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## Soil Chemistry Modification by Guinea Grass in Semi-Arid Soils: A Litter Mediated Positive Feedback

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SOIL CHEMISTRY MODIFICATION BY GUINEA GRASS IN SEMI-ARID SOILS: A  
LITTER MEDIATED POSTIVE FEEDBACK

A Thesis

by

VANESSA ELIZABETH THOMAS

Submitted to the Graduate College of  
The University of Texas Rio Grande Valley  
In partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

August 2021

Major Subject: Biology



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LITTER MEDIATED POSTIVE FEEDBACK

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August 2021



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## ABSTRACT

Thomas, Vanessa E., Litter mediated soil chemistry alterations by Guinea grass (*Megathyrsus maximus*) in semi-arid soils. Master of Science (MS), August, 2021, 48 pp., 5 tables, 8 figures, references, 116 titles.

Nutrients are a key component of healthy soils. Their composition plays an important role in plant growth through nutrient cycling and directly influences the functioning of plant communities in both agricultural and natural ecosystems. Shifts in macronutrients such as phosphorus and nitrogen may be initiated by invasive growth as a driver for competition with native plants. The goal of this study is to explore the plant soil feedback in an exotic invasive plant, Guinea grass (*Megathyrsus maximus*), an invasive bunch grass originally from Africa, across different habitat types in the Lower Rio Grande Valley (LRGV).

To determine a positive plant soil feedback in Guinea grass, this research analyzed the physical and chemical aspects of the collected soils. Our results show that Guinea grass has significantly higher total nitrogen in the rhizosphere than natives which was strongly correlated with total leaf nitrogen, soil carbon, soil phosphorus, soil organic matter, and moisture. This indicates a higher macronutrient pool under Guinea grass compared to natives which further aids in the invasion success of Guinea grass.



## DEDICATION

The completion of my master studies is dedicated to my beloved father, for his endless guidance and support. He was always a source of inspiration, strength and continuously provided moral and emotional support when I needed it most.



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## CHAPTER I

### REVIEW OF EXOTIC FORAGE GRASS, *MEGATHYRSUS MAXIMUS*: ECOLOGY AND INVASION POTENTIAL

#### **Abstract**

Invasive plant species are reported to pose a serious threat to biodiversity, ecosystem functioning, and cost millions of dollars to manage. Several introduced African grasses are known to present recurring patterns of invasiveness and cause a severe impact on the diversity and functioning of ecosystems worldwide. Guinea grass, *Megathyrus maximus*, a forage grass species native to South Africa, is widely used in the tropics and warm temperate regions for hay and silage production. However, with the decline in livestock operations and grazing pressure, this plant is reported to be highly invasive and poses a serious threat to native biodiversity in the introduced range. Despite the severe ecological threats posed by Guinea grass worldwide, there is a dearth of information on the ecological and agroecological impact of Guinea grass. Most of the available information for this plant is on its forage value in grey literature. In this review, we present general information on Guinea grass, its distribution, ecology, economic and ecological threats, gaps in current knowledge, and recommendations for future research.

## Introduction

With the introduction of species outside their native range, humans have caused a significant impact on the composition of biological communities worldwide. While a significant portion of introduced species do not get established in proportions that can have ecological impacts, a few become highly successful in invading the recipient habitats. These exotic invasive species pose a serious threat to native species and potentially alter the ecosystem functioning. Invasive plants are known to threaten biodiversity, reduce carbon storage, and influence the fundamental ecosystem processes such as fire regimes and nutrient cycling. Invasive species not only pose considerable harm to the native ecosystem and biodiversity but also have a significant economic impact. For example, the widely cited Pimentel, Zuniga, & Morrison (2005), paper estimates the annual cost of invasive plants in the United States to be at least US\$27B. While the high cost of invasive species control is one of the challenges faced by land managers, researchers have also acknowledged the social dimensions of invasive species management (Pimentel *et al.*, 2005). This challenge is further compounded when invasive plant species have commercial value. For example, managing invasive grasses with agronomic value for farmers results in conflict between farmers who want to exploit them as grazing grasses and conservationists who are concerned about ecological impacts (CABI 2019).

Exotic invasive grasses, originally introduced as forage grasses, are known to cause a significant impact on the functioning and stability of ecosystems (D'antonio and Vitousek, 1992). They also pose a threat to agriculture as major agronomic weeds (Parker *et al.*, 2013). Invasive grasses of African origin are particularly known to cause a severe impact on the diversity and functioning of ecosystems worldwide. These grasses have evolved under the high pressure of herbivory

(Cerling *et al.*, 2015) and adapted to a wide range of environmental conditions (Barunch, 1994) which gives them a competitive advantage against the natives in colonizing ruderal habitats. The life history traits that make them valuable as forage grasses are also the ones that promote invasiveness in these grasses (Overholt and Franck, 2017).

Here we present the ecology, economic, and ecological threats, and challenges in the management of Guinea grass (*Megathyrsus maximus*, [Jacq.] B.K. Simon & S.W.L. Jacobs (Poaceae), previously *Panicum maximum* and *Urochloa maxima* [Jacq.]) introduced to the tropics and subtropics as a forage grass. In the introduced regions, Guinea grass has escaped from the cultivated rangelands and invaded disturbed sites, roadsides, untended areas, and grazing pastures at alarming rates (Figure 1). Despite the severe ecological threats posed by Guinea grass, there is limited information on the ecology of and the potential threats posed by Guinea grass in the invaded regions, particularly in the southern United States, where it poses a significant threat in both agricultural fields and natural areas. The aim of this review is to highlight the potential threats posed by Guinea grass in the semi-arid subtropics if not managed efficiently.

### **Origins and Distribution**

Guinea grass, a forage grass native to Africa, was universally introduced for hay and silage production but has caused significant ecological impacts. Guinea grass has become an invasive species in tropical areas and warm temperate areas including the United States, India, Australia, and Brazil (Daehler *et al.*, 1998; Sarkar *et al.*, 2018) (Figure 1). By 1915, Guinea grass was present in United States, Mexico, Guatemala, Honduras, El Salvador, Nicaragua, Costa

Rica, Panama, Trinidad, Bermuda, Bahama, Cuba, Jamaica, and Haiti (Hitchcock and Chase, 1915). In the United States, Guinea grass was first introduced to Florida and across the Gulf of Mexico in the early 1800s as grazing fodder for cattle and sheep, which then further spread into Mexico (Parsons, 1972; Vasey, 1887). By 1907, Guinea grass was reported to grow along the coast of Alabama, Mississippi, and Texas as a forage grass. Guinea grass was cited to have been growing along the bank of the Guadeloupe river in Texas as early as 1884 (Arthur, 1894). It is now a prominent invasive plant in south Texas (Soti *et al.*, 2020) and all major islands of Hawaii (Ammond *et al.*, 2013).

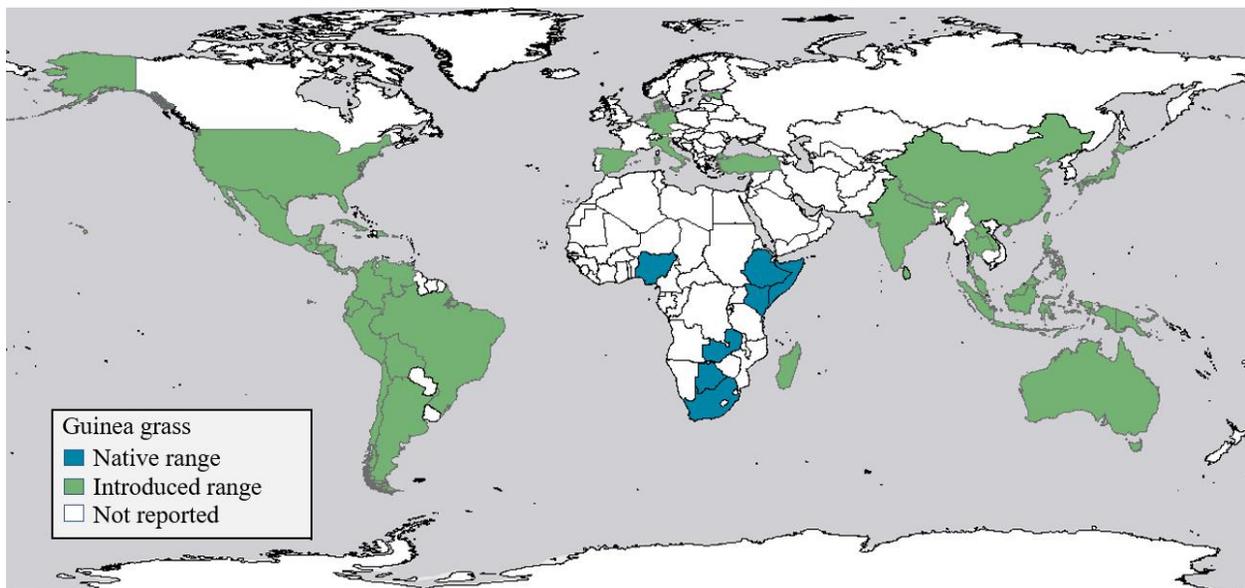


Figure 1. Native and introduced range of Guinea grass. Data source <https://www.cabi.org/isc/datasheet/38666>

### **Morphology and Biology**

Guinea grass is a deep-rooted C4 perennial bunchgrass. It grows in erect clumps with a clump radius ranging from 0.21 m to 2.89 m. Stems are cylindrical, 2.5m -3.5m tall (Aganga and Tshwenyane, 2004; Everitt, 2011) with a slightly flattened base. However, the height is dependent on other habitat conditions such as soil moisture, nutrients, shade, etc. Stems are

streaked with white wax at the nodes and internodes with leaf blades growing from the lower nodes (Moore, 2010). Leaf-blades are clustered, 20-35cm long and 7-20mm wide, with few appressed hairs. When the leaves are older the ends curl and dry (Everitt, 2011; Gould, 1975). Roots are dense and fibrous with extensive root hairs near the surface but continue to grow deeper, up to 4.5m (Sumiyoshi, 2012). The dense rhizomes and roots, which can grow up to 1m deep, allow Guinea grass to survive drought conditions (Aganga and Tshwenyane, 2004) and tolerate fire.

