INFLUENCE OF CHEMICAL, CULTURAL AND MECHANICAL PRACTICES ON PARA GRASS (*Urochloa mutica*) MANAGEMENT

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
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I would like to dedicate this work to my mother and father for being the source of my inspiration and pride. They have always been there giving me love and support.

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Major: Agronomy

Para grass (*Urochloa mutica*) is an invasive exotic, C4 perennial grass introduced as forage to the United States in the late 1800s. Currently, it is no longer recommended for forage; however, it has persisted in Florida and become a major problem in wetland ecosystems. The goal of this research was to improve wetland ecosystem health by reducing the potential of para grass invasion via an integrated approach using mechanical, cultural and herbicide inputs.

Following an initial greenhouse screening, effective herbicides were evaluated under field conditions using different water regimes in conjunction with burning and flooding for para grass control. Two field studies were conducted in 2008–09 and both repeated in 2009–10 at T. M. Goodwin Waterfowl Management Area near Fellsmere, FL. In both years, herbicides were applied in late November or early December. In 2009, the entire experimental area was burned in May and flooded after burning. In the first field study, all rates of imazapyr provided a similar level of control ranging from 70 to 88%, regardless of the initial water level 1 month after treatment (MAT). In the second field study, at least 91% para grass control was obtained with glyphosate at 1

MAT, regardless of the initial water level and was greater than that observed with imazapyr. There were no significant differences in para grass control among herbicide treatments in either field study in relation to initial water levels at 6 and 12 MAT, which was 2 and 8 months after burning-flooding (MAB-F), respectively. Additionally, it was observed that burning followed by flooding in the untreated checks provided at least 62% reduction of initial para grass at 12 MAT from both field studies. Excessive rainfall in 2010 resulted in an incomplete burn and para grass control following flooding was much lower than that observed in 2009.

The second objective was to evaluate total nonstructural carbohydrate concentration in para grass crown and stolon tissues to determine the time-frame for the most efficacious herbicide applications. Carbohydrate concentration in both stolon and crown were typically lowest in the late winter and early spring, but increased from May through September. This indicates that para grass may be more susceptible to herbicide applications in early summer when herbicides will be transported with carbohydrates to reproductive tissues.

The third objective was to examine the impact of cultural and mechanical techniques on para grass re-growth under greenhouse conditions. Burning plants and subjecting to either saturated or flooded conditions resulted in at least 92% less biomass 5 weeks after treatment than cut plants subjected to the same conditions. Regression analysis revealed that to reduce para grass biomass by 90% after simulated roller-chopping, at least 17 days of flooding or 29 days of saturated conditions were required.

In conclusion, late fall application of 0.85 kg/ha imazapyr or 1.12 kg/ha glyphosate followed by spring burning and immediate flooding are effective in controlling para grass in wetlands where flooding can be controlled. Roller-chopping followed by flooding can be an option to control para grass when burning is not possible.

CHAPTER 1
SCOPE AND JUSTIFICATION

Background

Para grass (*Urochloa mutica*) is a perennial C4 grass in the *Poaceae* family with an aggressive growth habit that competes with surrounding vegetation. It is native to tropical Africa and South America (Cameron and Kelly 1970). Para grass was well established in Brazil as early as 1823 (Parsons 1972) and was most likely introduced to the United States through Brazil “at an early date” (Hitchcock and Chase 1951). Para grass may have been brought to America as bedding in slave ships in early 1800s (Parsons 1972) and introduced as a forage plant into Florida in the 1870s (Austin 1978). In 1910, para grass was promoted as forage by the Florida Agricultural Experiment Station (Mislevy and Quesenberry 1999). Since its introduction, naturalization of para grass has occurred throughout several U. S. states including Alabama, Florida, Hawaii, South Carolina and Texas (Masterson 2007). Currently, it has become a serious weed problem in cultivated and un-grazed disturbed areas (MacDonald et al. 2008). It is reported as an invasive species in Hawaii (Holm et al. 1977) and Florida (FLEPPC 2009); is no longer recommended for utilization in Florida (IFAS Invasive Plant Working Group 2008). In Florida, para grass is widespread, found in several ecosystems including: floodplains, forests, swamps, lakes, marshes, rivers, and other disturbed areas (Richerson and Jacona 2003; Stone 2010). Para grass infestation has been confirmed in almost all central and south Florida counties by Early Detection and Distribution (EDD) Mapping System (EDD Maps 2010).

The detrimental economic and environmental consequences of this exotic invasive perennial grass in Florida and lack of published literature concerning para grass prompted this research at the University of Florida. Therefore, the goal of the thesis research herein was to expand available information regarding management of para grass.

Taxonomy and Biology

Para grass is an invasive, perennial grass that belongs to the *Poaceae* family. It is also known as buffalo grass, dutch grass, california grass, carib grass, scotch grass and watergrass. It has been scientifically renamed several times and its synonymy includes *Brachiaria mutica* (Forsk.) Stapf, *Brachiaria purpurescens* (Raddi) Hern., *Panicum muticum* (Forsk.), *Urochloa mutica* (Forsk.), *Panicum barbinode* Trin., *Panicum purpurescens* Raddi (Figure 1-1) (USDA-NRCS 2010).

Para grass is a robust C4, stoloniferous and competitive grass that grows up to 1 m tall when erect and up to 3 m long when creeping horizontally (Langeland and Burks 1998). It can form dense stoloniferous mats in water depths of at least 1 m (Holm et al. 1977) and extend floating stolons across the water 6 m or more in length (Handley and Ekern 1981). Stem nodes are swollen and covered with dense hairs. Rooting is initiated from the lower nodes of stems. Leaf blades are flat, 10 to 30 cm long and 1.3 cm wide, glabrous but often with small hairs at base above and below. Leaf sheaths are covered with dense stiff hairs below and sparse hairs above. The ligule consists of a row of short, stiff hairs.

The inflorescence is a terminal panicle that consists of numerous subsessile, 3 mm long and paired spikelets (Langeland and Burks 1998). Initially, the flowerhead is yellowish green and turns brown as seed ripens (Cameron and Kelly 1970). Flowering occurs from September through December in Florida (Hall 1978). Seed production is prolific (>10,000 seed per square meter), but seed viability is reportedly poor (Wesley-

Smith 1973) and no seed germination was observed from seed germination experiments (personal observations; data not shown).

According to Grof (1969) seed viability of para grass is restricted to low latitudes and humid tropical environments. Viable para grass seeds were collected at latitude 13^{0}S in the Northern territory of Australia (Wesley-Smith 1973). Therefore, the primary means of spread and reproduction is vegetative (stolons) in Florida.

Favorable Habitat and Climatic Tolerance

Para grass prefers to grow in wet and warm areas where annual rainfall exceeds 1,000 mm and the mean temperature is 25^{0}C (Duke 1983). It prefers soil with a pH of 5.5–7.0, but soil type does not appear to matter as it can thrive on any soil type where soil moisture is consistently high (Cameron and Kelly 1970). It requires frost-free days for growth (USDA-NRCS 2010) and cannot grow at temperatures lower than 8^{0}C (Wheeler 1950). Although frost events result in para grass defoliation and dieback, regrowth is common (Cameron and Kelly 1970).

Para grass is able to survive in a wide range of environmental conditions including short periods of drought, shade, fire, brackish water and water inundation of up to 2 m (Holm et al. 1977). In Vietnam, Binh (1998) found a positive relationship between para grass growth and flooding, with green biomass production ranging from 53.5 t/ha/yr in well drained soil to 97.8 t/ha/yr in waterlogged conditions. According to Holm et al. (1977), as well as our personal observations, it is able to form a stolon mat in water depth of up to 1 m.

Special anatomical, morphological and physiological characteristics of para grass allow for growth under flooded conditions. The presence of aerenchyma in the root cortex (Baruch and Merida 1995), formation of adventitious roots (Baruch 1994, Mattos et al. 2005) and hollow stolons are important features of para grass that aid in maintaining growth under flooded conditions. The formation of aerenchyma and adventitious roots enhances the diffusion of atmospheric oxygen, thereby maintaining root aerobic respiration as well as water and nutrient absorption (Baruch 1994). According to Ram (2000), the increased activities of alcohol dehydrogenase and malate dehydrogenase play a central role in metabolic adaptation to flood stress; ethanol fermentation is the main source for energy production under flooded conditions in para grass.

Sexena et al. (1996) reported that para grass can tolerate shady conditions; produced higher biomass under shaded conditions with high soil moisture as compared to open areas with low soil moisture. Para grass can tolerate fire; re-growth typically begins within 2 weeks after burning (Stone 2010, personal observations) and the sward has the ability to re-grow to pre-fire levels within 3 to 6 months (Stone 2010). Para grass has also been reported to tolerate sodic soil conditions (Kumar and Abrol 1982) and irrigated saline water (Maliwal et al. 1999). For example, five years of continuous saline water irrigation resulted in para grass biomass of approximately 13,000 kg/ha/yr (Maliwal et al. 1999).

The root system of para grass (Guenni et al. 2002) is known for its drought tolerance and adaptation to flooding (Baruch 1994). Para grass is also able to withstand short periods of drought due to an efficient root system (Guenni et al. 2002), stomatal closing at relatively high leaf water potential and early leaf senescence (Guenni et al. 2004). The ability of para grass to grow under various conditions is likely the reason for its invasion in various ecosystems.

Benefits of Para Grass

Although para grass is considered a problematic weed, it can be beneficial in certain environments. It is an effective means for reducing the nitrate content in ground water by irrigating with secondary treated domestic sewage effluent (Handley and Ekern 1981). Approximately 79% of effluent nitrogen was removed by para grass resulting in excellent forage quality consisting of 13% protein content and caloric value of 4,000 Kcal/kg (Handley and Ekern 1981).

Para grass is allelopathic and the toxic compounds (phenolics and unidentified ninhydrin positive) inhibit the germination and growth of other plants (Chang- Hung 1977). Mehta and Sharma (1975) reported that para grass is a suitable choice to displace *Typha* species and production for fodder in drainage ditches and waterlogged areas where unobstructed flow is required only during the rainy season. They found that planting para grass after cutting *Typha* plants resulted in displacement of *Typha* plants within one year.

Para grass was likely introduced from Africa to most of the tropical and subtropical regions of the world as a valuable forage grass (Parsons 1972) and possibly erosion control (Bunn et al. 1998). It is cultivated as a forage grass in several parts of world including: Australia, Brazil, Columbia, Cuba, Fiji, Guatemala, Hawaii, India, Philippines, Puerto Rico, Thailand, and Vietnam. Several para grass cultivars have been developed: ‘TARS’ in Australia, ‘Sao Palo’ in Brazil, and ‘Medellin’ in Columbia (Duke 1983). Para grass has been established for use as ponded-pasture in Central Queensland, Australia (Kibbler and Bahnisch 1999). Ponded-pasture involves collecting water during the wet season and water evaporates during the dry season; allowing cattle progressive access to higher quality pasture. One animal per 1.5-2 ha is recommended as a safe stocking rate for para grass pasture (Cameron and Lemcke 2008). However, it can withstand heavy grazing when soil moisture is high (Cameron and Lemcke 2008). It is also used for making green silage and hay (Duke 1983).

These advantages rarely outweigh the disadvantages associated with para grass in natural ecosystems. Para grass that has been planted for pasture spreads into non-target areas; chokes streams, displaces native vegetation and destroys waterfowl habitats. Therefore, an effective management program for para grass control must be determined.

Justification

Invasive species are defined as "a species that is non-native to the ecosystem that causes, or is likely to cause, economic or environmental harm or harm to human health" (National Invasive Species Management Plan 2006). Approximately 5,000 plant species have escaped and now exist in natural ecosystems in the United States, compared with a total of nearly 17,000 species of native plants (Morse et al. 1995). These invasive species have been identified as one of the major threats to ecosystem function and biodiversity through competition, suppression and displacement of native species (Wilcove et al. 1998). Approximately, 42% of the animals and plants that are listed as threatened or endangered under the Endangered Species Act are at risk primarily because of competition with invasive species (Wilcove et al. 1998). Invasive species cost the U. S. economy $120 billion annually in lost production, control costs, and environmental damage (Pimentel et al. 2004).

