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Integrating chemical and cultural practices to control para grass (*Urochloa mutica*)

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ABSTRACT

Nonnative para grass (*Urochloa mutica* [Forsk.] T.Q. Nguyen) is no longer used as forage and has invaded Florida wetlands. This perennial grass out-competes native vegetation and grows into monotypic swards, resulting in unsuitable wildlife habitat. The goal of this research was to improve wetland ecosystem health by reducing para grass invasions via an integrated approach using cultural and herbicide inputs. Experiments were conducted to determine herbicide efficacy on para grass under different water depths in combination with burning followed by flooding. Herbicides were applied in late fall, followed by burning and flooding in early summer. At 1 month after treatment (MAT), all rates of imazapyr and glyphosate provided similar levels of control ranging from 70 to 88% and 91 to 95%, respectively, regardless of the initial water level. Burning followed by immediate flooding reduced the initial para grass ground cover in the nontreated checks by at least 62% at 12 MAT, which was 8 months after burning and flooding (MAB-F). Reestablishment of native species was similar in all plots. Stolon and crown tissues were sampled at monthly intervals for 2 years and analyzed for total nonstructural carbohydrate (TNC) concentrations. Carbohydrate concentrations in stolon and crown tissues were typically lowest in the late winter and early spring but increased from May through September. Therefore, para grass may be more susceptible to herbicide applications in early summer when herbicide will be transported with carbohydrates to reproductive tissues. These data indicate that excellent control of para grass can be obtained with fall applications of 1.12 kg ai/ha glyphosate or 0.86 kg ai/ha imazapyr in combination with early summer burning followed by flooding. However, an early- to mid-summer application of glyphosate and imazapyr may be more effective for areas where flooding cannot be controlled.

Key Words: burning, invasive grass, flooding, *Urochloas mutica*, wetlands.

INTRODUCTION

An invasive species is 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” (NISC 2006). Approximately 5000 plant species have escaped and now exist in natural ecosystems in the United States, compared with 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 listed as threatened or endangered under the Endangered Species Act are at risk, primarily because of competition with invasive species (Wilcove et al. 1998).

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 (2011) reported 1401 exotic plant species are currently present in Florida. Of these, 71 species are considered to be highly invasive, or category 1, in natural areas because they are disruptive to native plant community structure and function (FLEPPC 2009). Para grass is listed as a category 1 plant in central and south Florida (FLEPPC 2009).

Para grass is a C4 perennial grass native to Africa that was introduced to the United States through Brazil (Hitchcock and Chase 1951). It was introduced into Florida in the 1870s (Austin 1978) and was recommended as a 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. Para grass is a prolific seed producer (>10,000 seeds per square meter) with poor seed viability (Wesley-Smith 1973). Therefore, spread and invasion of para grass can mostly be attributed to its stoloniferous growth habit (Langeland and Burks 1998).

While once widely distributed as a forage grass in most tropical and subtropical areas, para grass is now considered a serious weed world-wide. It is reported as an agricultural pest in 23 crops in 34 countries, including the United States (Holm et al. 1977). As early as 1921, it was postulated that para grass could be problematic in areas that remain wet (Briggs 1921). 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).

These aquatic ecosystems provide diverse habitat for waterfowl by providing a forage base, breeding and nesting habitat, cover from predators, and habitat for social interactions (Murkin et al. 1997). In Florida, T. M. Goodwin Waterfowl Management Area (TMGWMA) is a 1570 ha fresh water restoration project that began in 1988. Historically a

