands, rights-of-way, and roadsides (L. Turner, et al., 2003). Since the introduction of small smutgrass to Florida it has been detected in 23 states (McCaleb, et al., 1971), primarily in the southeastern portion of the United States. Two varieties exist in the U.S., giant smutgrass (*Sporobolus indicus* (L.) R. Br. var. *pyramidalis* (Beauv.) Veldkamp) and small smutgrass (*Sporobolus indicus* (L.) R. Br. var. *indicus*.). Both exhibit similar growth patterns, seed dispersal, and compete well with forages.

Proper resource management depends upon the delineation of invasive species (Byers, et al., 2002). Traditionally, the mapping of pasture and rangeland species has been an intensive process and must be exhaustive of the area to create an accurate representation of the present species. The accuracy thereof also depends heavily upon the expertise and experience of the observer. Furthermore, certain areas may be limited in access, causing species shifts and infestations to go unnoticed.

Utilizing unmanned aerial vehicles (UAV) can be an inexpensive and flexible method of high-resolution observation that allows for faster land observation and access to areas not accessible by man. UAV obtained images have been used in numerous ways for precision weed management including weed mapping (Peña, et al., 2013), species identification (Gomez-Casero, et al., 2010), integration with UAV based spraying platforms (Castaldi, et al., 2017), and even the mapping of herbicide resistant weeds (Huang, et al., 2018), all with acceptable levels of accuracy. In range and grassland settings, UAV's have demonstrated valuable utility for estimating plant biomass (Zhang, et al., 2018), shrub and grass/forb monitoring (Laliberte, 2010; Rango, et al., 2009), species detection (Lass, et al., 2005; Mirik, et al., 2013) and classification (Laliberte & Rango, 2011).

Multispectral and RGB imagery may be obtained from consumer grade cameras that can be attached to a UAV. These images can be analyzed through object based segmentation, an imagery analysis technique in which objects are created from pixels of similar spectral information, and can be applied to species and vegetation level classification (Blaschke, 2010; Husson, et al., 2016). It has been suggested at the ecosystem level, the coupling of spectral and elevation data may further bolster classification (Treitz, et al., 2000). This can be accomplished through canopy height modeling. Canopy height modeling (CHM) extracts the canopy height of the vegetation from point clouds to produce a usable representation of the actual heights of objects. Structure from motion algorithm (SfM) uses a series of overlapping 2D RGB images acquired by a UAV to automatically obtain similar feature points, creating a 3D geometry (Turner, et al., 2012). Little CHM work has been done in grassland settings, presumably due to the high quality of point cloud data needed as height differences within grasslands tend to be small (Zhang, et al., 2018). However, Possoch, et al. (2016) found that plant height derived from UAV obtained crop surface models gave robust estimations of forage mass. At a quadrat scale, Zhang, et al. (2018) demonstrated that UAV-derived CHM is useful for grassland biomass estimation and vegetation height.

A coupling of spectral imagery with elevation data that exploits the height of smutgrass can aid in identification and invasion delineation. The mapping of smutgrass can be beneficial for land and resource managers to make the proper management and control decisions and to evaluate the implemented measures. This mapping can also be incorporated into precision weed management leading to reduced herbicide inputs and allowing for herbicidal options otherwise prohibited by broadcast application due to the sensitivity of the forage.

Methods and Materials

This study was conducted in a smutgrass pasture (0.5-ha) near Bryan, Texas (30.726306ºN, -96.368222 ºW). The study area consists of pastureland primarily composed of common bermudagrass that has been grazed, with approximately 30% of the area infested with smutgrass. Majority (>90%) of the smutgrass were found with inflorescence.

A preliminary flight was performed in August 2019 to determine the optimal flight parameters and favorable light conditions. Following the preliminary flight, another flight was performed in September 2019 at the Bryan, Texas site. A third flight was to be performed in early summer of 2020 at a location near Richards, Texas, but was postponed due to the telework restrictions of the collaborators in response to the SARS-CoV-2 pandemic. A Homeland Surveillance and Electronics (HSE) UAV AG-V6A was flown at an altitude of 40-m with 70% overlap to acquire images with two vertically downward facing Nikon D7100 cameras: one for capturing near infrared (NIR) and the other for capturing red, green and blue(RGB) imagery. The UAV was equipped with a global positioning system (GPS), and nine ground control points were placed in the study area with their GPS location collected for accurate georeferencing.

Acquired images were stitched together by Pix4D software (Pix4D SA, Switzerland), georeferenced and radiometrically corrected. As a result, two ortho-rectified mosaic images, one with RGB bands and other with NIR bands and two digital surface and terrain models from the respective sets of images were obtained. SFM method was used in Pix4D to obtain the 3D perspective of the orthomosaiced imagery. The orthomosaiced imagery and 3D models were qualitatively evaluated to select the best set of imagery and 3D model for further processing. 3D model generated with the imagery with true color bands were found to be suitable for further processing. The true color bands were fused with NIR bands to generate a multispectral imagery. The canopy height model was generated by subtracting digital terrain model from digital surface model and then resampled to match the spatial resolution of the multispectral imagery.