Many human activities, such as agriculture, aquaculture, recreation and transport promote both the intentional and accidental spread of invasive species across their natural dispersal barriers (Kolar et al. 2001). The initial introduction of species from one continent to another has been overwhelmingly at the hands of humans. The woody vine kudzu (*Pueraria lobata* Willd) was introduced from Japan for erosion control, but currently encroaches over thousands of hectares of fields and forests every year in Southern and South-Central North America (Rossman 2001).

Habitat destruction, fragmentation and disturbance are the favorable conditions for establishment of invasive species (Michelle et al. 2004). The establishment of non-native species can easily occur by a disturbance that changes the physical and chemical structure of ecosystems (Galatowitsch et al. 1999). Invasive plants are able to out-compete native plants due to an ability to survive in areas of removed vegetation, nutrient loading, higher salinity, hydrological fluxes and/or reduced herbivory (Galatowitsch et al. 1999).

The invasion and rapid spread of exotic plant species poses a serious threat for native flora and fauna of Florida's natural areas. Wunderlin and Hansen (2007) reported 1,365 exotic plant species in Florida, out of these 71 species considered highly invasive or category I species in natural areas because they are disruptive to native plant community structure and function (FLEPPC 2009). Para grass is listed as a category I plant in central and south Florida (FLEPPC 2009) and is no longer recommended for use (IFAS Invasive Plant Working Group 2008).

Para grass is a robust and stoloniferous tropical grass that is a native of tropical Africa, was introduced as a forage into Florida in the 1870s (Austin 1978). Once established, para grass aggressively competes with other plants, is highly productive and fast growing, and exhibits allelopathic properties allowing it to form dense monotypic swards (Chang-Hung 1977). It is a wide-spread plant found around lakes, river shorelines, swamps, marshes (Richerson and Jacono 2003), low lying un-grazed pasture land, and in sugarcane fields. In Florida, para grass is abundant and often reported to dominate other plant species in wetland areas of seasonally inundated floodplain forests along the Little Manatee River in south-central Florida, Lake Okeechobee, and Everglades National Parks (Stone 2010). In these wetlands, it grows along the water surface and creates monotypic swards that reduce plant diversity.

Wetlands have always played a major role in Florida's ecology and economy. Agricultural production in the 1900s resulted in drainage of many watersheds within Florida, reducing wetland wildlife habitat in many areas. One wetland ecosystem, the T. M. Goodwin Waterfowl Management Area (WMA), also known as the C-54 Retention Area, is a 1,570 ha fresh water restoration project, which began in 1988. Beginning in 1950s, this floodplain marsh area was diked and drained, and later managed for agricultural purposes, primarily citrus, sod and cattle production (FWC 2004). Improved pastures of flood tolerant grass species like torpedo grass (*Panicum repens*), limpograss (*Hemarthria altissima*), West Indian marsh grass (*Hymenachne amplexicaulis*) and para grass were used for cattle production. Ranchers preferred these grasses because the area was subjected to frequent flooding during the rainy season.

Destruction of valuable wetlands, increased flood peaks, degraded water quality, diverted excessive quantities of fresh water to Indian River Lagoon, and decreased water supplies were the main problems that had emerged due to the drainage of wetlands for agricultural purposes (Champbell et al. 1984). In 1988, the land was purchased by the St. Johns River Water Management District and the property was leased to the Florida Fish and Wildlife Conservation Commission (FWC) for the purpose of establishing a waterfowl management area. Currently, the primary objectives of this land are to provide storm water retention to reduce freshwater discharge into the Indian River Lagoon and reduce flood hazards. Secondary objectives of this area are to restore and enhance wetland habitat for wintering, migrating and resident waterfowl, and provide public recreation area.

In restoration efforts, ten 61 ha impoundments were established on the south end of the T. M. Goodwin WMA; on the north end, 607 ha is used to store water for managing the impoundments. Manipulation of water level within each of these impoundments is the primary management tool to restore native wetland plant communities. Other wetland management techniques include mechanical manipulation (i.e., disking and roller chopping), prescribed burning and herbicide applications.

Dabbling ducks, diving ducks, geese and swans are generalist waterfowl that are present in T. M. Goodwin WMA. Waterfowl alter their diet and habitat according to the migratory cycle of birds and seasonal habitat. They consume more invertebrates during nesting, migration, and molting to maintain the high requirement of protein and fat stores required for healthy body condition. During the winter months waterfowl need fodder that are high in carbohydrates such as seeds, tubers, and rhizomes to meet their high energy requirement. Therefore, diverse plant communities play an important role in waterfowl health directly by consumption of aquatic plants and indirectly by hosting the invertebrates needed to subsidize waterfowl migration, nesting and molting.

Recent observations in T. M. Goodwin WMA, however, revealed that approximately 60-70% of the impoundments are infested with para grass (S. Rockwood, personal communication). The spread of para grass in the T. M. Goodwin WMA may have been favored by water manipulation and other wetland management techniques such as disking and roller chopping. Large infestations of para grass in T. M. Goodwin WMA are reducing the habitat complexity that is required to support diverse invertebrate communities and suitable feeding areas for waterfowl (Rockwood 2000). In addition to T. M. Goodwin WMA, para grass is present in 53% of 448 Florida’s public water bodies surveyed in 2005, covering approximately 500,000 hectares of fresh water (Bureau of Invasive Plant Management 2005).

Therefore, para grass is a highly invasive non-indigenous pest in wetland ecosystems. Control of para grass through an environment friendly integrated approach will increase wildlife habitat as well as the value of tourist attractions in Florida. Therefore, this research was needed to understand the management practices to suppress para grass growth and invasion in wetland ecosystems.

Taxon: *Urochloa mutica* (Forssk.) T.Q. Nguyen

Kingdom: *Plantae* - plants

Subkingdom: *Tracheobionta* – vascular plants

Superdivision: *Spermatophyta* – seed plants

Division: *Magnoliophyta* – angiosperms, flowering plants

Class: *Liliopsida* – Monocotyledons

Subclass: *Commelinidae*

Order: *Cyperales*

Family: *Poaceae* – Grass family

Genus: *Urochloa* P. Beauv. – signalgrass

Species: *Urochloa mutica* (Forsk.) T.Q. Nguyen – para grass

Synonyms to Urochloa mutica: *Brachiaria mutica* (Forsk.) Stapf, *Brachiaria purpurescens* (Raddi) Hern., *Panicum muticum* (Forsk.), *Panicum barbinode* Trin., *Panicum purpurescens* Raddi

Other common names: buffalo grass, dutch grass, california grass, carib grass, scotch grass and watergrass.

Figure 1-1. Botanical classifications of Para grass (USDA-NRCS 2010).

CHAPTER 2
GREENHOUSE AND FIELD EVALUATION OF POTENTIAL HERBICIDES FOR PARA GRASS CONTROL

Para grass (*Urochloa mutica*) is a C4 perennial grass native to Africa, and was introduced to the U.S. through Brazil (Hitchcock and Chase 1951). It was introduced into Florida in the 1870s (Austin 1978) and was later recommended as forage by the Florida Agricultural Experiment Station in 1910 (Mislevy and Quesenberry 1999). Para grass was later used in World War II as camouflage around military installations in south Florida (Austin 1978). It can be distinguished from other grass species by the presence of swollen nodes with dense hairs and a ligule consisting of a row of short, stiff hairs. Seed production of para grass is prolific (>10,000 seed per square meter), but seed viability is poor (Wesley-Smith 1973). Therefore, spread and invasion of para grass can be attributed to its stoloniferous growth habit (Langeland and Burks 1999).

While once widely distributed as a forage grass in most tropical and sub-tropical areas, para grass is now considered a serious weed world-wide (Parsons 1972). It is reported as an agricultural pest in 23 crops in 34 countries, including the United States (Holm et al. 1977). In as early as 1921, it was postulated that para grass could be problematic in areas that remain wet (Briggs 1921). In fact, para grass prefers sites that are wet nearly year-round and can survive in standing water; invasion is common along the edges of canals, streams, creeks, rivers, and other wetland ecosystems (Masterson 2007).

Wetlands are defined as shallow-water ecosystems, providing functions such as productivity, biodiversity support, nutrient cycling and floodwater storage (Zedler 2000). These ecosystems provide diverse habitat for waterfowl, providing a forage base, breeding /nesting habitat, cover from predators and habitat for social interactions

(Murkin et al. 1997). In Florida, T. M. Goodwin Waterfowl Management Area (WMA) is a prime example of restoration efforts to promote wildlife habitat. Since acquisition of over 1,570 ha beginning in 1988, land managers have successfully restored the property for waterfowl and other wildlife habitat (FWC 2004). In restoration efforts, ten 61 ha wetland impoundments were established on the south end of the T. M. Goodwin WMA to provide waterfowl habitat (FWC 2004).

Vegetation management at T. M. Goodwin WMA is accomplished through various techniques. Manipulation of water level within each impoundment is the primary management tool to restore native wetland plant communities. In addition, mechanical manipulation (i.e. disking and roller chopping), prescribed burning, mowing and herbicide applications are also utilized for vegetation management (FWC 2004). However, management techniques such as disking, roller chopping and water level manipulation may have increased the spread of para grass in the T. M. Goodwin WMA. Currently, it is estimated that approximately 60-70% of the impoundments are infested with para grass (S. Rockwood, personal communication).

Information concerning para grass control is somewhat limited. Three applications of asulam (3.22, 3.22, and 2.15 kg/ha), and two applications of dalapon + TCA (6.45 + 3.65 kg/ha and 3.22 + 1.8 kg/ha), at monthly intervals provided 80% and 90% control of para grass, respectively (Whitney et al. 1973). High rates of simazine and monuron (up to 21.5 kg/ha active ingredient) provided 100% control of para grass three months after application (Van Riji 1963). Two applications of 4 kg/ha of dalapon applied in one week intervals provided effective control of para grass in citrus orchards, but this rate resulted in undesirable injury to citrus trees (Kretchman 1961). However, these herbicides are either no longer registered or are not registered for aquatic sites.

The use of non-selective herbicides may provide adequate control of para grass in semi-aquatic ecosystems. Blackburn (1974) determined that 2.2 kg/ha of glyphosate effectively controlled para grass in drainage ditches. Furthermore, Obien et al. (1973) determined that 2.0 and 4.0 kg/ha glyphosate provided 71 and 80% control, respectively, of mature (flowering stage) para grass 80 days after treatment. For immature (actively growing) para grass, almost complete stand kill was obtained with 3.0kg/ha glyphosate at 46 days after treatment. In aquatic sites, however, it is unknown if water level at the time of glyphosate application would negatively affect para grass control as in torpedo grass (*Panicum repens*) (Smith et al. 1992).

Relatively little information exists concerning the use of other herbicides for para grass control. It is possible that imazapyr, another non-selective herbicide, will provide good to excellent control of para grass, because it has been used for effective control of aquatic grass species including torpedo grass (Smith et al. 1992) and limpograss (*Hemarthria altissima*) (Sellers et al. 2007). In addition to imazapyr, some other recently registered herbicides for fluridone resistant hydrilla, such imazamox or quinclorac, may be additional options for para grass control in flooded environments. During the dry season, it may be possible to achieve acceptable levels of para grass control with graminicides such as clethodim and fluazifop.

In addition to herbicides, prescribed burning is often utilized to control weed species and to manage species diversity in natural areas (Tu et al. 2001). However, para grass can tolerate fire (Cameron and Lemcke 2008) and regrowth has been reported within 2 weeks after burning (Stone 2010). Doren et al. (1991) reported that para grass cover did not change after 5 annual prescribed fires at Everglades National Park. Para grass can adapt to a wide range of moisture conditions and grow very well in up to 1 m deep water (Holm et al. 1977). Therefore, it appears that prescribed burning or flooding have no impact on para grass control. However, there is little to no information concerning the effect of burning followed by flooding in conjunction with herbicides on para grass control.

One of the most important decisions when employing herbicides into an integrated pest management strategy for perennial grasses is herbicide application timing. Knowledge of the seasonal variation of total nonstructural carbohydrate (TNC) reserves in para grass tissues may aid in determining the proper herbicide application timing. Carbohydrate reserves are important in perennial plants for winter survival, initiation of early spring growth, and to initiate regrowth after herbage removal (White 1973). Kalmbacher et al. (1993) reported 40% higher wax myrtle mortality when triclopyr 1.12 kg/ha was applied in late summer (September) as compared to spring (March); at this time herbicide translocation towards roots may have been improved due to the movement of carbohydrates to the root tissues.