Reproduction occurs through seed as well as vegetative propagation in Guinea grass. It is a prolific seed producer, each plant can produce up to 9000 seeds, however, seed yields are low due to seed shattering and the small seed size (Sukhchain and Sidhu, 1992). While the plant biomass is reported to be significantly higher under shade, seed production is reported to be low (Sukhchain and Sidhu, 1992). The germination rate of Guinea grass seeds is reported to be relatively low (Mishra *et al.*, 2008). But the seed viability could be well over 80% if they are dried gradually to 10% moisture (Muir and Jank, 2004). They have been cited to experience seed dormancy for more than 3 years (Muir, 2004) and can germinate at 1.0 -1.5 cm in the soil after the dormancy period (Muir, 2004).

### **Habitat preference**

Guinea grass occurs in two distinct forms, giant and small (Mercadier *et al.*, 2001). The giant form is more common in lowland wet areas, while the small form generally occurs in hot, dry upland habitats (Vacek *et al.*, 2021). In Texas, the giant form grows along the Rio Grande (Soti *et al.*, 2020) while the small form introduced as forge grass is now spread throughout the

region. In its native range, subtropical south Africa, Guinea grass is adapted to grow under trees. It is reported to grow well under 25-50% shading, and the growth declines at 75% shading (Malaviya *et al.*, 2020). Under shaded conditions, Guinea grass is reported to have a higher nitrogen concentration in the tissue (Paciullo *et al.*, 2017). In south Texas, it does well under both shade and open canopy (personal observation). This could potentially explain high Guinea grass growth under mesquite trees, a leguminous plant. Guinea grass tolerates a wide range temperature of 12.2 – 27.8°C. The optimum temperature for seed germination is estimated at 19.1-22.9°C but plant growth and biomass accumulation are higher in higher temperatures, with temperature having a strong positive correlation with root biomass (Muir, 2004). Guinea grass grown under high temperatures are reported to have a strong association with mycorrhizal fungi, leading to higher phosphorus uptake under higher temperatures (Řezáčová *et al.*, 2018).

Guinea grass is generally reported as a drought-tolerance species. However, soil moisture is reported as the major limiting factor for Guinea grass growth. It grows well in areas with a total annual rainfall of 87-100 cm and grows moderately in drier soils. Under low soil moisture conditions, leaf biomass production declines significantly (Viciedo *et al.*, 2019). Guinea grass is known to grow well in a wide range of soil conditions. It prefers well-drained soils; however, the seeds can survive some flooding, but prolonged water logging will reduce seed viability and germination rate (Muir, 2004). It grows well in light-textured soils, sandy loams, or loams (Bogdan, 1977; Holm *et al.*, 1977). However, in Malaysia, Guinea grass is reported to grow on peat (Gajaweera, *et al.*, 2011), and in Sri Lanka, it is reported to do well in low humic gley soils with very high-water holding capacity. Guinea grass also has a wide pH tolerance range. In south Texas, it grows in soils with pH greater than 8, while in Sri Lanka it grows in pH 5.5-7.7, and in

Malaysia in 3.0-3.5 (Chew *et al.*, 1980). Though it has a wide pH tolerance range, biomass production in Guinea grass is reported to decline in soil pH >8 and <4 (Bernardes *et al.*, 2018). It has high nitrogen demand and is highly competitive in nitrogen-rich soils producing higher biomass than the cooccurring natives.

### **Ecological impact**

Guinea grass invades both agricultural fields and natural areas causing a significant impact on the ecosystem functioning and processes by altering the fire regime, soil quality, and attracting pests and diseases of crops (Mantoani *et al.*, 2016). It has been reported to be a major pest in both annual and perennial crops such as rice, corn, sugarcane, coffee, citrus, and other fruit orchards causing a major reduction in crop yield (Table 1). Guinea grass has been associated with agronomic pests such as *Bipolaris yamadae*, a leaf spot disease infecting sugarcane, serving as a refuge during the otherwise fallow season.

Not only is Guinea grass fire resistant but is also reported to alter fire regime in the dry tropical forests of Hawaii (Ellsworth *et al.*, 2014) and other tropical and subtropical landscapes. The tall Guinea grass plants, growing under trees, add a high fuel load and can act as fire ladders carrying fire from the surface to tree canopies during dry season causing lasting damage in the invaded systems (Best, 2006). Guinea grass, since it is fire-tolerant and can rapidly regenerate from rhizomes after the fire, thus creates a positive feedback loop favoring its own growth in the high nutrient ash beds (Aganga and Tshwenyane, 2004). The Guinea grass fire cycle behavior does not only affect the native plants not accustomed to the frequent intensive fire but alters the populations of arthropods in the habitats nearby (Warren *et al.*, 1987). In Queensland, Australia,

the dense tussocks of Guinea grass outcompete the native species along rivers and floodplains (Calvert, 1998). In south Texas, the native plant restoration project has been significantly impacted by the extensive invasion by Guinea grass (Figure 2).



Figure 2. Guinea grass invasion in south Texas. Image was taken at Sal Del Rey Wildlife Refuge where restoration of native plants is being disturbed by Guinea grass invasion

While there is not much information on the impact of Guinea grass on wildlife, it has been reported to degrade the northern bobwhite *Colinus virginianus* habitat in Texas and cause a decline in ground-dwelling insects in Puerto Rico. In Australia, Guinea grass is reported to reduce the larval survival rates of *Mycalesis spp* butterflies (See Table 1).

Table 1. Summary of ecological and agronomic impacts of Guinea grass in the introduced range.

Location/Region	Ecological and Agronomic Impacts	References
Australia	Reduction in the larval survival rates of <i>Mycalesis</i> spp butterflies.	Braby <i>et al.</i> , 1995
Argentina	Major weed in sugar cane fields leading up to 60% crop loss.	Cabrera <i>et al.</i> , 2020
Brazil	Aggressive invader of annual and perennial crops, including rice, sugarcane, coffee, citrus, and other fruit orchards.	Alves and Xavier, 1986; Durigan, 1992
Ecuador	Reduction in biodiversity of the Northern Ecuadorian Amazon area.	González <i>et al.</i> , 2021
India	Host of a major pest, fall armyworm ( <i>Spodoptera frugiperda</i> )	Maruthadurai <i>et al.</i> , 2020
Sri Lanka	Invades natural areas such as forests and scrublands and disturbed degraded lands negatively impacting forestry and agriculture.	Weerawardane <i>et al.</i> , 2005
Hawaii	Reduction of native grasses and woody plant communities. Add fuel to brush fires.	Cabin <i>et al.</i> , 2002; Ammond <i>et al.</i> , 2012; Ellsworth, 2014

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	Pose a threat to crops such as <i>Jatropha curcas</i> i.e., Barbados nut directly by influencing the fire regime and indirectly by changing soil nutrient status.	
Florida, Texas, and Louisiana	Major weed in cotton and sugarcane. Serves as an alternate host for sugarcane aphid <i>Melanaphis sacchari</i> . Serves as host for <i>Bipolaris yamadae</i> , leaf spot disease, which infects sugar cane crops. Degradation of the northern bobwhite <i>Colinus virginianus</i> habitat.	Overholt <i>et al.</i> , 2017; Schenck <i>et al.</i> , 2000; de Souza <i>et al.</i> , 2019 Adhikari <i>et al.</i> , 2020; Moore, 2010
Puerto Rico	Decrease in the abundance of ground-dwelling arthropods.	Moreno <i>et al.</i> , 2014

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### **Economic and Environmental Value**

Guinea grass was universally introduced as a fodder species for its high protein content and for its high tolerance to grazing and environmental stresses (Habermann *et al.*, 2019). It is one of the most productive forage grasses which is highly palatable to cattle, thus is highly preferable to farmers. Since it is a perennial bunchgrass with dense root growth, it has the potential to hold soil and reduce soil erosion (Maass *et al.*, 1988; Mishra *et al.*, 2008). Guinea grass has also been reported to be a moderate metal accumulator and has the potential to be used as a phytoremediation/phytoextraction candidate in soil and wastewater treatment projects (Olatunji *et al.*, 2014, de Sousa *et al.*, 2019, Anigbogu *et al.*, 2020). In low rainfall areas in

Africa, Guinea grass mulch is used as a drought management strategy (Wade and Sahchez, 1983; Manu *et al.*, 2017). In addition, Guinea grass incorporated into the corn legume cropping cycle is reported to increase soybean yields, improve forage quality, minimize nutrient loss, and thus maintain soil fertility in tropical conditions (Costa *et al.*, 2020). Guinea grass can also potentially host predatorial arthropods including earwigs and spiders and could be utilized as a trap plant in maize fields to reduce spotted stem borer, *Chilo partellus* eggs and larva (Koji *et al.*, 2017).