A total of 5 layers of features were fused into the multispectral imagery. A supervised pixel-wise machine learning approach was used to classify the imagery into smutgrass and non-smutgrass. A total of 1000 training samples (i.e. pixels), 500 for each smutgrass and non-smutgrass were chosen from the imagery, out of which 400 samples were used for training and 100 samples were used for validation of each class. Artificial neural networks (Rumelhart, et al., 1986) was used as the machine learning system in ENVI (L3Harris Geospatial Inc., USA) to train on the training samples and implement the trained model oOBver the rest of the imagery. The overall accuracy of the classification was measured (Story & Congalton, 1986) as the classes are balanced and resulting true positive and true negatives are important. Overall accuracy is described by the equation:

$$\text{accuracy} = \left(\frac{\text{true positive} + \text{true negative}}{\text{true positive} + \text{true negative} + \text{false positive} + \text{false negative}}\right)$$

$$= \left(\frac{\text{correct classification}}{\text{total validation samples}}\right)$$

[1]

The biomass of 15 smutgrass plants in separate areas were collected, 5 each from small (>33 cm tall, <20cm base width), medium (33 – 66 cm tall, 20-23cm base width), and large (>66 cm tall, >23 cm base width) sizes. The position of corresponding smutgrass in the classified imagery were determined with the help of GPS coordinates that were taken during biomass harvest. However, 8 of these collections were made too close to the flown perimeter, thus an accurate assessment of biomass could not be made from these samples. Therefore, 7 samples spanning small to large plants were used. Collected plants were weighed before and after drying at 70 C for 72 h. The biomass of the smutgrass (Y-variable) were regressed against pixel coverage of the corresponding smutgrass obtained from classified imagery (X-variable).

Results and Discussion

Classification Accuracy

The images were classified into smutgrass and non-smutgrass (Fig. IV-1). An overall accuracy of 87% was achieved in the classification process. The user and producer accuracy for smutgrass and non-smutgrass were 85 and 89%, and 90 and 84% respectively (Table IV-1). The larger producer accuracy for smutgrass compared to non-smutgrass means that fewer validation samples of smutgrass were misclassified as non-smutgrass. However, higher user accuracy for non-smutgrass indicates that the classified instances of non-smutgrass can be used more confidently. Nonetheless, higher overall accuracy of the classifications makes the classified map reliable. However, it should be noted that the map cannot be used at full confidence because of some level of error associated with classification. These results indicate that using a combination of spectral and CHM observations can provide a useful system for identifying individual smutgrass plants in a low growing, grazed forage setting.

While little research has been done on mapping grasses within grasses, these results are similar to other studies in a variety of settings. In maize, Peña, et al. (2013) successfully mapped three categories of weed coverage with 86% accuracy. Husson, et al. (2016) were able to obtain as high as 99% accuracy for water-versus-vegetation level classification. Jiménez-Brenes, et al. (2019) detected bermudagrass, a problematic pest of vineyards, with the use of object-based image analysis (OBIA) for site specific weed management.

In our study, we incorporated multispectral imagery processed through OBIA with CHM. Though many grass species are spectrally similar, the incorporation of CHM provided a robust system for mapping smutgrass within a grass pasture. Furthermore, Cole, et al. (2014) demonstrated the significant change in spectral signature of species across seasons. In our case, incorporating CHM with the multispectral imagery may help protect against misclassification due to smutgrass phenological changes, and may be true of other perennial weeds.

Predictive Modeling

The classified images were utilized to derive canopy coverage area information for smutgrass, which was further used in regression analysis with smutgrass biomass. The biomass of smutgrass were predicted with fair coefficient of determination (r^2 = 0.38) (Fig. IV-2). The major reason for not achieving a higher coefficient of determination was due to the low number of experimental units used in the predictive analysis. An increase in experimental units may improve the predictive analysis, given that there is less variability within the experimental units.

Though few studies have been conducted to observe spectral imagery derived CHM and biomass relationships, our results differ from that of most others. Matese, et al. (2017) demonstrated the feasibility of categorically assessing biomass using canopy height. Zhang, et al. (2018) developed an aboveground biomass estimation model using data collected from three grassland ecosystems. They found that the mean of the canopy height model had a linear relationship (R^2 = 0.90) with field height, and a logarithmic relationship (R^2 = 0.89) with aboveground biomass. With slightly weaker results, Roth and Streit (2018) indicated a strong relationship between plant height and biomass for four specific species (R^2 = 0.74).