Glyphosate-based herbicides predominantly have been used to control para grass. However, little information is available with regard to glyphosate efficacy on this weed in wetland ecosystems. In addition, imazapyr and two herbicides recently registered for aquatic use, imazamox and quinclorac, have not been evaluated for para grass control. Therefore, the first objective of this research was to evaluate the efficacy of different herbicides under greenhouse conditions; the most effective herbicides were further evaluated under field conditions with different water regimes integrated with burning and flooding for para grass control. The second objective of this study was to evaluate total nonstructural carbohydrate concentration in para grass crown and stolon tissues to determine the time-frame for the most efficacious herbicide applications.

Materials and Methods

Greenhouse Studies

Experiments were conducted in April 2008 and repeated in October 2008. Para grass plants were collected from the Range Cattle Research and Education Center near Ona, Florida and transplanted into one gallon pots containing a professional potting mix. Plants were clipped to 10 cm above the soil surface after transplanting and watered daily using an automated watering system. Plants were allowed to grow under optimum conditions and treated with herbicides when they were approximately 60 cm tall.

Herbicide treatments included glyphosate at 2.2 and 3.4 kg a.e./ha, imazamox at 0.04 kg a.i./ha, imazapyr at 0.84 kg a.e./ha, imazapic at 0.21 kg a.e./ha, quinclorac at 1.1 kg a.i./ha, clethodium at 0.28 kg a.i./ha, fenoxaprop at 0.08 kg a.i./ha, fluazifop at 0.43 kg a.i./ha, and an untreated check. Herbicides were applied using a pressurized CO_2 sprayer equipped with an 11002 flat-fan nozzle calibrated to deliver a spray volume of 187 L/ha at 186 kPa. Each herbicide treatment included adjuvants as required by the herbicide label (Table 2-1). Plants were blocked based on plant size at time of application. Therefore, treatments were arranged in a randomized complete block design with four replications; each experimental unit was one pot containing one para grass plant. At 4 week after treatment, plants were harvested by clipping to 10 cm above the soil surface. Fresh-weight biomass was recorded to evaluate herbicide efficacy.

Field Studies

Field studies were conducted in 2008–09 and repeated in 2009–10, at T.M. Goodwin Waterfowl Management Area near Fellsmere, FL. In 2008–09, two impoundments that contained at least 95% cover of para grass were chosen to investigate the effect of water depth on herbicide efficacy. The impoundments were designated as “saturated” and “flooded”, and the water level in the impoundments at the time of herbicide application were up to soil saturation (no standing water present) and 40 cm (flooded), respectively. Water levels were adjusted by pumping water in and out of the impoundments. The experimental design was a split-block, with water depth (saturated vs. flooded) as the blocking factor and herbicide treatment as the sub-plot factor. In 2009–10, only one impoundment that contained approximately 95% cover of para grass growth was chosen as initial water depth had no impact on para grass control in the 2008–09 study. The experimental design in the second year was a randomized complete block.

Each year, two different studies were conducted and impoundments were divided into 24 by 360 m^2 plots for herbicide treatments:

1) Imazapyr study: The first field study included four rates of imazapyr at 0.28, 0.56, 1.12, and 1.68 kg a.i./ha and an untreated check. All treatments included a non-ionic surfactant at 0.25% v/v and were replicated four times in both years.

2) Glyphosate and imazapyr study: Treatments for the second study included imazapyr at 0.84 and 1.68 kg a.i./ha, glyphosate at 1.12, 2.24, and 3.36 kg a.i./ha, and an untreated check. All treatments included a non-ionic surfactant at 0.25% v/v. Four replications of each treatment were applied in 2008, but only three replications in 2009 due to area constraints in the impoundment.

All herbicides were applied aerially with a helicopter calibrated to deliver 93 l/ha. Herbicide treatments were applied on 10 December 2008 and 19 November 2009.

Herbicide efficacy was evaluated visually at 1 month after treatment (MAT) on a scale of 0 to 100%, with 0 equal to no control and 100 equal to complete kill.

In both years, impoundments were drained and burned in May by Florida Fish and Wildlife Conservation Commission (FWC) staff to remove dead plant tissue. In the spring of 2009, the 'flooded' impoundment was flooded immediately after burning but the 'saturated' impoundment was flooded 7 days after burning because FWC staff cannot flood two impoundments at same time. In spring of 2010, rainfall was 43 cm above than previous year and burning was not complete due to lack of total drying. Flooding was delayed for four weeks to dry the impoundment for further burning, however, rainfall continued and the impoundment was flooded at the end of the four week waiting period. Before flooding in both years, one 3 by 3 m^2 permanent quadrat was randomly placed into each plot for monitoring native plant establishment. Para grass control was visually evaluated at 2 and 8 months after burning/flooding during 2009 and one month after flooding in 2010 using the same rating scale as described previously. Due to the rapid regrowth of para grass following flooding in 2010, the plots received a second herbicide application of the same treatments on 19 August 2010. Para grass control was visually evaluated two months after re-treatment in 2010 using the same rating scale as described previously. Native plant establishment was recorded only in 2009 due to the re-treatment of plots in 2010.

Total Non-Structural Carbohydrate (TNC)

A total of eight para grass plants were collected from Ona and T.M Goodwin WMA (four plants from each) at monthly intervals for two years (January 2009 to December 2010). At each harvest, a 30 x 30 x 30 cm area was dug and soil was washed from the roots before being placed on ice for transport to the laboratory. At the laboratory, roots and the lowermost 60 cm of stolon tissues were severed from the crown. All plant parts were thoroughly washed with water to remove soil and other debris. All tissues were placed in a forced air dryer at 100^{0}C for two hours to halt enzymatic activity, and temperature was adjusted to 60^{0}C for four days. After attaining a constant weight, samples were ground and processed in laboratory according to the procedure outlined by Christiansen et al. (1981).

Statistical Analysis

Greenhouse and field data were subjected to analysis of variance using the PROC GLM procedure of SAS. Means were separated using Fisher's Protected LSD at $p < 0.05$ when appropriate. Data were checked for homogeneity of variance and normality. Plant species cover data were not statistically analyzed due to the large amount of variability among plots. TNC data of stolon and crown tissues for both locations (Ona and TMG) were combined across years after doing test for homogeneity of variance (Petersen 1994). A polynomial regression equation ($y = a+bx+cx^2+dx^3$; where y represents TNC concentration and x represents date of sampling) was utilized to determine the effect of sampling date on TNC concentration in plant tissues.

Results and Discussion

Greenhouse Studies

Fresh weight biomass data from both trials were combined after ensuring that variances were homogeneous (Petersen 1994) and no run by treatment interaction was present. At four weeks after treatment, glyphosate and imazapyr provided the highest level of para grass control compared to all other treatments (Table 2-1). Glyphosate at 3.36 kg/ha provided a 50% reduction in biomass, while imazapyr at 0.84 kg/ha and glyphosate at 2.24 kg/ha provided 44 and 33% reduction in biomass as compared to untreated, respectively. All other treatments were not different from the untreated check. These results indicate that only glyphosate and imazapyr would provide effective control of para grass under field conditions.

Field Studies

Imazapyr study. The water level by treatment interaction (P = 0.270) was not significant 1 month after treatment (MAT), therefore data were pooled across initial water levels. At 1 MAT, imazapyr provided 77-88% control at all application rates (Table 2-2). At 6 months after treatment / 2 months after burning-flooding (6 MAT / 2 MAB-F) the water level by treatment interaction (P = 0.003) was significant. All imazapyr rates plus burning-flooding combinations reduced para grass cover by 85 to 97% compared to the initial level of infestation. At this evaluation date, burning followed by flooding alone (untreated check) reduced para grass cover by at least 30 and 55% in the saturated (flooded 7 days after burning) and flooded (immediately flooded after burning) impoundments, respectively; this reduction was significantly lower than para grass treated with all rates of imazapyr. At 12 MAT / 8 MAB-F the water level by treatment interaction (0.400) was not significant and herbicide treatment was pooled across water levels. Para grass was reduced by at least 91% in all treatments including the untreated check regardless of initial water level and flood timing (Table 2-2).

In 2009–10, para grass control ranged from 67 to 81% and was similar among application rates 1 MAT (Table 2-3). At 7 month after treatment / 2 month after burning / 1 month after flooding (7 MAT / 2 MAB /1 MAF), para grass control was highly variable within and among imazapyr rates. Re-treatment resulted in at least 91% control when imazapyr was applied at rates equal to or greater than 0.56 kg/ha 2 MAT.

Glyphosate and imazapyr study. The water level by treatment interaction was significant for visual control at 1 MAT (P = 0.008) and 6 MAT / 2 MAB-F (P = 0.032). Except for imazapyr at 1.68 kg/ha, para grass control following application of all herbicides was similar 1 MAT, regardless of the initial water depth (Table 2-4). Para grass control with imazapyr at 1.68 kg/ha was 18% greater when applied under saturated as compared to flooded conditions. In the flooded impoundment para grass control was approximately 10% greater following 0.84 kg/ha imazapyr as compared to 1.68 kg/ha. At 6 MAT / 2 MAB-F, all herbicides in conjunction with burning-flooding reduced para grass cover by 87–100% compared to the initial level of infestation. However, burning followed by immediate flooding of untreated control plots resulted in at least 30% less para grass cover as compared to plots that were flooded seven days after burning. At 12 MAT / 8 MAB-F, the water level by treatment interaction (P = 0.202) was not significant and herbicide treatment was pooled across water level. There were no significant differences (P = 0.320) among treatments, and burning followed by flooding alone resulted in at least a 63% reduction in para grass cover, while all herbicide treatments reduced para grass cover by at least 82% (Table 2-4).

In 2009–10, all rates of glyphosate provided at least 95% para grass control and were at least 13% greater than that observed following treatment with imazapyr at 1 MAT (Table 2-5). Para grass control with 1.68 kg/ha imazapyr was 12% lower than that observed at 0.84 kg/ha. Similar to the 2009–10 imazapyr study, para grass control was highly variable within and across herbicide treatments 7 MAT (2 MAB / 1 MAF). Glyphosate and imazapyr provided 24–48% and 57–74% control, respectively. There were two potential reasons for this variation in control; 1) one month delay in flooding, that allowed re-growth of para grass, and 2) incomplete burning of para grass due to high soil moisture. Para grass control ranged from 82 to 95% with glyphosate and greater than 95% control with imazapyr 2 months after re-treatment.

The results of both studies from 2008–09 indicate the effect of water depth at the time of herbicide application does not affect para grass control. This indicates that the amount of para grass that was exposed to herbicide spray was sufficient in both studies. Water depth at the time of application was of concern because torpedo grass control with glyphosate (0.28, 0.56, and 1.12 kg/ha) increased as tissue exposure increased (Smith et al. 1999).

The other documented research on para grass control in semi-aquatic ecosystems by Blackburn (1974), evaluated glyphosate, dalapon, and asulox under field conditions. At 4 WAT, at least 84% control was observed with 1.12 kg/ha and higher rates of glyphosate. Our study supported the above findings as we observed at least 90% control from 1.12 kg/ha glyphosate at 4 WAT.

During 2008–09, in the imazapyr and glyphosate study, 0.84 kg/ha imazapyr provided higher control as compared to 1.68 kg/ha imazapyr in flooded impoundment and there was no significant difference between these two rates in saturated impoundment at 1 MAT. Conversely, in 2009–10, higher control was observed from 0.84 versus 1.68 kg/ha imazapyr at 1 MAT under saturated conditions. The reason for the difference in para grass control among saturated versus flooded impoundments is not clear. However, the rate of plant death with this herbicide family is typically slow and it generally takes several weeks to kill the plant (Cox 1996, Tu et al. 2001). Initially, para grass control was to be visually assessed 8 WAT; however, injury from frost precluded recording these data. It is possible that the differences we observed 4 WAT would not have been evident 8 WAT.

These data indicate that glyphosate and imazapyr are viable options for para grass control in wetland ecosystems. However, herbicides may play a critical role to ensure desiccation of the grass. For example, if a significant frost does not occur in a timely fashion to ensure a proper burn, the inclusion of herbicides (0.85 kg/ha imazapyr or 1.1 kg/ha glyphosate) can greatly enhance the likelihood of a complete burn. Additionally, regrowth from burning alone has been shown to occur within 2 weeks (Cameron and Lemcke 2008; Stone 2010). If these conditions are expected or if flooding must be delayed due to logistical complications, using herbicide on para grass regrowth may provide a longer timeframe for flooding. Spot treatments will likely be needed to prevent escapes and total re-infestation of initially highly infested areas.