## **Management**

The characteristics of Guinea grass, such as high growth rate and tolerance to heavy grazing, shade, drought, salinity, and soil pH, which make it preferred forage grass species also make it an aggressive invader in non-target habitats. In addition, prolific seed production and ability to rapidly regrow from rhizomes after fire make this species difficult to manage in the arid and semi-arid regions where prescribed burning is typically used for invasive species control (DiTomaso and Johnson, 2006). Given the extensive spread of Guinea grass, mechanical and chemical management are reported to be ineffective. Furthermore, because of its high agronomic value, complete eradication of Guinea grass from introduced regions is impossible and/or highly controversial. Clearly, there is no single strategy to effectively manage this invasive grass. Several efforts to introduce biological control agents for Guinea grass management have had mixed results. While the fungal pathogens *Dreschlera gigantean*, *Exserohilum rostratum*, and *E. longirostratum* have shown promising results in managing Guinea grass in sugarcane fields in Florida (Chandramohan, *et al.*, 2004), a recent effort to introduce stem boring moths, *Buakea kaeuae* (Moyal *et al.*, 2011) which is specific to small Guinea grass of south-central Kenya, was reported to be unsuccessful (Vacek *et al.*, 2021). Along with biocontrol, treating with 1%

glyphosate is reported to be effective Guinea grass management (Smith *et al.*, 2012). In south Texas, management strategies have involved a combination of cattle grazing and prescribed burning. It has been reported to reduce the density of Guinea grass and increase the native plant species richness (Ramirez-yanez, 2005; Ramirez-yanez *et al.*, 2007). Effective management of Guinea grass can be achieved through a combination of public awareness, integrated biocontrol including cattle grazing, prescribed burning, and herbicides.

### **Conclusions**

Guinea grass is a forage grass species with high agronomic value, widely distributed in the tropics and sub-tropics where it is now considered as a highly invasive species. Given its high tolerance for biotic and abiotic stresses, it is likely to further expand its distribution range. Because of its agronomic value and extent of spread, complete eradication of Guinea grass from the introduced range is not desirable and not possible. Thus, the primary strategy for Guinea grass management should be to reduce its impact on native communities and crops in agricultural fields. For the effective management of Guinea grass, site specific strategies based on the habitat environmental conditions need to be developed. In areas where Guinea grass has not extensively invaded cropping fields and native grasslands, it can be managed by well-planned grazing. In areas where Guinea grass is already established, management can potentially be achieved through the integration of biocontrol (including planned grazing), cultural, and mechanical methods. It tends to perform better in sites with high soil moisture and nitrogen concentration (Holland *et al.* forthcoming), thus in agricultural fields proper management of nitrogen fertilizer and precision irrigation could prevent reduce its extensive growth. Further comprehensive studies on the seed viability, germination, and site-specific Guinea grass physiology and growth

analysis are necessary for effective management. In addition, habitat modeling to identify the habitat preference and potential impact of changes in climatic variables is important in preventing further spread of Guinea grass while still using it for its intended purpose.

## CHAPTER II

### LITTER MEDIATED SOIL CHEMISTRY ALTERATIONS BY GUINEA GRASS (*MEGATHYRSUS MAXIMUS*) IN SEMI-ARID SOILS

#### **Abstract**

Nutrients are a key component of healthy soils. Their composition plays an important role in plant growth through nutrient cycling and directly influences the functioning of plant communities in both agricultural and natural ecosystems. Shifts in macronutrients such as phosphorus and nitrogen may be initiated by invasive growth as a driver for competition with native plants. The goal of this study is to explore the plant soil feedback in a non-native invasive plant, Guinea grass (*Megathyrsus maximus*), originally from Africa, across different habitat types in the Lower Rio Grande Valley (LRGV). To determine a positive plant soil feedback in Guinea grass, this research analyzed the physical and chemical aspects of the collected soils. Our results show that Guinea grass has significantly higher total nitrogen in the rhizosphere than the native grasses which was strongly correlated with the total leaf nitrogen, soil carbon, soil phosphorus, soil organic matter, and moisture. Our results show a higher macronutrient pool under Guinea grass compared to native grasses which further aids in the invasion success of Guinea grass.

## Introduction

African C4 grasses have been introduced worldwide and cultivated in pastures because of their unique physiological characteristics including high growth rate, grazing tolerance, and abiotic stress tolerance (Kolb *et al.*, 2003; MacDougall *et al.*, 2004; Wied *et al.*, 2020). The characteristics that make these grasses ideal as forage grasses also make them aggressive invaders, particularly in the arid and semi-arid regions. In the introduced range, African grasses have escaped from cultivated areas and spread into rangelands, natural areas, roadsides, and agricultural fields at an alarming rate (Williams and Baruch, 2000) where they impact ecosystem structure and functions. They have been reported to alter above ground biotic composition by reducing native species diversity and thereby drive changes in habitat community structure and functions in the introduced range (Olden *et al.*, 2004; Pyšek *et al.*, 2012; Ellsworth *et al.*, 2014).

Invasive plants have the potential to outgrow native plants forming dense monocultures, reducing native seed density and viability, and causing an invasion-induced decline in species richness across ecosystems (Marshall and Ostendorf *et al.*, 2012; Edwards *et al.*, 2019; Wied *et al.*, 2020). For example, spotted knapweed, (*Centaurea stoebe*) is reported to affect herbivory, and shift community composition in upper grasslands of Lac Du Bois, Canada Foster *et al.*, 2021; Foster *et al.*, 2020. Similarly, invasive grasses like buffelgrass, [*Pennisetum ciliare* (L.) Link. (syn. *Cenchrus ciliaris*)], Lehmann lovegrass (*Eragrostis lehmanniana* Nees), weeping lovegrass (*E. curvula* (Schrad.) and kleingrass (*Panicum coloratum* L.) are reported to cause a significant impact on herbaceous species richness in the invaded tropics, subtropics, and warm temperate regions (Williams and Baruch, 2000; Marshall and Ostendorf, 2012). These grass species not only shift the trophic structure, fire regime, and aboveground community interactions,

but also influence the belowground ecosystem by influencing the microbial community and nutrient cycling through altered litter input and root exudates (Greer *et al.*, 2014; Rodríguez-Caballero *et al.*, 2017).

Rapidly growing invasive grasses input greater leaf litter biomass than natives and have faster decomposition rates than natives (Allison *et al.*, 2004), thereby altering soil nutrient cycling to their own advantage (Ehrenfeld *et al.*, 2001; Perkins *et al.*, 2011). They can also alter soil chemistry by creating a resource deficit through excessive uptake (Lambers *et al.*, 2008) which can further alter the soil chemistry including the pH, solubilization of nutrients, and enzyme activity (Hinsinger *et al.*, 2003; Perkin *et al.*, 2011; Zhou *et al.*, 2019). Invasive grasses not only impact natural communities directly by competing for resources, but they also influence the growth of competitors by shifting the soil chemical composition (Rodríguez-Caballero *et al.*, 2017; Rudgers *et al.*, 2009). In general, invasive grasses are reported to have higher nitrogen use efficiency than natives. For example, Pickett *et al.*, (2019) found higher nitrogen and carbon content in soils invaded by Harding grass (*Phalaris aquatica* L.). Similarly, Vasquez *et al.*, (2018) reported enhanced soil nitrogen under cheat grass, *Bromus tectorum*, thus giving it a competitive advantage over the natives. Similarly, invasive plants through leaf litter accumulation, can help facilitate phosphorus uptake (Allison and Vitousek, 2004). Invasive plants with leaf litter rich in malate, citrate, and oxalate, are known to increase phosphorus availability (Whitford *et al.*, 1999; Belnap and Sherrod, 2008). The shift in species composition, nutrient cycling and overall structure and functioning of the ecosystem in the recipient habitats can potentially create a positive feedback leading to further expansion of the invading species (Allison and Vitousek, 2004; Kaproth *et al.*, 2013). In this study, we compared the soil chemistry of the rhizosphere and

the potential soil changing effects of an exotic forage grass species Guinea grass (*Megathyrus maximum*, syn. *Panicum maximum* and *Urochloa maximum*) which has invaded roadsides, agricultural fields, and rangelands in the introduced range.

Guinea grass is a perennial C4 bunch grass. It was introduced as cattle fodder to the United States in the early 1800's and has expanded into natural ranges where it has displaced native vegetation (Wied *et al.*, 2020; Soti and Thomas Forthcoming). Guinea grass is reported to be nitrogen dependent, and while under stress, N intake can increase (Britto de Assis Prado *et al.*, 2016; Gonçalves *et al.*, 2020) with a symbiotic relationship with beneficial soil microbes (Rocha *et al.*, 2020). Furthermore, Guinea grass is reported to release root exudates in low phosphate soils to take up recalcitrant phosphorus (Almeida *et al.*, 2020). Thus, with higher nutrient scavenging and mining, Guinea grass can potentially produce nutrient rich litter, which aids in nutrient cycling and creates positive plant-soil feedback. We hypothesized that soil under Guinea grass would be significantly higher in nutrients compared to coexisting natives with the addition of nutrient rich litter, thus creating a litter mediated positive plant-soil feedback. To test the hypothesis, we collected and analyzed rhizosphere soil and plant tissue samples of Guinea grass and coexisting native plants from five different locations in southwest Texas with different histories of Guinea grass invasion. Two phenotypes (standard and giant) are reported to occur in Texas (Soti *et al.*, 2020) However, in this study we only encountered the standard phenotype.