These results help fill the gap for UAV based weed mapping in a pasture setting. Furthermore, it successfully maps a perennial grass within a perennial grass setting, a crucial first step to site-specific weed management of smutgrass. This is significant as others have demonstrated UAV based spray application for site specific weed management. The incorporation of smutgrass mapping with targeted UAV or ground based see and spray, or prescription mapping could significantly reduce herbicide use (Castaldi, et al., 2017; Hoffmann, et al., 2008) and allow for the use of non-selective herbicides (Hunter III, et al., 2020). Biomass estimation may be improved with an increase in sampling, and the information may be used for species monitoring before and after management interventions and assessing the utilization of smutgrass by cattle. Together, this information furthers the research needed to integrate new technologies for smutgrass control. Further research is needed to determine how hyperspectral imagery may further improve smutgrass mapping, the minimum height difference needed to successful distinguish smutgrass with CHM, and mapping integration with UAV spraying systems.

Figure IV-1 Two sample plot RGB photos and their respective smutgrass distribution maps following classification.

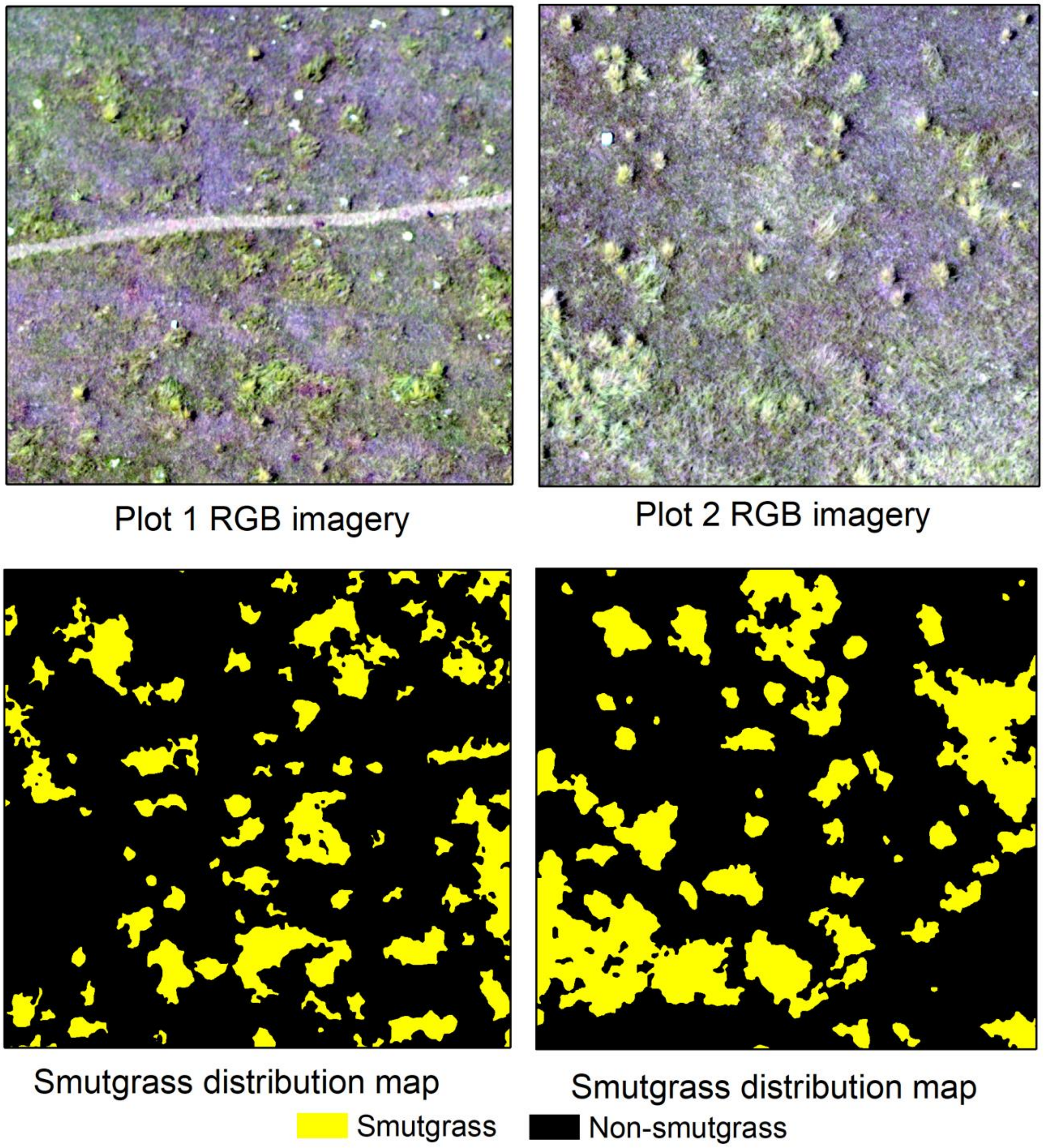

Figure IV-2 Regression of dry biomass and pixel coverage for smutgrass

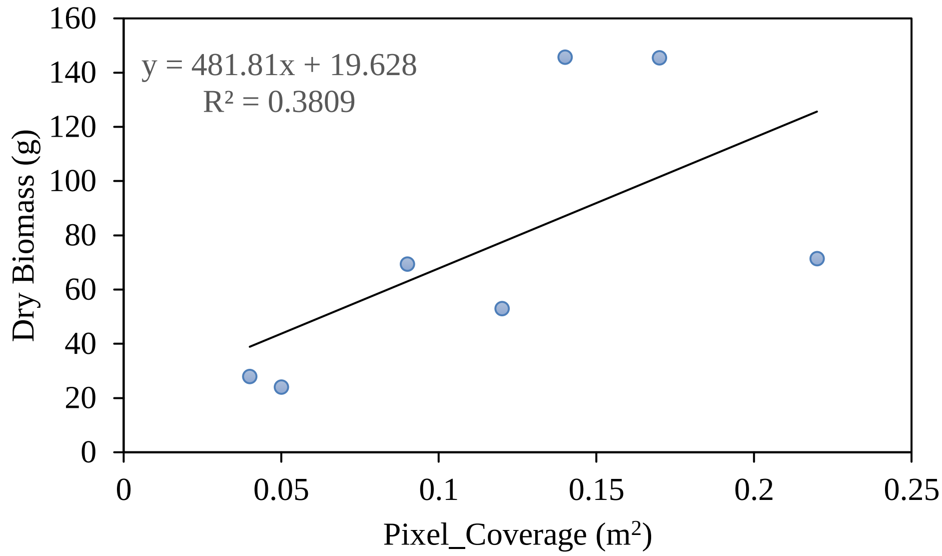

Table IV-1 Accuracy matrix and results for smutgrass and non-smutgrass classification.

Reference Classifier

Map Classifier	Smutgrass	Non-smutgrass	Totals
Smutgrass	450	80	530
Non-smutgrass	50	420	470
Totals	500	500	1000

Estimated overall accuracy (450+420) / 1000 = 87%

	Estimated producer's accuracy	Estimated user's accuracy
Smutgrass	450/500 = 90%	420/470 = 89.4%
Non-Smutgrass	420/500 = 84%	450/530 = 84.9%

CHAPTER V

CONCLUSIONS

Hexazinone and glyphosate + imazapic achieved the overall highest levels of control of smutgrass. Furthermore, when applied in the summer at 1.12 kg ha^{-1} rate, effective smutgrass management can still be seen the following spring. However, successful control is partially dependent upon adequate rainfall and adequate growing conditions following the application. Overall, spring and fall applications were variable and unsuccessful for both hexazinone and glyphosate + imazapic. Regardless, these findings indicate that follow-up