Native plant establishment. Reestablishment of plant species was observed in 2008–09 at the same time of visual control assessments following burning and flooding of the impoundments (data not shown). Alligator weed (Alternanthera philoxeroides), cattail (Typha latifolia), pickerel weed (Pontederia cordata), pennywort (Hydrocotyle spp.), southern water grass (Hydrochloa caroliniensis), spatter-dock (Nuphar lutea), Sagittaria spp., southern naiad (Najas guadalupensis) and spike rush (Eleocharis spp.) were the predominant species present in most of the plots in both impoundments. Minor plant species included muskgrass (Chara spp.), Egyptian paspalidium (Paspalidium geminatum), para grass, sedge (Cyperus spp.), Sesbania spp., smartweed (Polygonum spp.), and waterlilly (Nymphaea spp.).

Burning the top growth of dead para grass allowed light to reach the soil surface, which is needed for germination of desirable plant species. Plant diversity (data not shown) was greater in the saturated impoundment (flooded 7 days after burning) as compared to flooded impoundment (flooded immediately after burning). One reason behind this may be that delayed flooding provided sufficient time for seed germination of plant species. Plant diversity and the number of a given species were expected to be substantially lower in the imazapyr treated plots; however, both plant diversity and numbers were not different among herbicide treatments (data not shown). The possible reason is that the half-life of imazapyr is 2 to 3 days in water (Mallipudi et al. 1991) and glyphosate has no soil activity; it is likely that the flooding after burning reduced the effect of imazapyr on native plant establishment.

Total Non-Structural Carbohydrate (TNC)

Date of sampling had a cubic effect on TNC concentration in para grass stolon and crown tissues at both locations (Figure 2-1 and 2-2). In both stolon and crown tissues, TNC concentration were lowest between February and April after which TNC increased to a maximum between July and September at both locations. TNC concentration began to decline from October to December at both locations in both plant tissues (Figure 2-1 and 2-2). This pattern of carbohydrate assimilation is dissimilar to many other perennial weed species. For example, TNC concentration in wax myrtle (Kalmbacher et al. 1993) and saw palmetto (Kalmbacher et al. 1983) were lowest in August.

The carbohydrate level in para grass stolon and crown tissues were lower during spring due to the dormant period of plant growth. During this period para grass growth ceases due to the frost and it is possible that stolon tissues began to degrade following a frost event; therefore, stolon TNC concentration would continue to decrease. When re-growth resumes in March and April, TNC concentration continued to decrease in crown tissues because the plant was relying on carbohydrate reserves to initiate plant growth during the spring. McIlvanie (1942) also reported a decline in carbohydrate reserves during the dormant season in bluebunch wheatgrass (*Agropyron spicatum*). Liyanage (1982) reported that stored carbohydrate reserves in para grass stem cuttings provide energy only during initial stage of sprouting of shoots and roots; the major portion of dry matter for new growth is provided by the photosynthate assimilation in the newly formed shoots. Carbohydrate reserves accumulate rapidly in para grass tissues as active plant growth continues throughout the rainy season (June through September). The decline in TNC concentration in the fall was likely related to flowering and seed setting of para grass. This trend in TNC concentration was also evident in sand blackberry (*Rubus cuneifolius*) and bluebunch wheatgrass during flowering (McIlvanie 1942 and Kalmbacher and Eger 1994).

The TNC concentrations were different at each location during the same month for stolon and crown tissues. The seasonal variation of carbohydrate reserves can differ for the same species grown in different environments (White 1973). Temperature, availability of water and nutrients are the main factors affecting the seasonal variation of carbohydrate reserves (White 1973). During this study, para grass samples were collected from areas with no standing water most of year except during the rainy season in Ona, while samples were collected from soil-saturated conditions almost year-round in Fellsmere. This could be the possible reason for variation in carbohydrate concentration in same plant part at different locations.

These results show that para grass may be more susceptible to herbicide applications in early summer (early May to June) when carbohydrates begin accumulating in stolon and crown tissues. Herbicide applications during the early summer may potentially result in increased translocation of herbicides to reproductive plant tissues, ultimately resulting in enhanced para grass control. The results of the field studies were obtained from single application date (late fall). However, the effect of these herbicides on para grass control may differ with regards to application timing. Therefore, the effect of glyphosate and imazapyr application timing on para grass control needs to be evaluated.

Table 2-1. Para grass control in the greenhouse with post-emergent herbicides at 4 WAT.[a]

Treatment				Fresh Weight
Herbicides	Rate (kg a.i./ha)	Adjuvant	Rate	g
Untreated	0.00	–	–	117
Fenoxaprop	0.09	Non-ionic surfactant	1.16 l/ha	140
Imazamox	0.04	Methylated seed oil	2.33 l/ha	128
Clethodim	0.31	Crop oil concentrate	1.00%v/v	113
Quinclorac	1.12	Methylated seed oil	1.75 l/ha	100
Fluazifop	0.48	Non-ionic surfactant	0.25%v/v	97
Imazapic	0.21	Non-ionic surfactant	0.25%v/v	91
Glyphosate	2.24	Non-ionic surfactant	0.25%v/v	78
Imazapyr	0.84	Non-ionic surfactant	0.50%v/v	66
Glyphosate	3.36	Non-ionic surfactant	0.25%v/v	59
LSD (0.05)				29

[a]Abbreviation: WAT, weeks after treatment.

Table 2-2. Percent control (visual ratings) of para grass from saturated and flooded (40 cm water level) impoundments after imazapyr treatments at T. M. Goodwin Waterfowl Management Area in 2008–09.

		Visual Control[a]			
		1 MAT[b,c,d]	6 MAT[e] (2 MAB-F)		12 MAT[c,e] (8 MAB-F)
Treatment	Rate		Saturated	Flooded	
	kg a.i./ha	---------------------------------% control--------------------------			
Untreated	0.00	0	30	55	98
Imazapyr	0.28	70	85	92	98
Imazapyr	0.56	77	95	94	91
Imazapyr	1.12	85	90	99	92
Imazapyr	1.68	88	95	97	94
LSD1 (0.05)[f]		8	18		NS
LSD2 (0.05)		-	10		-

[a]Weed control rated on 0 to 100% scale; 0% equals no plant response and 100% equals plant death.
[b]Abbreviations: MAT, month after treatment. MAB-F, month after burning-flooding.
[c]Results pooled across saturated and flooded impoundments at 1 MAT and 12 MAT (8 MAB-F) due to no water level by treatment interaction.
[d]Non-treated control not included in statistical analysis of 1 MAT.
[e]At 6 MAT and 12 MAT, % control represent % reduction of initial para grass ground cover.
[f]LSD1 separates means within column and LSD2 separates means across column within the same treatments.

Table 2-3. Percent control (visual ratings) of para grass after imazapyr treatments at T. M. Goodwin Waterfowl Management Area in 2009–10.

		Visual Control[a]		
		1 MAT[b,c]	7 MAT[d] (2 MAB /1 MAF)	2 MART[c]
Treatment	Rate			
	kg a.i./ha	-------------------------% control	-----------------------------	
Untreated	0.00	0	0	0
Imazapyr	0.28	67	57	77
Imazapyr	0.56	81	69	91
Imazapyr	1.12	79	86	99
Imazapyr	1.68	76	92	100
LSD (0.05)		NS	29	11

[a]Weed control rated on 0 to 100% scale; 0% equals no plant response and 100% equals plant death.
[b]Abbreviations: MAT, months after treatment; MAB, months after burning; MAF, months after flooding; MART, months after re-treatment.
[c]Non-treated control not included in statistical analysis of 1 MAT and 2 MART.
[d]At 7 MAT, % control represent % reduction of initial para grass ground cover.

Table 2-4. Percent control (visual ratings) of para grass from saturated and flooded (40 cm water level) impoundments after glyphosate and imazapyr treatments at T. M. Goodwin Waterfowl Management Area in 2008–09.

		Visual Control[a]				
		1 MAT[b,c,d]		6 MAT[e] (2 MAB-F)		12 MAT[c,e] (8 MAB-F)
Treatment	Rate	Saturated	Flooded	Saturated	Flooded	
	kg a.i./ha	% control				
Untreated	0.00	0	0	67	98	63
Glyphosate	1.12	94	91	87	97	82
Glyphosate	2.24	95	93	91	100	85
Glyphosate	3.36	92	92	91	100	86
Imazapyr	0.84	87	81	95	100	88
Imazapyr	1.68	90	74	95	100	82
LSD1 (0.05)[f]		6		20		NS
LSD2 (0.05)		6		21		-

[a]Weed control rated on 0 to 100% scale; 0% equals no plant response and 100% equals plant death.
[b]Abbreviations: MAT, month after treatment. MAB-F, month after burning-flooding.
[c]Results pooled across saturated and flooded impoundments at 12 MAT (8 MAB-F) due to no water level by treatment interaction.
[d]Non-treated control not included in statistical analysis of 1 MAT.
[e]At 6 MAT and 12 MAT, % control represent % reduction of initial para grass ground cover.
[f]LSD1 separates means within column and LSD2 separates means across column within the same treatments.

Table 2-5. Percent control (visual ratings) of para grass after glyphosate and imazapyr treatments at T. M. Goodwin Waterfowl Management Area in 2009–10.

		Visual Control[a]		
		1 MAT[b,c]	7 MAT[d] (2 MAB /1 MAF)	2 MART[c]
Treatment	Rate			
	kg a.i./ha	--------------------------% control	----------------------------	
Untreated	0.00	0	0	0
Glyphosate	1.12	90	24	82
Glyphosate	2.24	95	53	93
Glyphosate	3.36	95	48	95
Imazapyr	0.84	83	57	95
Imazapyr	1.68	73	74	100
LSD (0.05)		6	42	6

[a]Weed control rated on 0 to 100% scale; 0% equals no plant response and 100% equals plant death.

[b]Abbreviations: MAT, month after treatment. MAB, month after burning. MAF, month after flooding. MART, month after re-treatment.

[c]Non-treated control not included in statistical analysis of 1 MAT and 2 MART.

[d]At 7 MAT, % control represent % reduction of initial para grass ground cover.