## Materials and Methods

Study Sites. Our study sites span across two ecoregions in south Texas, the South Texas Plains and Western Gulf Coastal Plain (Figure 1). The Western Gulf Coastal Plain is the band of lowland about 100 Km wide, adjacent to the Gulf Coast, with elevation ranging from sea level up to 122 meters (Griffith *et al.*, 2004). The Western Gulf Coastal Plain's includes the eastern most parts of the Lower Rio Grande Valley within which is the Lower Rio Grande Alluvial Floodplain (Griffith *et al.*, 2004). The Lower Rio Grande Valley has coastal prairie's, Tamaulipan brushland, and riparian woodlands. This riparian woodland has a dense growth of shrubs and tree cover, including mesquite (*Prosopis glandulosa*), granjeno (*Celtis pallida*) Texas ebony (*Pithecellobium flexicaule*) and sugar hackberry-cedar elm (*Celtis laevigata-Ulmus crassifolia*) (Diamond, 1998). Parks for sample collecting (Bentsen State Park, Estero Llano Grande State Park, and Hugh Ramsey Nature Park) were collected within the alluvial flood plain. Soils are characterized by alluvial delta deposits with dominant soils characterized as clay loams and sandy clay loams. Mean annual precipitation is 58-69 cm with temperatures ranging from 23-35°C in July (Griffith *et al.*, 2004). The lower Rio Grande has wetlands and resacas; one of the sample sites in this area is the Resaca De la Palma.

The Southern Texas plains are dominated by thorny brush and grassland, with caliche soils. Locally known as the Tamualipan thornscrub country, it is subhumid to dry region with clay variated soils, including clay loam and sandy clay loam with pH ranging from alkaline to slightly acidic (Griffith *et al.*, 2004). One of the parks for sample collection was Falcon state park, located within this ecoregion identified as the Rio Grande Floodplain and Terraces. This region has ustic to aridic and hyperthermic soils (Griffith *et al.*, 2004). There are some flood

plain forests in this region with common hackberry (*Celtis laevigata*), cedar elm (*Ulmus crassifolia*), Mexican ash (*Fraxinus berlandieriana*) and dominant invasive grass buffelgrass (*Pennisetum ciliare* syn. *Cenchrus ciliaris*) (Reiley *et al.*, 2019).

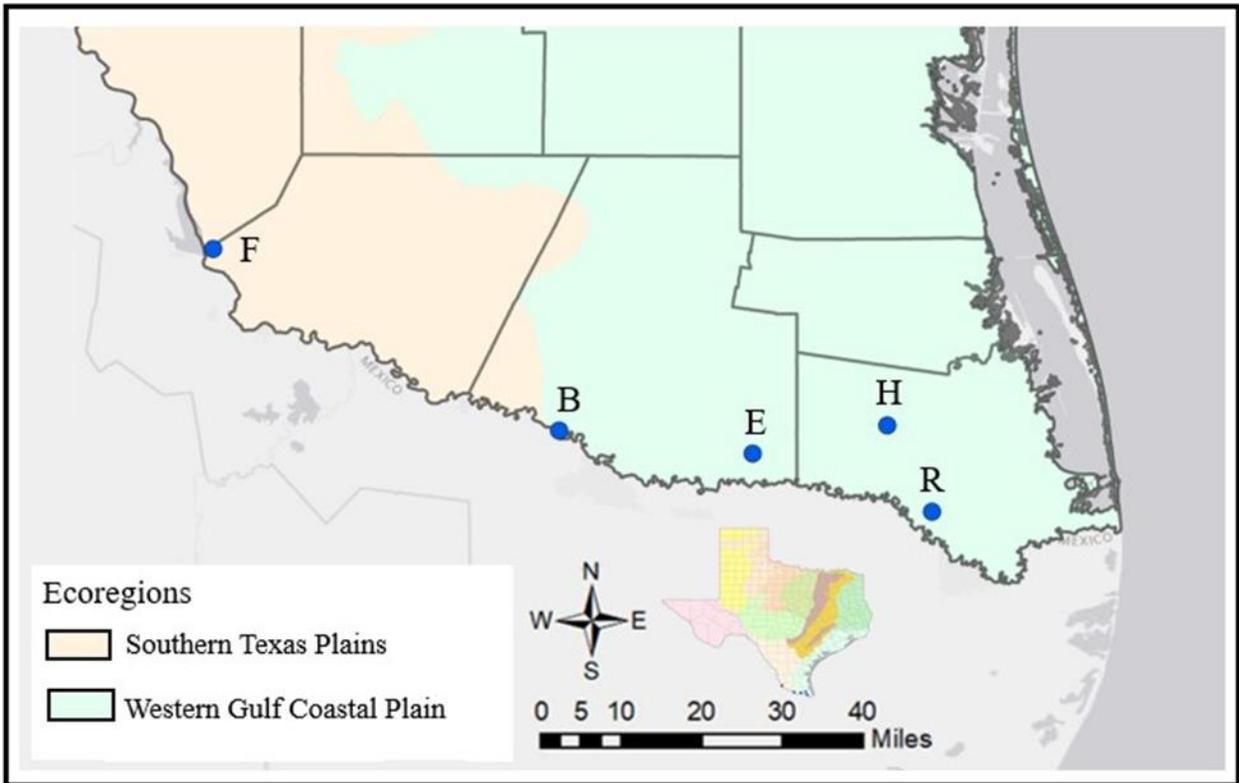


Figure 3. Location of the sample collection sites in the Lower Rio Grande Valley. Sampling sites were state parks across 3 counties, Hidalgo, Cameron, and Starr. The parks include Falcon State Park (F); Bentsen State Park (B); Estero Llano State Park (E); Hugh Ramsey Nature Park (H); and Resaca De Las Palmas State Park (R).

Sample collection. At each site, 5 random plots with Guinea grass and 5 random adjacent plots with native vegetation were selected. In each site soil samples were collected directly under Guinea grass and coexisting native vegetation following the method by McPherson *et al.*,

(2018). At each site, above ground plant tissue samples were also collected from Guinea grass and natives. The soil and plant tissue samples were stored in airtight bags and transported to the lab in a cooler filled with ice. The soil samples were air dried and passed through a 2mm sieve to remove large plant debris and gravels before analysis.

Soil and plant tissue analysis. The following parameters were assessed in all 50 soil samples: moisture, soil organic matter (SOM), pH, salinity, phosphorus, iron, zinc, total carbon, and total nitrogen. Soil moisture content percentage was measured by gravimetric method (after drying in an oven for 70°C for 48 hours). Soil organic matter (SOM) content was determined by dry combustion method (500°C for 4 hours). Soil pH was measured with a benchtop pH meter (Oakton Instruments, Vernon Hills, IL, USA) in deionized water 1:2 (volume) soil solution ratio. Soil electrical conductivity, soil salinity, was measured with Accumet pH/conductivity meter (Fisher Accumet® AB200) with deionized water soil solution 1:2 v. Total carbon and nitrogen in soil and plant tissue were determined through the dry combustion method using a LECO CN928 combustion macro determinator for (LECO Corporation, St. Joseph, MI, Model CN928 series).

For phosphorus analysis 0.25g of finely ground soil samples were digested in 6N HCl and HNO<sub>3</sub> and analyzed colorimetrically using the GENESYS™ 10S UV-Vis spectrophotometer (Thermo Fisher Scientific, Barcelona, Spain) (U.S. Environmental Protection Agency [US EPA] 1983). Zinc and Iron preparation for analysis with 1g of soil sample in 5ml of 30% HNO<sub>2</sub> in 95°C for 10min, then cooled before adding another 5ml of HNO<sub>3</sub>. Solution was placed on heating block at 95°C for 34 hours and additional 5ml was added and continued

heating until the solution was clear yellow. Solution was cooled to 4°C and added 2ul of DIW water and 3ul of 30% H<sub>2</sub>O<sub>2</sub>, then placed into 50ml centrifuge tube where it was further diluted to 50ml. Sample was then centrifuged at 2000 rpm for 10 minutes and analyzed using the PerkinElmer PinAAcle™ 900T atomic absorption (AA) spectrophotometer (Shelton, CT, USA).

For the total C and N in both native and Guinea grass leaf tissues, the leaves were dried in an oven for 74 hours at 60°C and finely ground using a mortar and pestle. The samples were then analyzed using the LECO CN928 combustion macro determinator for (LECO Corporation, St. Joseph, MI, Model CN928 series).

Statistical analysis. The statistical assessment was performed with JMP 15 statistical software (JMP, SAS Institute, 1999). Data were subjected to a normality test, soil moisture, soil pH, leaf C/N, and soil C/N were not normal. Since data transformation did not normalize these variables, they were subjected to a nonparametric test. Correlation analysis was done to determine the association among different soil variables. One-way ANOVA was done to determine the difference in the soil characteristics among the different parks. Among the different soil variables, soil moisture, C/N ratio, soil pH was subjected to a nonparametric test (Wilcoxon each pair) and soil OM%, conductivity, total C, total N, and total P were subjected to a Tukey-Kramer HSD test. One-ANOVA was also conducted to determine the differences in the soil characteristics under the natives and Guinea grass. Two-way ANOVA was done to determine the site-specific differences in the soil characteristics under natives and Guinea grass.