management techniques such as repeat applications, rotational grazing strategies, or burning are needed if producers expect further smutgrass control the following year. Both hexazinone and glyphosate + imazapic are expensive herbicides. Applications of glyphosate also proved to be an option and is considerable cheaper. Further research should be conducted on the rate needed to for adequate smutgrass control, while still providing transient bermudagrass injury. Regardless, herbicide can be implemented into a renovation program as an affordable option for lessening smutgrass competition to new forage prior to the initial cultivation of the land. Applications should also be made when no additional environmental stress (i.e. drought) is being imposed on the smutgrass. However, regardless of treatment, this research indicates producers should see a recovery of forage by 18-weeks after application.

The pre-emergent herbicide efficacy study conducted in the greenhouse demonstrated that indaziflam and hexazinone can control smutgrass germinating form seeds. Pendimethalin significantly reduced seedling emergence but did not fully control the germinating plants. However, due to the present stunting and chlorosis of the smutgrass seedlings regardless of rates used, these seedlings will not be fit for competition amongst stands of forage and would most likely be controlled from resource competition. While all herbicides significantly reduced seedling emergence in the greenhouse, further in field research will be crucial for furthering the recommendation of imadaziflam, pendimethalin, and hexazinone's use as an effect pre-emergent herbicide option for smutgrass seedling control.

Results from the UAV identification and mapping study indicate that NIR and RBG imagery can be useful for mapping smutgrass infestations. Identification of a perennial grass in a perennial grass pasture is a crucial first step for infestation monitoring and further integration with site specific weed management. Biomass estimation may also be useful for these purposes, but this study indicates that more samples are needed. Further research is also warranted for purposes of increased mapping accuracy. NIR spectroscopy takes advantage of a relatively small number of bands, whereas hyperspectral imagery utilizes a wider array of bands and may provide better separation between species.

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