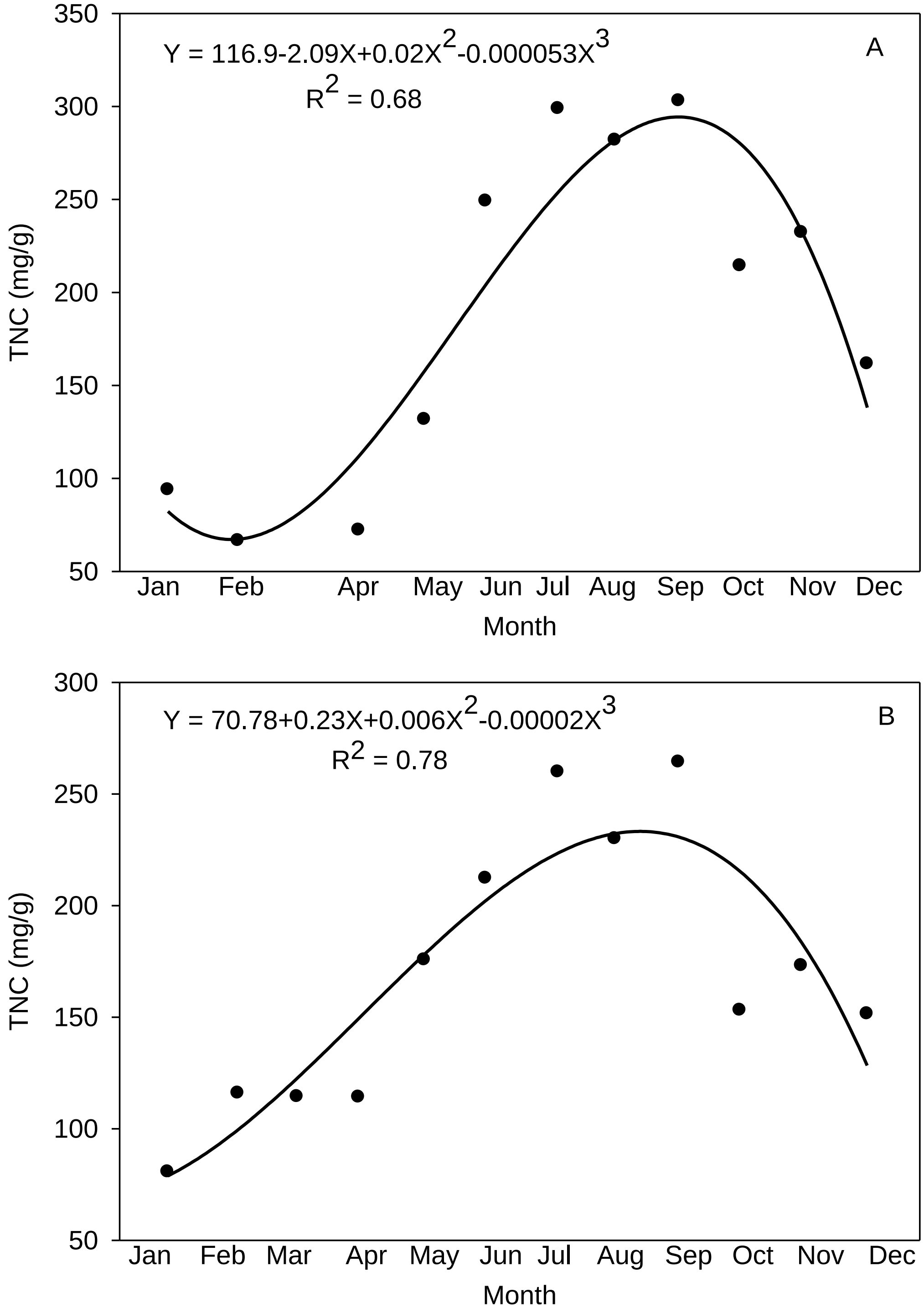

Figure 2-1. Seasonal variation in total nonstructural carbohydrate concentration (TNC) in para grass (A) stolon (B) crown tissues pooled over two years at Ona, FL.

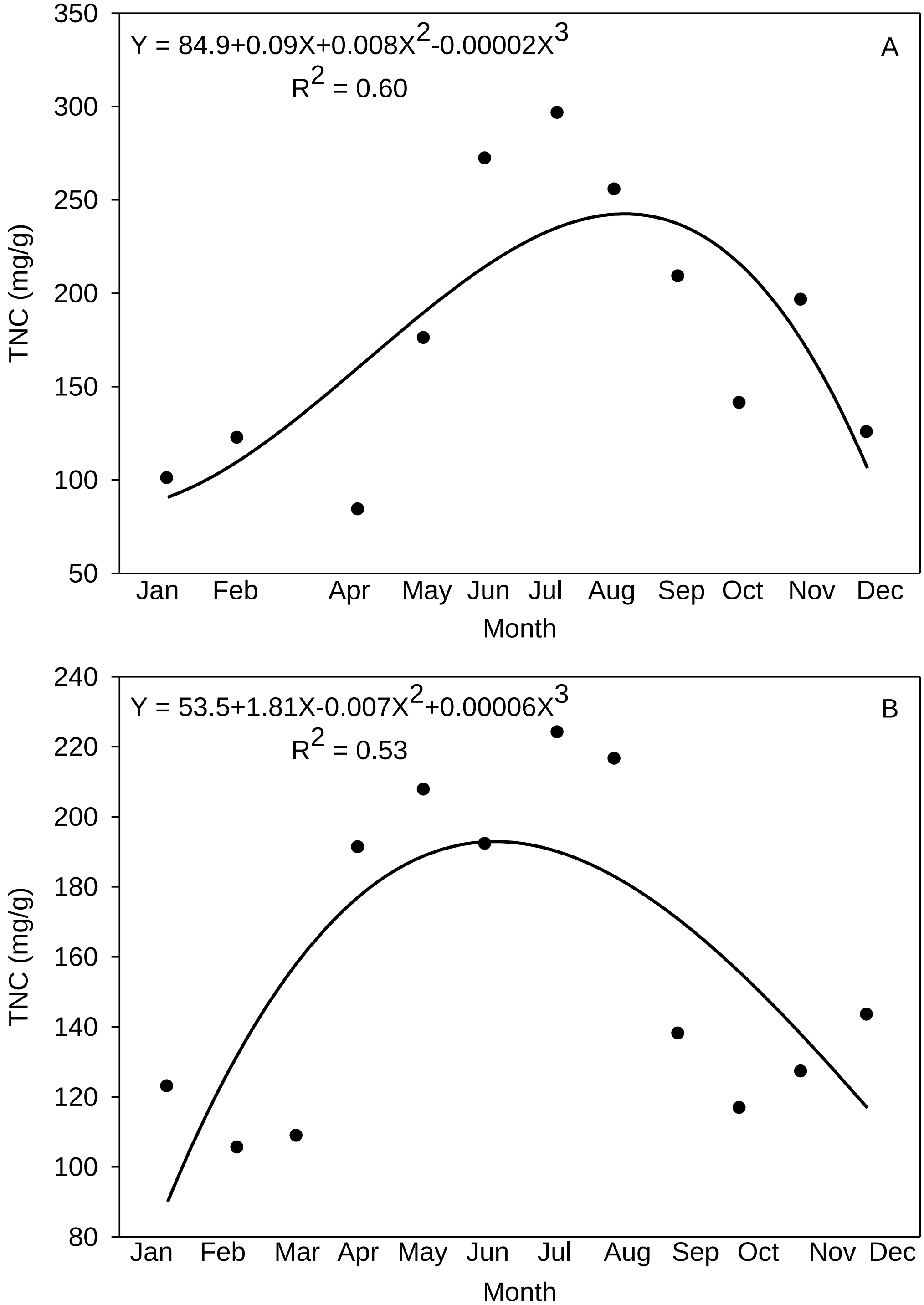

Figure 2-2. Seasonal variation in total nonstructural carbohydrate concentration (TNC) in para grass (A) stolon (B) crown tissues pooled over two years at T. M. Goodwin Waterfowl Management Area, Fellsmere, FL.

CHAPTER 3
THE EFFECT OF CULTURAL AND MECHANICAL PRACTICES ON PARA GRASS RE-GROWTH

Para grass (*Urochloa mutica*), a C4 perennial grass species native to Africa, was introduced into Florida as forage in the 1870s (Austin 1978). Although a valuable forage at one time, it is currently considered one of the worst weeds of 23 crops in 24 countries, including the United States (Holm et al. 1977). According to the IFAS Assessment of Non-Native Plants in Florida's Natural Areas (IFAS Invasive Plant Working Group 2008), para grass is invasive and not recommended for planting within Florida. Additionally, para grass is considered a category I invasive weed in central and south Florida (FLEPPC 2009) that displaces native vegetation and invades disturbed sites. In the 1990s, para grass was reported in 52% of Florida public water bodies (Schardt and Schmitz 1991).

The smothering growth habit and allelopathic activity of para grass leads to a reduction in ecosystem biodiversity (Chang-Hung 1977; Ferdinands et al. 2005). Invasion of para grass at T. M. Goodwin WMA in Florida is reducing the habitat complexity that is required to support diverse invertebrate communities and suitable feeding areas for waterfowl. Currently, it is estimated that approximately 60–70% of the impoundments are infested with para grass (S. Rockwood, personal communication). Additionally,Para grass is also a major destructive pest at Mary River Floodplain and Townsville Common in Australia, where it is displacing wild rice (*Oryza meriodionalis*) grasslands and water chestnuts (*Eleocharis dulcis*), respectively. The resulting change in vegetation has negatively impacted Magpie geese (*Anseranas semipalmata*) and brolgas (*Grus rubicunda*) (a bird in the crane family) populations (Low 1997; Ferdinands et al. 2005). One possible reason for the decrease in Magpie geese populations may be the high biomass and complex architecture of para grass which suppress the germination of wild rice seed (Wurm 2007). Therefore control of para grass in these ecosystems is important to maintain wildlife habitat and biological diversity.

Prescribed burning is one method that is used by natural area managers to control non-native and invasive plants (Langeland et al. 2009). However, para grass is relatively tolerant to fire and re-growth is commonly observed within 2 weeks after burning (Cameron and Lemcke 2008; Stone 2010). Doren et al. (1991) reported that para grass cover did not change after 5 years of annual prescribed fire at Everglades National park, Florida. Therefore, prescribed burning alone seems to have little impact on para grass control. However, burning para grass followed by flooding resulted in at least 62% control of para grass 8 months after burning and flooding (Chaudhari 2011). This indicates that burning followed by flooding may be an additional option for para grass control where herbicide use may be limited due to site limitations.

Another option that some land managers have used for para grass control is mechanical disking or roller-chopping. Roller-chopping alone has not been successful as para grass quickly produces new shoots from stolon cutting (S. Rockwood, personal communication). This is not surprising to consider that stem cuttings with 2 or 3 nodes has been used to establish para grass pastures (Duke 1983, Cameron and Lemcke 2008). However, there is limited information concerning the use of roller-chopping or disking in conjunction with flooding.

To develop a robust weed control strategy, a diverse and integrated program using herbicides and cultural or mechanical methods is essential. Control of para grass invasions can be achieved with grass-specific herbicide (Chaudhari 2011); however, despite the effectiveness of herbicide, the use of chemicals is prohibited in many systems due to environmental, economic or social concerns (Guynn et al. 2004). For example, the uses of herbicides are restricted due to the nontarget and residual effect on plants and animals, and the costs associated with large-scale application. Therefore, in this study the effect of multiple nonchemical methods are evaluated on para grass control. The objectives of this study were to examine the effect of water depth (saturated vs. flooded) after burning and cutting, and the effect of water depth and duration after simulated roller-chopping on para grass regrowth examine.

Materials and Methods

Experiment 1

Greenhouse experiments were conducted to determine the impact of burning or cutting followed by flooding on para grass stolon re-growth. The study was first conducted in the summer of 2009 and repeated during the summer of 2010. Twenty four para grass plants were randomly dug with 12 × 12 × 12 cm area of soil from the Range Cattle Research and Education Center Ona, FL. Twelve plants were cut to 10 cm stubble and twelve were burned with a propane weed burner to approximately 10 cm stubble length. Individual cut and burned para grass plants were transplanted into 4-L pots containing a professional potting mix and a 1 cm layer of sand was placed on each pot to prevent the potting mixture from floating out of the pots during the water treatment. Each pot was considered an experimental unit and the initial number of stolons was recorded from each pot. Four pots of cut and burned plants were watered daily and designated as control plants. The remaining plants were placed into 1 m diameter water troughs. Water levels were adjusted so that remaining half burn and cut plants were saturated (water level was at the soil surface) or flooded with 45 cm of water. The water levels were maintained for five weeks.

At 5 weeks after treatment, the number and length of stolons were measured and dry weights of harvested materials were recorded after samples were dried at 50^{0}C for 5 days. The experiment was conducted using a factorial (2 × 3) arrangement of plant (cut vs. burn) and water treatments (control, saturated, and flooded) in a complete randomized design with four replications of each treatment.

Experiment 2

An experiment was conducted to examine the effect of water depth, number of nodes per section and duration of water treatment on para grass stolon re-growth after simulated roller-chopping. The experiment was conducted on June 2010 and repeated in August 2010. Para grass stolons were collected from natural infestations at the Range Cattle Research and Education Center near Ona, FL. Simulated roller-chopping was performed by cutting para grass stolons into one-, two- and three- node sections and planted into 54 × 28 × 7 cm flats containing a professional potting mixture and covered with a 1 cm layer of sand to prevent the potting mixture from floating out of the flats during the water treatment. Each flat contained 9 sections of a particular node number and was considered an experimental unit. Five 2.4 m diameter water troughs were connected using 10.6 cm diameter PVC pipe in full sun. Water circulation was provided with a water pump transferring 4,319 L of water per hour. Water level was maintained up to 54 cm in each trough.

Four flats from each node section were watered daily and designated as control. One-half of the remaining flats were flooded in water troughs and the other-half was placed on tables in the water troughs to maintain soil saturation of the flats. At 3, 7, 14, 28, and 42 days after planting, 4 flats of each node section were removed from both water treatments, placed on benches and watered daily. At 8 weeks after initiating the study, the number of shoots that emerged from the stolon segments was counted and dry weights of harvested materials were recorded after samples were dried at 50^{0}C for 5 days. The experiment was conducted in a completely randomized design with an incomplete three way factorial (3 × 5 × 3) arrangement of number of nodes (one-, two-, and three-node sections), duration of water treatment (3, 7, 14, 28, and 42 days), and water level (control, saturated, and flooded) with four replications of each treatment.