## Results

Our results show that soil characteristics were different among the parks which have different Guinea grass invasion history (Table 2). Soil pH in all the sites were close to neutral, 7.02-7.39 (Table 2). Resaca de la Palma State Park had the highest average pH while Hugh Ramsey Nature Park had the lowest ( $P < 0.0001$ ) (Table 4). Soil salinity ranged from 188.15uS/m to 455.16uS/m with the highest in Hugh Ramsey Nature Park ( $P < 0.0001$ ) while the lowest was found in Bentsen State Park. The soil C/N ratio ranged from 22.28-34.54, with the highest at Falcon State Park and lowest at Estero Llano Grande State Park. Similarly, Hugh Ramsey Nature Park had the highest soil moisture (11.27%,  $P = 0.0002$ ) and Falcon State Park with the lowest, (4.13%). Soil organic matter (SOM), ranged from 4.95-6.82, highest mean was found in Resaca de La Palma State Park while lowest was recorded at Falcon State Park ( $P = 0.0109$ ). Total Nitrogen ranged from 0.12-0.21, highest in Resaca de La Palma State Park while lowest was recorded at Falcon State Park, but these differences were not statistically significant. Similarly, significantly higher soil C/N ratio measurements were recorded at Bentsen Rio Grande State Park ( $P = 0.016$ ), followed by Hugh Ramsey Nature Park ( $P = 0.008$ ), while Falcon State Park was the lowest ( $P < 0.0001$ ).

We also found a significant difference in the tissue nitrogen concentration among the different sites (Table 3). Total leaf nitrogen was highest at Bentsen State Park ( $P = 0.0069$ ) and lowest at Falcon State Park ( $P < 0.0001$ ). Leaf C/N ratio was highest in Bentsen State Park ( $P < 0.03$ ), followed by Falcon State Park ( $P < 0.012$ ).

Table 2. Differences in soil composition among parks and plant type.

Site	Plant type	pH	Salinity $\mu\text{S/m}$	C/N ratio	Moisture%	SOM%	N
				30.93 $\pm$			
F	Invasive	7.37 $\pm$ 0.042	271.88 $\pm$ 62.31	12.60	4.19 $\pm$ 2.67	4.47 $\pm$ 1.22	0.14 $\pm$ 0.06
				34.54 $\pm$			
	Native	7.3 $\pm$ 0.15	249.82 $\pm$ 103.77	11.20	4.13 $\pm$ 0.99	4.95 $\pm$ 0.80	0.12 $\pm$ 0.03
	p-value	0.16	0.52	0.95	0.8	0.43	0.58
E	Invasive	7.25 $\pm$ 0.18	309.24 $\pm$ 64.991	22.28 $\pm$ 9.36	9.19 $\pm$ 3.37	6.20 $\pm$ 2.98	0.20 $\pm$ 0.06
	Native	7.32 $\pm$ 0.28	296.06 $\pm$ 109.35	31.58 $\pm$ 10.98	8.59 $\pm$ 4.42	5.28 $\pm$ 2.20	0.17 $\pm$ 0.06
	p-value	0.63	0.82	0.19	0.81	0.59	0.45
B	Invasive	7.36 $\pm$ 0.11	282.63 $\pm$ 28.12	23.49 $\pm$ 3.74	8.76 $\pm$ 2.18	9.38 $\pm$ 1.42	0.25 $\pm$ 0.06
	Native	7.38 $\pm$ 0.06	188.15 $\pm$ 30.35	22.08 $\pm$ 1.0	4.87 $\pm$ 2.25	5.77 $\pm$ 1.81	0.20 $\pm$ 0.02
	p-value	0.74	0.016	0.56	0.09	0.05	0.25
				29.40 $\pm$			
H	Invasive	6.83 $\pm$ 0.23	541.58 $\pm$ 46.6	11.81	12.40 $\pm$ 2.77	7.47 $\pm$ 2.81	0.20 $\pm$ 0.06
				38.54 $\pm$			
	Native	7.02 $\pm$ 0.08	455.16 $\pm$ 42.61	23.67	11.27 $\pm$ 2.70	5.31 $\pm$ 1.25	0.17 $\pm$ 0.06
	p-value	0.12	0.015**	0.46	0.53	0.15	0.45
R	Invasive	7.32 $\pm$ 0.19	389.22 $\pm$ 97.78	23.56 $\pm$ 8.53	11.38 $\pm$ 2.77	8.0 $\pm$ 2.67	0.25 $\pm$ 0.10
	Native	7.39 $\pm$ 0.05	285.6 $\pm$ 54.20	24.52 $\pm$ 4.76	9.61 $\pm$ 3.48	6.82 $\pm$ 2.02	0.21 $\pm$ 0.07
	p-value	0.44	0.07	0.83	0.4	0.45	0.47

Table 3. Total leaf C, N, and C/N ratio in natives and Guinea grass across the different sites.

Site	Plant type	Total Carbon	Total Nitrogen	C/N ratio
F	Invasive	42.92± 0.29	1.77± 0.26	30.93 ± 12.60
	Native	44.75 ± 3.97	1.08± 0.37	34.54 ± 11.20
	p-value	ns	ns	ns
E	Invasive	42.54 ± 0.65	2.27± 0.24	18.89 ± 2.35
	Native	41.35 ± 2.54	1.36 ± 0.39	31.98 ± 2.63
	p-value	ns	0.05	0.02
B	Invasive	43.2± 0.84	2.47 ± 0.61	18.49 ± 2.35
	Native	43.56 ± 1.43	2.38 ± 0.52	18.93 ± 2.35
	p-value	ns	ns	ns
H	Invasive	43.74 ± 1.04	2.70 ± 0.27	16.36 ± 2.35
	Native	42.34 ± 1.46	2.03 ± 0.10	21.43 ± 2.35
	p-value	ns	ns	ns
R	Invasive	43.64 ± 0.83	2.62 ± 0.10	16.64 ± 2.35
	Native	36.96 ± 11.19	1.47 ± 0.50	25.54 ± 2.35
	p-value	ns	ns	ns

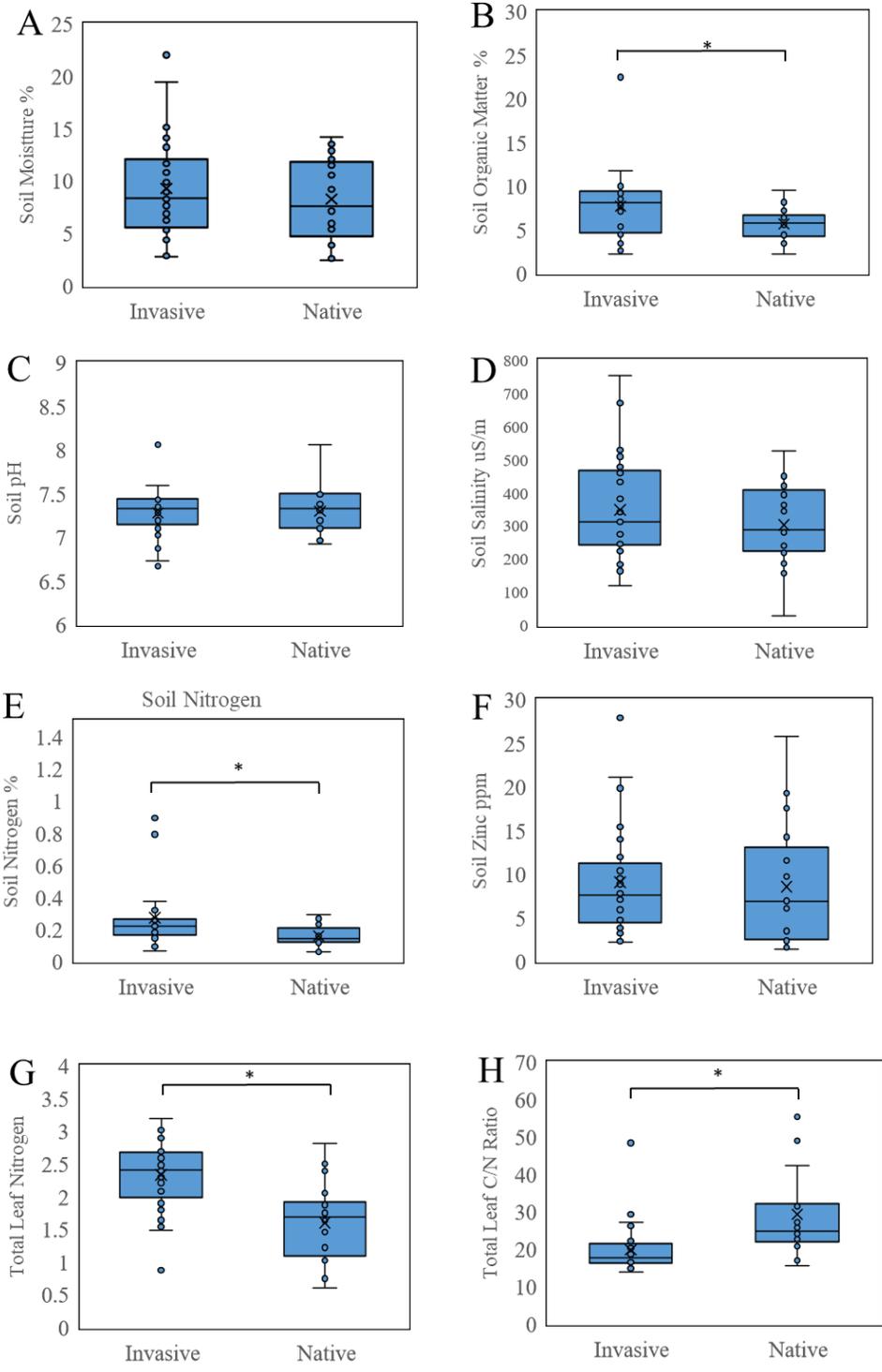


Figure 4. Invasive vs. natives' comparing range of soil chemical characteristics. Soil moisture (A), soil organic matter (B), soil pH (C), soil salinity (D), soil Nitrogen (E), soil zinc (F), total leaf nitrogen (G), total leaf C/N ratio (H).