Statistical Analysis

All data were subjected to analysis of variance using the PROC GLM procedure of SAS to test for treatment effects and interactions. Means were separated using Fisher's protected Least Significant Difference (LSD) at $P \leq 0.05$ when appropriate. Data were checked for homogeneity of variance and normality. All the data from first and second experiment were combined across runs after checking the homogeneity of variances (Petersen 1994). In the first experiment, stolon data were converted to the percentage of initial number of stolons prior to analysis. In the second experiment, the data were converted to the percentage of the control plants prior to analysis of variance. An exponential decay regression equation ($y = ae^{-x}$; where y represents plant biomass and x represents duration of water treatment) was utilized to determine the number of days needed to reduce para grass biomass by 90% following simulated roller-chopping and water treatments.

Results and Discussion

Experiment 1

The plant (cut vs. burn) and water treatment (control, saturated, and flooded) interaction for number of stolons ($P = 0.040$), stolon length ($P = 0.0002$) and plant biomass ($P = 0.01$) was significant. Overall, burning had a greater impact on number of stolons, stolon length and biomass, than cutting, regardless of water treatment. No re-growth was observed from plants that were burned and flooded. Burned-control plants had 40% fewer stolons than cut-control plants (Figure 3-1). There were at least 98% fewer stolons when plants were burned and subjected to flooded or saturated conditions as compared to burned-control plants. Conversely, plants that were cut and saturated had at least 92% more stolons than plants that were burned and saturated or flooded.

Stolon length for burned-control plants was approximately 78 and 100% greater than those that were burned-saturated and burned-flooded, respectively (Figure 3-2). The stolon length of cut-flooded plants was at least 20 and 70% less than cut-saturated and cut-control plants, respectively. Stolons of plants that were cut-saturated were 64% longer than burned-saturated plants.

The dry weight of cut-flooded plants was approximately 93 and 97% less than cut-saturated and cut-control plants (Figure 3.3). Dry weight of burned-control plants was at least 98% greater than burned-saturated and burned-flooded plants. Cut-saturated plants had 95% greater biomass than burned-saturated plants.

As expected, biomass of cut and burned plants did not differ when watered daily (control). In contrast, under saturated or flooded conditions, all variables of plant growth were significantly reduced from burned plants as compared to cut plants. The effect of water treatments was clearly observed from cut plants; significantly higher re-growth was obtained under saturated versus flooded conditions. The possible reason could be that the portion of cut stolons above the water level under saturated conditions was sufficient to initiate plant re-growth. Stolon and crown tissues are the primary organs for carbohydrate reserves (Chaudhari 2011). There may have been sufficient carbohydrate reserves in the crown to initiate plant re-growth under saturated conditions. Additionally, the amount of stolons above the water surface in saturated conditions may have allowed sufficient oxygen diffusion to the roots. Furthermore, cut plants in flooded, and burned plants in both saturated and flooded condition had no significant difference in re-growth, suggesting that oxygen diffusion through stolon tissues may be necessary for plant re-growth. Hossain et al. (2002) reported that shoot removal before water inundation was effective in reducing torpedo grass re-growth.

Flooding in our study system played a key role in the magnitude of para grass tolerance after burning or cutting. The primary stress induced by flooding is reduced oxygen availability in the soil solution. Under normal growing conditions, para grass adapts to anoxic environments by altering its metabolism (Ram 2000) and root anatomy (Baruch and Merida 1995). The presence of aerenchyma enhances oxygen diffusion to the roots and the development of adventitious rootlets promotes water and nutrient absorption. Metabolic adaptation, such as induction of alcoholic fermentation occurs in roots for energy production. Anaerobic fermentation is very inefficient as compared to aerobic respiration and produces only 5% of the ATP generated by aerobic respiration (Summers 2000). However, under favorable conditions para grass stolons grow above the water surface and produce enough energy to support aerobic respiration of roots.

In this experiment, burning and cutting removed all green tissue, including stolons. Creating an anaerobic environment through flooding may reduce the ability of para grass to regenerate without energy reserves. This is potentially the reason for excellent control of para grass with cutting or burning followed by flooding. Similar results were also observed under field conditions where 62% para grass control was obtained from burning followed by flooding at 8 month after burning-flooding (Chaudhari 2011).

Experiment 2

The water level by duration of water treatment interaction was significant (P = 0.015) for stolon biomass. In both flooded and saturated conditions biomass exponentially decreased as the duration of either water treatment increased (Figure 3-4). The biomass of stolons subjected to flooded conditions was 42, 40, and 82% lower than stolons that were subjected to saturated conditions at 3, 7, and 14 days after water treatment (DAWT), respectively. However, the water level had no impact on stolon biomass at 28 and 42 DAWT as biomass was similar between the two water treatments. Results from the regression analysis revealed that in order to reduce para grass biomass by 90%, at least 17 days of flooded or 29 days of saturated conditions were required (Figure 3-4).

The main effects of water level (P = <0.001), number of nodes per section (P = 0.003) and duration of water treatment (P = <0.0001) were significant for biomass. Flooded stolons produced 50% less biomass than saturated stolons (Figure 3-5A). Biomass production from one-node sections was 37 and 51% lower than two- and three-node sections, respectively (Figure 3-6A). As duration of water treatment increased, biomass decreased and highest biomass was produced 3 or 7 days after water treatment (Figure 3-7A). A significant (at least 63%) amount of biomass reduction was observed after 14 days of water treatment as compared to 3 or 7 days. The duration of 28 or 42 days of water treatment was more effective and stolon biomass production was at least 88% lower as compared to those subjected to water treatments for 14 days.

The effects of water level ($P = 0.0007$), number of nodes per section ($P = 0.003$) and duration of water treatment ($P = <0.0001$) were significant for the number of stolons produced. The number of stolons was 29% higher in saturated as compared to flooded conditions (Figure 3-5B). The number of stolon from one-node sections was 30 and 35% lower than two- and three-node sections, respectively (Figure 3-6B). The number of stolons produced was at least 63% less at 14 DAWT as compared to 3 or 7 DAWT. Increasing the duration of water treatment to 28 or 42 days resulted in at least 82% fewer stolons as compared to 14 days (Figure 3-7B).

Results from this study indicate that water treatment is necessary to reduce para grass re-growth after roller-chopping. Flooding is one method of controlling propagules of perennial weeds (Ashton and Monaco 1991). It is probable that the life-span of para grass stolons in water is dependent on carbohydrate reserves, seasonal variations, water temperature, and water depth. The application of water after roller-chopping may help in reducing the ability of para grass stolons to produce new shoots. We observed decayed stolons from flats after water treatments; the number of decayed stolons increased as the duration of water treatment increased (data not shown). Therefore, less re-growth was obtained from stolons that were flooded or saturated for 28 or 42 days. Hossain et al. (2002) reported that removal of shoots in torpedo grass followed by

4 and 8 months of water inundation resulted in 47 and 87% decay of rhizome buds, respectively.

The number of nodes in each cutting is important factor on survival; survival decreased considerably when cuttings contained only one node as compared to two or three nodes. This might be due to increased carbohydrate reserves in three node segments as compared to one node. Large cuttings, propagules and seeds contain more food reserves that ultimately result in higher emergence (Peng 1984). Bernal (1971) also reported at least 50% higher germination from para grass cuttings that had two or three nodes as compared to one node.

In conclusion, burning, cutting and roller-chopping could be useful to control para grass if subsequent flooding is applied, in areas where wildlife is major concern. The best technique would be burning followed by flooding because of less expensive and easy to implement in wetland. However, roller-chopping followed by flooding can be an option to control para grass where burning is not possible

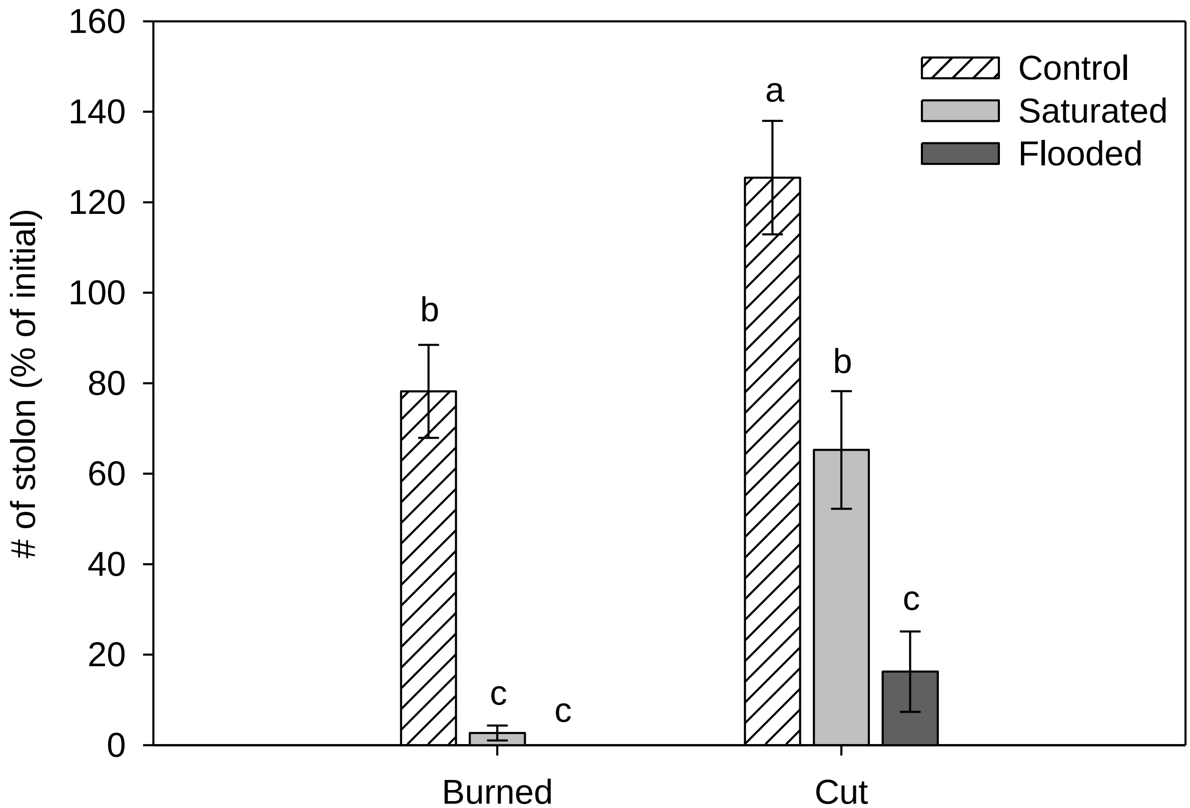

Figure 3-1. Number of para grass stolons (% of initial) 5 weeks after plant (burn vs. cut) and water treatments (control, saturated, and flooded). Treatments with same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$). Error bars represent the SE of the mean.