Overall, there was a significant difference in the soil nutrient concentration under the natives and Guinea grass (Table 2, Figure 4). Between the two plant types, there was a significant difference in soil organic matter ( $F= 5.27, P = 0.027$ ), total N ( $F= 6.01, P = 0.018$ ), soil C/N ratio ( $F= 6.04, P = 0.018$ ). Soil salinity and moisture were also higher in Guinea grass compared to the natives, but this difference was not statistically significant. There was no significant difference in the total Fe, P, and Zn concentration under the natives and Guinea grass.

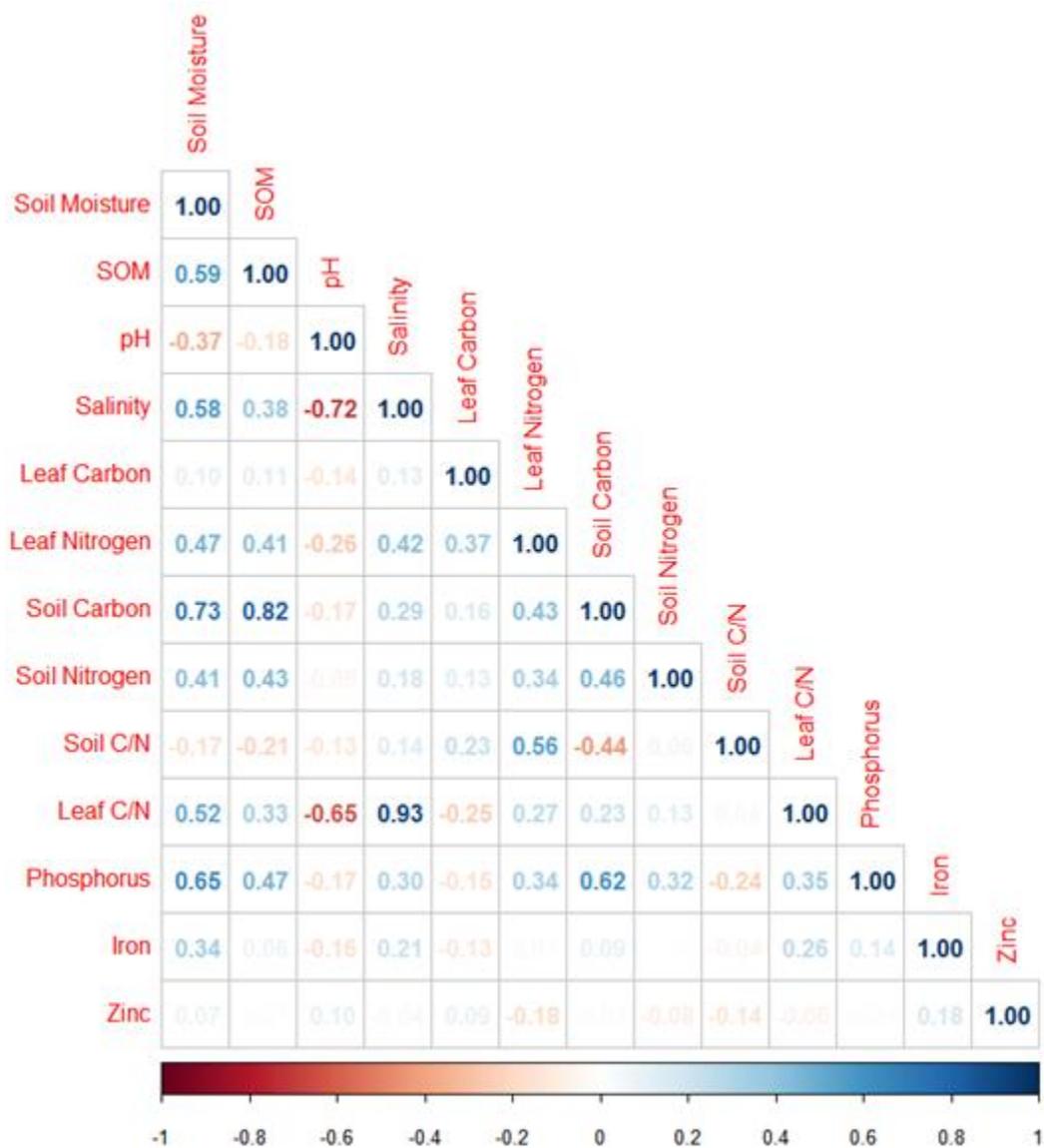


Figure 5. Correlation between soil variations including, soil moisture, soil organic matter (SOM), soil pH, soil salinity, soil carbon, soil nitrogen, soil carbon/nitrogen (C/N), soil phosphorus, soil iron, soil zinc. Including leaf nitrogen, leaf carbon and leaf C/N ratio.

Our results show that there is a strong correlation between the soil parameters and leaf nitrogen concentration (Figure 5). Soil nitrogen was positively correlated with soil moisture ( $r = 0.41$ ,  $P=0.0028$ ), soil organic matter ( $r = 0.43$ ,  $P= 0.0018$ ), and soil carbon ( $r=0.46$ ,  $P=0.0008$ ). Similarly,

leaf nitrogen had a strong positive correlation with soil moisture ( $r=0.47$ ,  $P= 0.0008$ ), soil organic matter ( $r=0.41$ ,  $P= 0.0034$ ), and soil salinity ( $r=0.42$ ,  $P= 0.0028$ ). Soil carbon had a strong correlation with soil moisture ( $r=0.72$ ,  $P< 0.0001$ ) and soil organic matter ( $r=0.82$ ,  $P<0.0001$ ). Leaf C/N ratio had a strong positive correlation with soil salinity ( $r=0.93$ ,  $P<0.0001$ ) and soil moisture ( $r=0.52$ ,  $P= 0.0030$ ); in contrast, there was a strong negative correlation with soil pH ( $r= -0.65$ ,  $P<0.0001$ ). Soil pH was negatively correlated to all tested variables. Soil phosphorus was strongly correlated to soil moisture ( $r=0.65$ ,  $P<0.0001$ ), soil carbon ( $r=0.62$ ,  $P<0.0001$ ), soil organic matter ( $r=0.47$ ,  $P= 0.0007$ ), soil salinity ( $r=0.30$ ,  $P= 0.031$ ), and total soil nitrogen ( $r=0.32$ ,  $P= 0.026$ ). Iron and zinc were not strongly correlated to any of the tested variables.

Table 4. Two-way ANOVA results showing the site-specific differences in the soil characteristics.

Source	Df	Moisture%	pH	SOM%	Salinity	Total N	Total C	Total P	C/N Ratio
Park	4	8.88***	10.66***	2.80*	16.49***	1.17	2.27	7.70***	1.24
Plant type	1	3.62	2.12	5.27*	7.89**	6.0*	2.9	1.41	6.04*
Plant type $\times$ Park	4	0.46	1.98	0.93	1.34	0.39	0.69	2.86*	0.91

Significance levels (\* $P < 0.05$ , \*\* $P < 0.01$ , \*\*\* $P < 0.001$ ).

Two-way ANOVA results show a mixed result for rhizosphere soil chemistry (Table 4). While soil moisture, pH, organic matter and salinity and total P were different in different sites and organic matter, salinity, total N and CN ratio were different plants, total P was the only variable that has a site-specific difference between natives and Guinea grass.

Table 5. Two-way ANOVA results showing the site-specific differences in the leaf biomass characteristics.

Source	DF	Leaf N	Leaf C/N
Site	4	12.52***	8.67***
Plant	1	20.76***	27.33***
Plant*Site	4	2.70*	1.9

Significance levels (\* $P < 0.05$ , \*\* $P < 0.01$ , \*\*\* $P < 0.001$ ).

Similarly for tissue nitrogen concentration, results found significant differences among native and invasive biomass composition. Leaf nitrogen was significantly higher in invasive grass compared to natives (df=45,  $F= 17.61$ ,  $P = 0.0001$ ). While carbon nitrogen ratio was significantly higher in natives (df=45,  $F= 9.88$ ,  $P = 0.003$ ).

## Discussion

In this study we characterized the rhizosphere soil chemistry of Guinea grass. As reported in previous studies, our results show that Guinea grass can grow in a wide range of soil conditions. While it is difficult to differentiate if the variation seen in our results is caused by Guinea grass invasion or the plant colonized the site with different soil conditions, we did find a significant difference in the rhizosphere soil chemistry of native plants and Guinea grass. Similar differences in the rhizosphere soil under native and invasive grasses have been seen in invasive *Pennisetum setaceum* in semi-arid region in the Mediterranean (Rodriguez-caballero *et al.*, 2017) and *Microstegium vimineum* in temperate forests (Matthew *et al.*, 2019). Soil organic matter was significantly higher in Guinea grass compared to the natives. This could be the result of high growth rate, both above ground and belowground, of Guinea grass (de Costa *et al.*, 2016). Previous studies have reported mixed results on invasive plants and soil organic

matter. Rossiter-Rachor *et al.*, (2017) reported higher organic matter under invasive African grass *Andropogon gayanus* in Australian savannahs, while Perkins *et al.*, (2011) in their analysis of a group of invasive grasses (*Aegilops triuncialis*, *Agropyron cristatum*, *Bromus tectorum*, and *Taeniatherum caput-medusae*) compared to native grasses (*Elymus elymoides*, *Pseudoroegneria spicata*, and *Vulpia microstachys*) reported species specific impact. The higher soil organic matter is correlated to nutrient decomposition and enhance growth and nutrient absorption, this can alter the soil environment including soil compaction, moisture, pH, fertility, and the soil microbial community (Zhang *et al.*, 2019; Saeromi and Lee, 2020). Invasive leaf litter directly affects nutrient availability and has the potential to disrupt seedling emergence and growth during the seedling stage (Facelli and Pickett, 1991). Furthermore, the high leaf litter could potentially be a mechanism to mediate salinity stress (Xue *et al.*, 2018), as Guinea grass is known to tolerate a wide range of soil salinity (Bora *et al.*, 2020; Pen *et al.*, forthcoming). In this study we found similar results, however the soil salinity under Guinea grass was significantly higher than the natives. Other invasive grasses such as *Urochloa arrecta* have been reported to be tolerant to high soil salinity (Bora *et al.*, 2020). While Texas native grasses such as *Chloris virgata* has been reported to grow in a heavily saline-alkaline soils (Wu *et al.*, 2017), tolerance to high soil salinity may provide Guinea grass a higher competitive advantage against natives. Additionally, Guinea grass roots can grow deep in the soil profile, increased rooting depth can mediate osmotic stress as wells nutrient deficiencies associated with salinity stress (Dai and Schlossberg, 2009) in Guinea grass. These selective pressures could result in short-term evolutionary processes creating a saline adaptive population in the recipient habitats (Bora *et al.*, 2020).

Guinea grass had significantly higher total nitrogen in the rhizosphere than the natives which was strongly correlated with the total leaf nitrogen, soil carbon, soil phosphorus, soil organic matter, and moisture. This indicates a higher macronutrient pool under Guinea grass compared to natives. While the soil microbial community analysis was beyond the scope of this study, such alteration in soil chemistry could potentially be also the result of plant growth-promoting microbes as reported by (Zhang *et al.*, 2019). Among the different sites sampled, we found that Guinea grass invasion was most extensive in Resaca de la Palma State Park which had the highest soil nitrogen and lowest in Falcon State Park which had the lowest soil nitrogen. This also indicates the preference of nitrogen rich soils by Guinea grass.

While previous studies have reported a significant difference in soil pH, Zn, and P under native and invasive plants (Batten *et al.*, 2008; Barlow *et al.*, 2020), we did not find a significant difference in the native and Guinea grass rhizosphere. Our results are similar to (Dassonville *et al.*, 2008) who reported no significant difference in the soil pH, Zn, and total P under invasives. The differences in the soil organic matter, total N, C/N, salinity, leaf N concentration indicates that Guinea grass has a potentially creates a litter mediated positive feedback loop that is different from uninvaded soils. This positive self-nutrient-driven cycle allows the invasive grass to increase the soil nutrient value and may indicate higher decomposition rates than natives. Other studies have found that invasives decomposition rates are much faster than natives allowing them to allocate the nutrients for positive nutrient cycling (Allison *et al.*, 2004). This shift in the nutrient cycling further influences the soil, including pH, nitrification rates, and litter dynamics, thereby altering the soil potentially to the invasives advantage (Ehrenfeld *et al.*, 2001). This may also be due to a beneficial microbial relationship between invasives to assist the decomposition and nutrient uptake. Beneficial microbes assist in nutrient uptake, protection from

pathogens, and display allelopathic effects (Li *et al.*, 2017). Therefore, research with microbial communities and guinea grass in semi-arid regions is important and needs to be explored further.

We found that Guinea grass prefers sites with higher soil nitrogen and further increases the soil nitrogen pool by the addition of nitrogen rich litter. These results are important in terms of developing Guinea grass management plan. While habitat manipulation of or invasive species management is highly debated (James *et al.*, 2011), it can potentially be used to manage and reduce the further spread of Guinea grass. Another aspect for consideration is competition and invasion potential of other invasive grasses. For example, Falcon State Park which had low soil nutrients and relatively lower Guinea grass invasion has a dense growth of another invasive forage grass, buffelgrass (*Pennisetum ciliare* syn. *Cenchrus ciliaris*), which is reported to do well in low nutrient and drier conditions (Marshall and Ostendorf, 2012). Our results could provide land managers restoring rangelands particularly in the semi-arid regions, the understanding of relationship between soil conditions and different invasive grasses' invasion potential, management of invasive grasses and invasion potential.

In conclusion, the semi-arid zones are naturally poor in soil nitrogen. Guinea grass, which prefers high nitrogen in soil, readily outcompetes natives in disturbed habitats with high soil nitrogen such as farm edges, roadsides, and abandoned agricultural fields. Thus, to prevent further expansion of Guinea grass it is important to manage soil moisture and nutrient levels. Future management plans and research should focus on incorporating habitat manipulation as a component of Guinea grass management plan.

## CHAPTER III

### CONCLUSIONS AND RECOMMENDATIONS

Exotic invasive grasses, originally introduced as forage grasses worldwide have been recognized to cause a significant impact on the ecosystem processes (Overholt and Frank, 2017). The semi-arid subtropical Texas habitats have been invaded by several exotic grasses such as, buffelgrass., Guinea grass, Lehman lovegrass, and blue stem (Wied *et al.*, 2020). These grasses, because of their tolerance to a wide range of environmental conditions, can potentially have an ecosystem-level impacts including alteration of fire regime, nutrient cycling, and shift in the soil microbial communities. With the change in climatic variables, there is an increased risk of range expansion by these exotic grasses, threatening the habitats already under stress.

#### **Climate change and Guinea grass**

Mechanisms for successful plant invasion include disturbance and tolerance to a broad range of abiotic and biotic factors compared to natives (Higgins and Richardson, 2014). As the effects of climate change are increasing, climatically suitable areas once unviable for tropical invasive growth may increase (Hellman *et al.*, 2008). Given its importance as a forage grass when grown in confinement and the threat it poses as an invasive species it is important to understand how the shifts in climatic variables influence Guinea grass and vice versa (Habermann *et al.*, 2019).

Climate change is projected to influence the rainfall pattern and temperatures with increased temperatures and prolonged drought periods. Though Guinea grass is reported to be drought tolerant, previous research has shown that Guinea grass above ground biomass growth is limited by soil moisture levels (Viciedo *et al.*, 2019). Though Guinea is a tropical forage grass species, increasing temperatures is reported to reduce nutrient uptake (Carvalho *et al.*, 2020). In addition, change in environmental conditions are reported to influence the physiology and growth of Guinea grass. A study from São Paulo, Brazil, analyzing the response of Guinea grass under climate change scenarios, temperature and drought stress showed that it maintained the leaf chlorophyll content under elevated temperatures but decreased under drought conditions. Similarly, under elevated ambient CO<sub>2</sub> levels resulted in increase to total leaf thickness; this response may include a thicker cuticle and increased stomatal density and size (Habermann *et al.*, 2019).

Changing climatic conditions has the potential to shift the habitat range for Guinea grass. For example, in Texas, Turner (2003) reported Guinea grass presence across several counties in the south, but our preliminary survey conducted during spring 2020 shows that the range has expanded, and the plant has grown into new areas, and this may continue (Figure 6). Given the results by (Borjas-Ventura *et al.*, 2019), under climate change scenarios, Guinea grass might reduce its expansion in natural areas with limited soil moisture, however it poses a significant expansion risk in irrigated agricultural fields, which are rich in soil nitrogen. To estimate the expansion of Guinea grass based on increasing temperatures I made habitat maps based on max temperatures intervals of 2020-2040, 2041-2060, 2061-2080, 2081-2100, in Texas (Figure 7), and all countries (Figure 8)