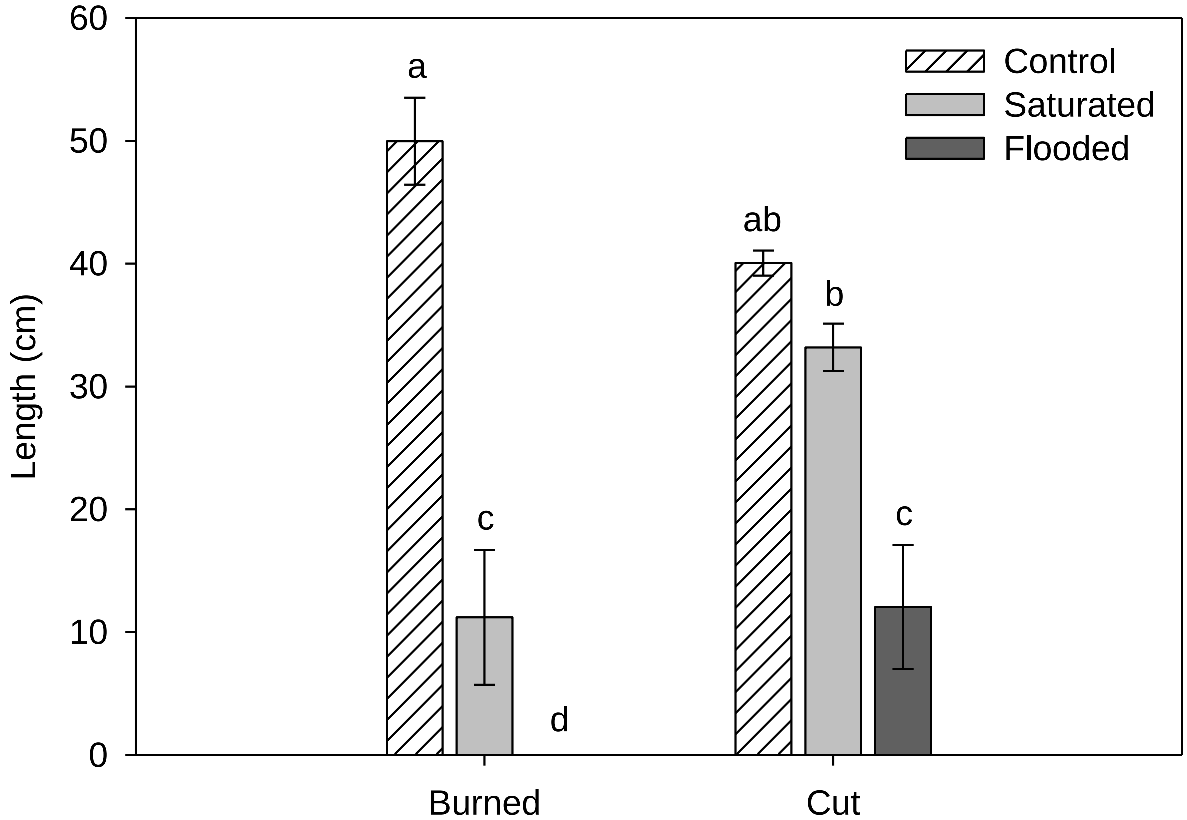

Figure 3-2. Length of para grass stolons 5 weeks after plant (burn vs. cut) and water treatments (control, saturated, and flooded). Treatments with same letter are not significantly different according to Fisher's Protected LSD (P≤0.05). Error bars represent the SE of the mean.

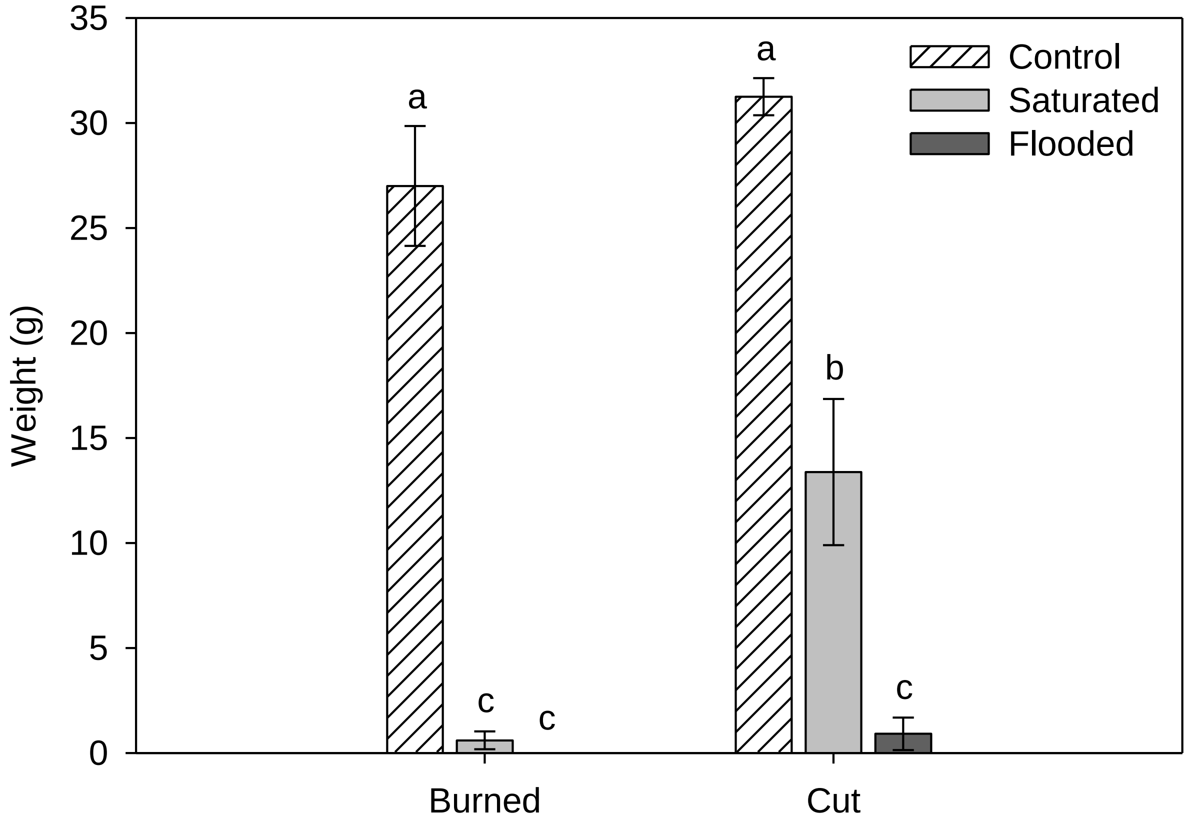

Figure 3-3. Dry weight of para grass stolons 5 weeks after plant (burn vs. cut) and water treatments (control, saturated, and flooded). Treatments with same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$). Error bars represent the SE of the mean.

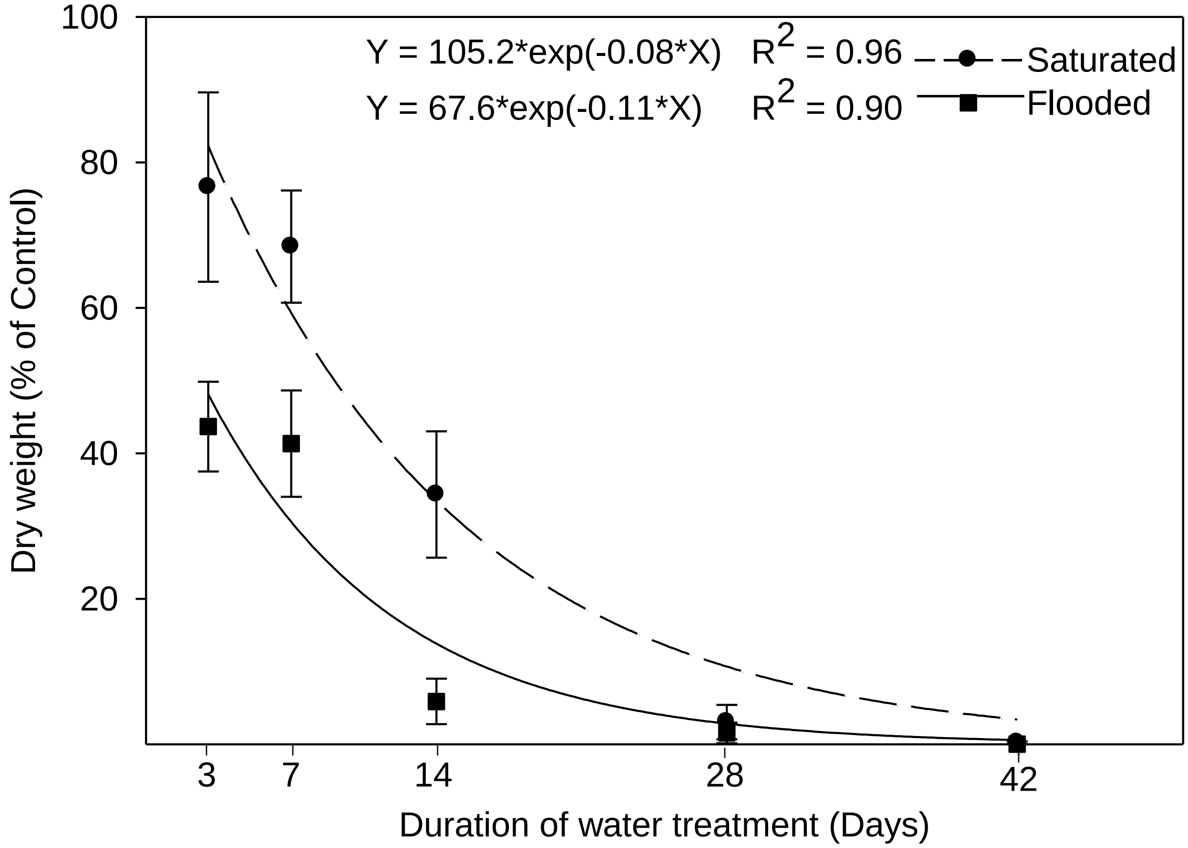

Figure 3-4. Change in para grass biomass (% of control) over time under saturated (dashed line) and flooded (solid line) conditions. Error bars represent the SE of the mean.

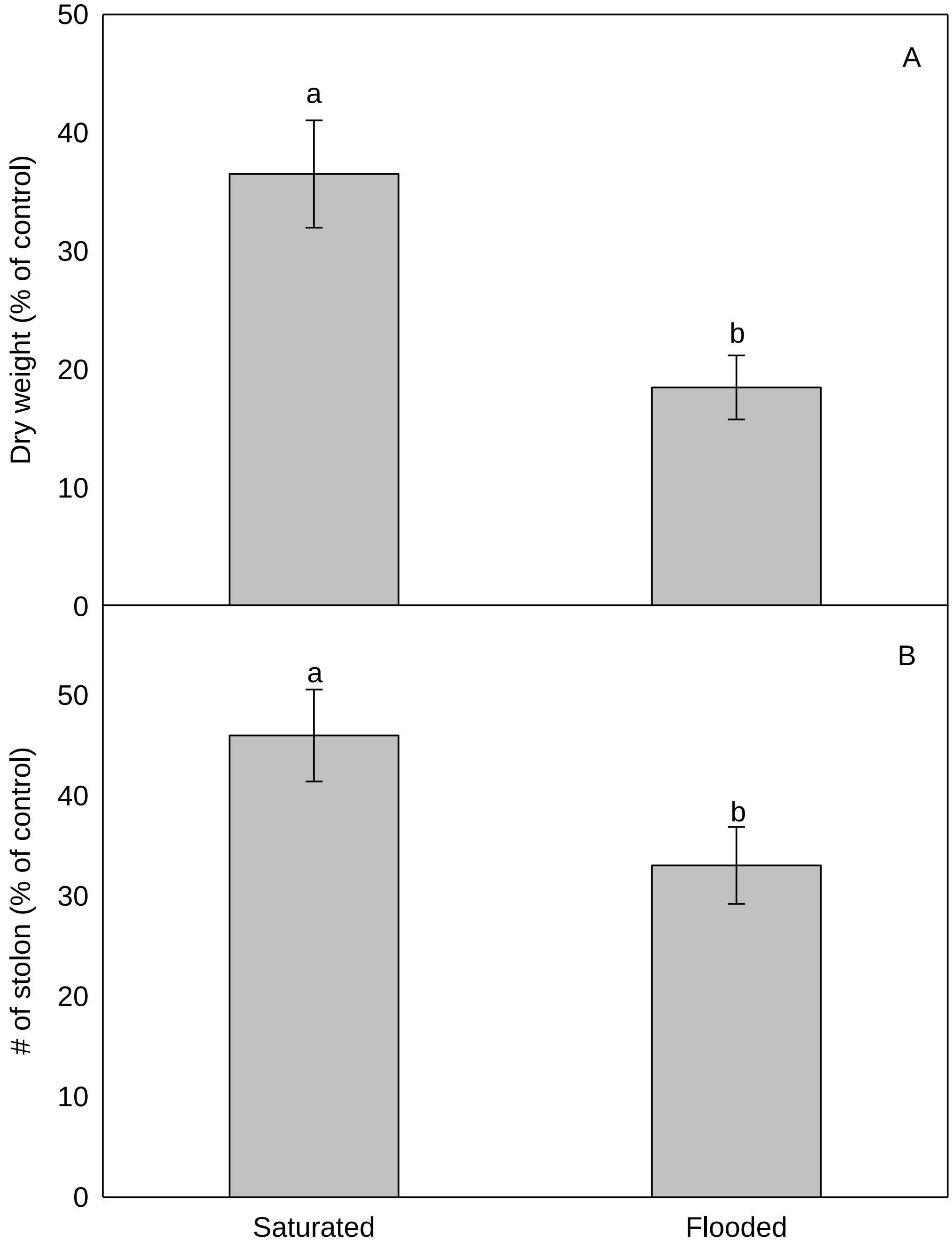

Figure 3-5. Para grass biomass (A) and number of stolons (B) in saturated and flooded conditions 8 weeks after treatment. Treatments with same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$). Error bars represent the SE of the mean.

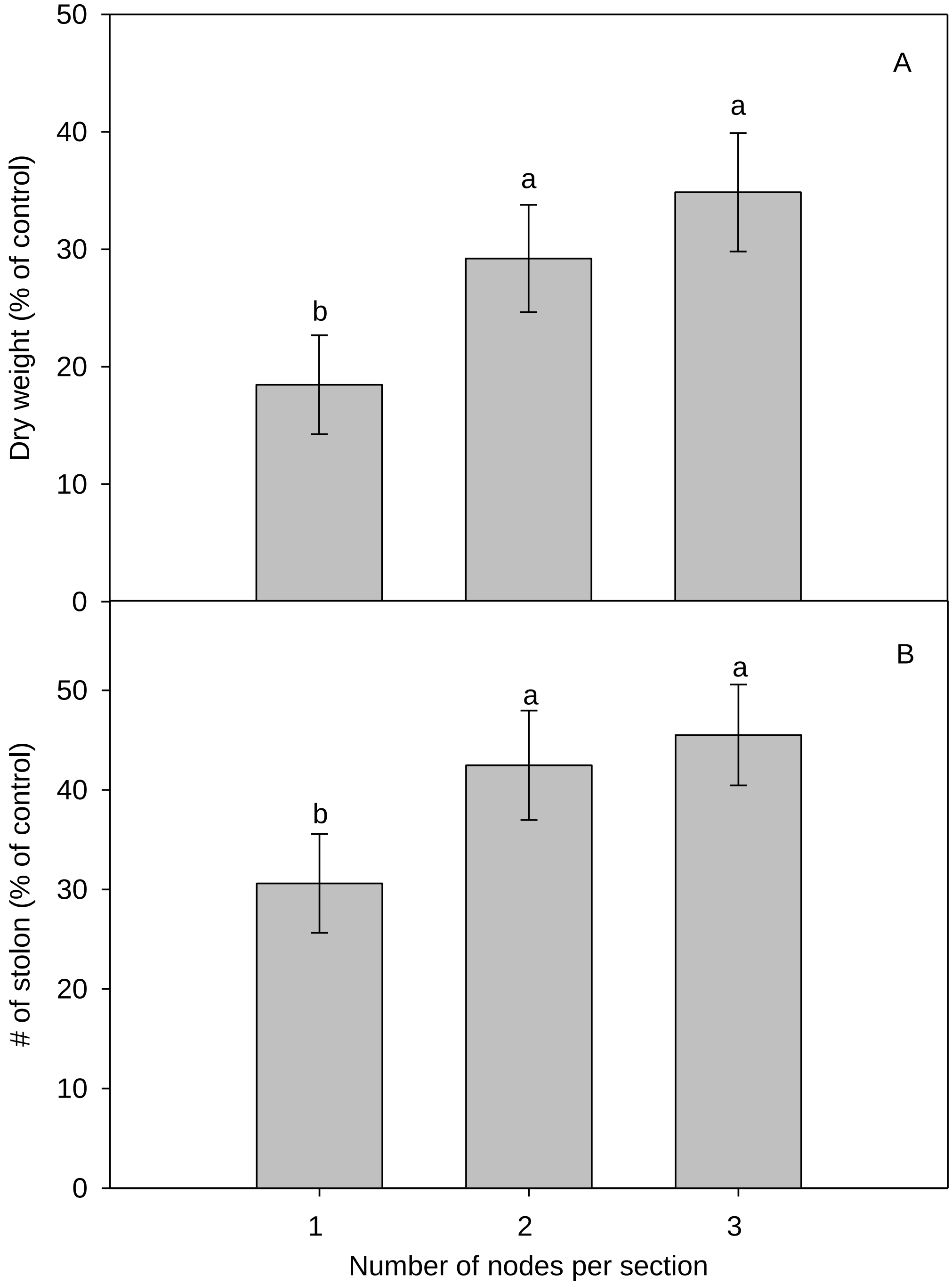

Figure 3-6. Para grass biomass (A) and number of stolons (B) from different node segments 8 weeks after treatment. Treatments with same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$). Error bars represent the SE of the mean.

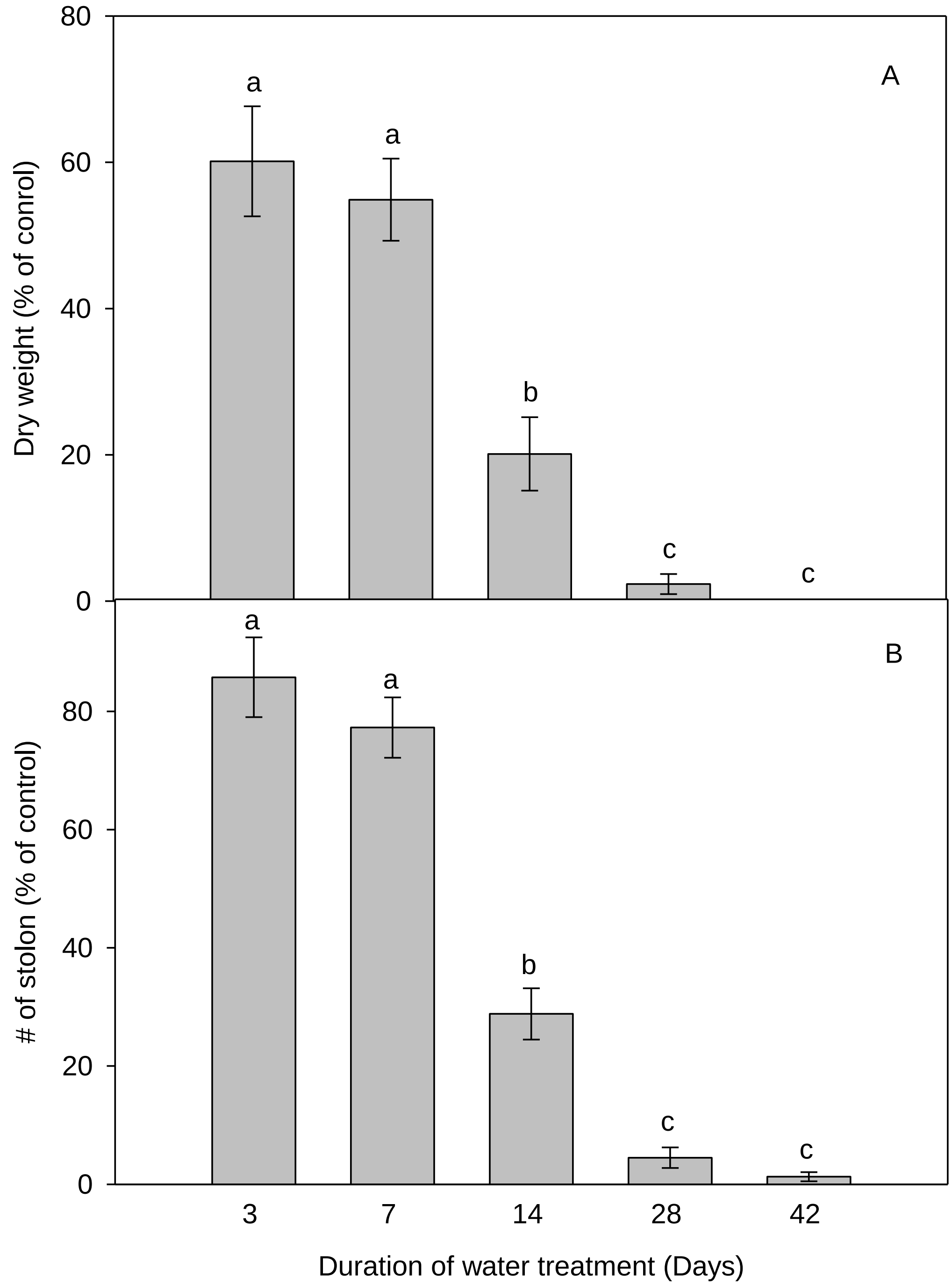

Figure 3-7. Para grass biomass (A) and number of stolons (B) when exposed to days of consecutive water treatments. Treatments with same letter are not significantly different according to Fisher's Protected LSD (P≤0.05). Error bars represent the SE of the mean.

APPENDIX
PARA GRASS BIOMASS DATA FROM BOTH FIELD STUDIES

Table A-1. Biomass (kg/ha) of para grass from saturated and flooded (40 cm water level) impoundments after imazapyr treatments at T. M. Goodwin Waterfowl Management Area in 2008–09.

		Biomass (1 MAT)[a]	
Treatment	Rate	Saturated	Flooded
	kg a.i./ha	--------------------kg/ha	------------------
Untreated	0	7199	6218
Imazapyr	0.28	5431	8190
Imazapyr	0.56	6812	7216
Imazapyr	1.12	6543	7395
Imazapyr	1.68	6207	4887
LSD1 (0.05)[b]		NS	
LSD2 (0.05)		NS	

[a]Abbreviation: MAT, month after treatment.
[b]LSD1 separates means within column, LSD2 separates means across column within the same treatments.

Table A-2. Biomass (kg/ha) of para grass after imazapyr treatments at T. M. Goodwin Waterfowl Management Area in 2009–10.

		Biomass (1 MAT)[a]
Treatment	Rate	Saturated
	kg a.i./ha	kg/ha
Untreated	0	15821
Imazapyr	0.28	21211
Imazapyr	0.56	16800
Imazapyr	1.12	17764
Imazapyr	1.68	16195
LSD1 (0.05)[b]		NS

[a]Abbreviation: MAT, month after treatment.

Table A-3. Biomass (kg/ha) of para grass from saturated and flooded (40 cm water) impoundments after glyphosate and imazapyr treatments at T. M. Goodwin Waterfowl Management Area in 2008–09

		Biomass (1 MAT)[a]	
Treatment	Rate	Saturated	Flooded
	kg a.i./ha	----------------------kg/ha------------------	
Untreated	0	4479	8571
Glyphosate	1.12	4572	8495
Glyphosate	2.24	4714	7495
Glyphosate	3.36	5627	6054
Imazapyr	0.84	5039	8655
Imazapyr	1.68	5070	9635
LSD1 (0.05)[b]		NS	
LSD2 (0.05)		2241	

[a]Abbreviation: MAT, month after treatment.
[b]LSD1 separates means within column, LSD2 separates means across column within the same treatments.

Table A-4. Biomass (kg/ha) of para grass after glyphosate and imazapyr treatments at T. M. Goodwin Waterfowl Management Area in 2009–10.

		Biomass (1 MAT)[a]
Treatment	Rate	Saturated
	kg a.i./ha	kg/ha
Untreated	0	13296
Glyphosate	1.12	16976
Glyphosate	2.24	9556
Glyphosate	3.36	17102
Imazapyr	0.84	16947
Imazapyr	1.68	15319
LSD1 (0.05)[b]		NS

[a]Abbreviation: MAT, month after treatment.

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BIOGRAPHICAL SKETCH

Sushila Chaudhari was born in the city of Sri Ganganagar, Rajasthan, India. Her father is a farmer and mother is a housewife. She started her undergraduate degree program in Agriculture at the Punjab Agricultural University Ludhiana, Punjab, India in 2004. Throughout her degree she was awarded with a National Talent Scholarship from the Indian Government. All through her college years, she participated in many campus activities and gained a lot of honors in games, clay-modeling, and rangoli. She enjoys team work and was active in the National Social Service program organized by the university and received a consolation prize at the end for her contributions.

In spring 2009, Sushila started her Master of Science in weed science program under the instruction of Dr. Brent Sellers at the University of Florida. She started her research on control of an invasive weed “para grass” in wetland areas. She has presented her research at the Southern Weed Science Society, Florida Weed Science Society, and Florida Exotic Pest Plant Council meetings. She has received a Master of Science from University of Florida in the spring of 2011. Sushila is planning on continuing her education in Weed Science through a PhD.