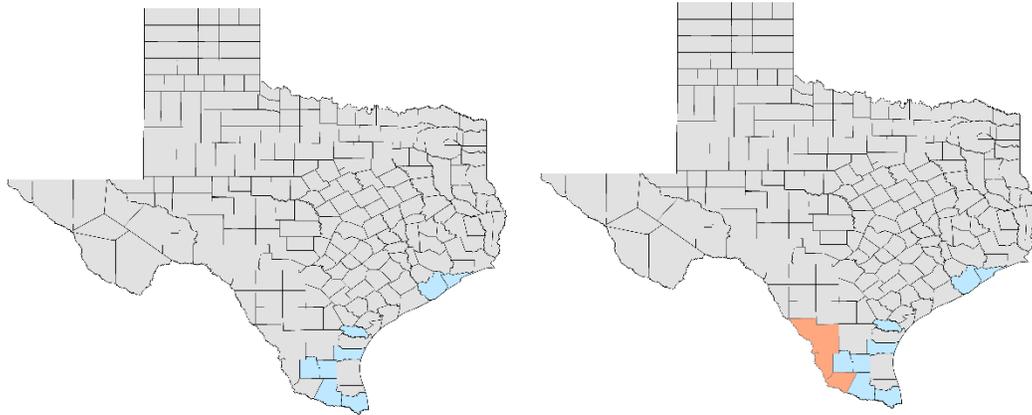


Figure 6. Guinea grass sightings adapted from 2004 by B.L Turner (left) and Survey by V. Thomas 2020 (right)

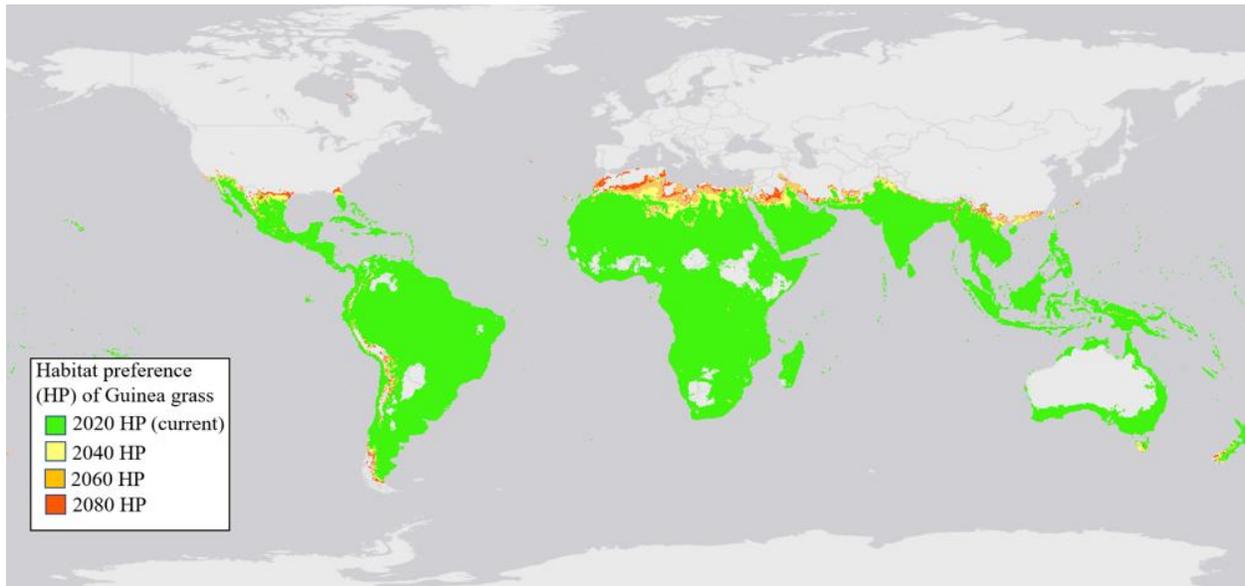


Figure 7. Increase of Guinea grass expansion from climate change from increasing global temperature (Data SSP 585 average temp), 2020 range  $-40^{\circ}\text{C}$  to  $43.88^{\circ}\text{C}$ , 2040 avg range  $-37.13^{\circ}\text{C}$  to  $44.79^{\circ}\text{C}$ , 2060 range  $36.18^{\circ}\text{C}$  to  $45.58^{\circ}\text{C}$ , 2080 range  $-33.8^{\circ}\text{C}$  to  $47.06^{\circ}\text{C}$ . Global Climate Model BCC-CSM2-MR, ssp 585, from <https://www.worldclim.org>.

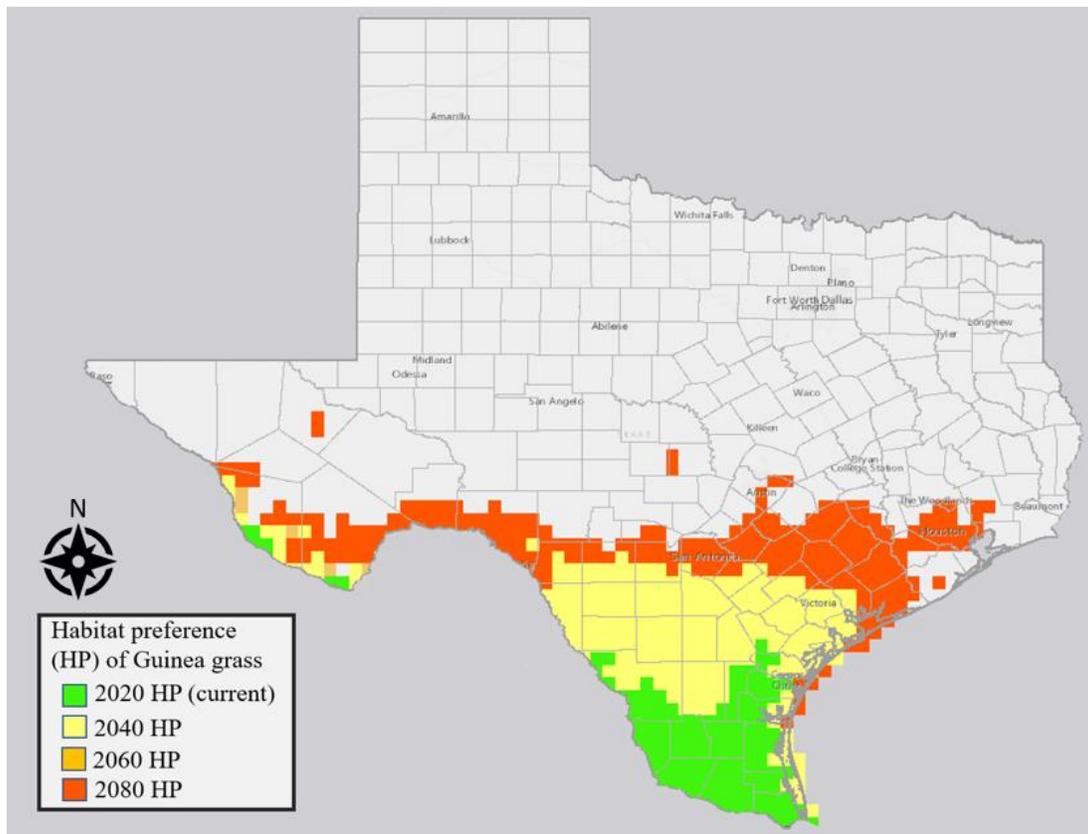


Figure 8. Increase of Guinea grass expansion from climate change in Texas from increasing global temperature (Data SSP 585 average temp), 2020 range  $-40^{\circ}\text{C}$  to  $43.88^{\circ}\text{C}$ , 2040 avg range  $-37.13^{\circ}\text{C}$  to  $44.79^{\circ}\text{C}$ , 2060 range  $36.18^{\circ}\text{C}$  to  $45.58^{\circ}\text{C}$ , 2080 range  $-33.8^{\circ}\text{C}$  to  $47.06^{\circ}\text{C}$ . Global Climate Model BCC-CSM2-MR, ssp 585, from <https://www.worldclim.org>.

### Management Strategies

While Guinea grass is reported to influence the fire regime in the invaded regions (Stewart, 2017), using prescribed burning as management technique has had mixed results. In Texas, a study by Ramirez-yanez (2005) found a combination of grazing and prescribed burning reduced the density of Guinea grass and increased native plant species richness related to deer and quail fodder. Combination of prescribing burns with cattle grazing, was reported to increased

native plant diversity over a year (Ramirez-yanez *et al.*, 2007). In contrast, prescribed burning to manage Guinea grass resulted in the decline in native plant diversity in Hawaii (Ellsworth *et al.*, 2013).

Biological control using isopods, earthworms, and fungi has been used to control invasive grasses (Sands & Goolsby, 2011). But the research on biological control of Guinea grass has mixed results. Fungal pathogens (*Dreschlera gigantean*, *Exserohilum rostratum*, and *E. longirostratum*) are reported to be effective in managing Guinea grass (Chandramohan *et al.*, 2004). However, stem-boring African moth found only on Guinea grass in the native range tested as a potential biocontrol agent did not provide effective results, neither the larvae or the adults developed or reproduced on the Guinea grass (Vacek *et al.*, 2021).

Our recent study shows that habitat manipulation could be an effective management technique for Guinea grass management (Holland *et al.*, Forthcoming). Guinea grass seems to perform outcompete native species in high soil moisture and nitrogen conditions as it has high nitrogen demand (Paciullo *et al.*, 2017). Similarly, Guinea grass can also create a positive plant soil feedback with the addition of nutrient rich litter (see Chapter 2) and recruitment of beneficial soil microbes.

Finally, in south Texas, Guinea grass invades farm edges, roadsides, and abandoned agricultural fields. These areas are generally rich in soil nitrogen, thus, to prevent further expansion of Guinea grass it is important to manage soil moisture and nutrient levels. Future

management plans and research should focus on incorporating habitat manipulation as a component of Guinea grass management plan.

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## BIOGRAPHICAL SKETCH

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