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floodplain marsh, the area was diked and drained in 1950s and later managed for agricultural purposes including citrus, sod, and cattle production (Anonymous 2004). Improved pastures of flood-tolerant grass species like torpedo grass (*Panicum repens* L.), limpograss (*Hemarthria altissima* [Poir.] Stapf & C.E. Hubb), West Indian marsh grass (*Hymenachne amplexicaulis* [Rudge] Nees), and para grass were used for cattle production. Ranchers preferred these grasses because the area was subjected to frequent flooding during the rainy season. Drainage for agricultural purposes destroyed valuable wetlands, increased flood peaks, decreased water supplies, and created water quality problems (Campbell et al. 1984). Since 1988, the Florida Fish and Wildlife Conservation Commission (FWC) has managed the property for multiple uses, including stormwater retention to reduce freshwater discharge into the Indian River Lagoon to restore high quality wetland habitat for waterfowl and to establish a public recreation area. Restoration efforts established ten 61 ha wetland impoundments on the south end of TMGWMA to provide waterfowl habitat (Anonymous 2004).

Vegetation management at TMGWMA is accomplished through various techniques such as manipulation of water level, mechanical manipulation (e.g., disking and roller chopping), prescribed burning, mowing, and herbicide applications (Anonymous 2004). However, improper implementation of management techniques such as disking, roller chopping, and water level manipulation may have increased the spread of para grass in TMGWMA. Currently, it is estimated that approximately 60 to 70% of the impoundments are infested with para grass (S. Rockwood, Wetland Habitat Specialist, Florida Fish and Wildlife Conservation Commission, pers. comm.). Large infestations of para grass in TMGWMA are reducing the habitat complexity required to support diverse invertebrate communities and suitable feeding areas for waterfowl; therefore, it is important to determine effective control measures for para grass control.

Information regarding the use of herbicides for para grass control is limited. Herbicides tested for para grass control include asulam, dalapon, simazine, and monuron (Van Rijn 1963, Whitney et al. 1973), but these herbicides are either no longer registered or are not allowed for aquatic sites. Nonselective herbicides, glyphosate, and imazapyr may possibly provide good to excellent control of para grass because they have been used for effective control of other aquatic grass species including torpedo grass (Smith et al. 1992), limpograss (Sellers et al. 2007), and west Indian marsh grass (Sellers et al. 2008). In aquatic sites, however, it is also unknown if water level at the time of herbicide application would negatively affect para grass control, as was shown in torpedo grass (Smith et al. 1992).

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 five annual prescribed fires at Everglades National Park. Para grass can adapt to a wide range of moisture conditions and grow very well in water up to 1 m deep (Holm et al. 1977). While it seems that prescribed burning or flooding has no impact on long-term para grass control, little to no information exists concerning the effect of burning followed by flooding in conjunction with herbicides on para grass control.

One of the most important decisions when integrating herbicides into a pest management strategy for perennial grasses is 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 1.12 kg/ha triclopyr was applied in late summer (Sep) as compared to spring (Mar); the authors suggested that increased movement of carbohydrates to the root tissues in summer also increased herbicide translocation toward root tissues.

Therefore, the objectives of this research were to (1) test herbicide efficacy in natural areas under different water regimes integrated with burning and flooding for para grass control, and (2) 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

Field studies

Experiments were initiated in December 2008 at TMGWMA near Fellsmere, Florida, to investigate the effect of water depth on herbicide efficacy. Each experiment was conducted in two impoundments (an impoundment is a 61 ha area approximately 1 m deep and surrounded by earthen levees) containing at least 95% para grass cover. Impoundments were designated as "saturated" (no standing water) and "flooded"; the water level in the flooded impounded was approximately 40 cm, and no standing water was present in the saturated impoundment at the time of application. Water levels were adjusted by pumping water in and out of the impoundments. The experimental design was a split-block with four replications. The blocking treatment was the water depth (saturated vs. flooded); individual plots measuring 24 by 360 m represented the herbicide treatments. Two different studies were conducted on each impoundment: (1) an imazapyr study that included four rates of imazapyr at 0.28, 0.56, 1.12, and 1.68 kg/ha and a nontreated check; and (2) a glyphosate and imazapyr study that included rates of imazapyr at 0.84 and 1.68 kg a.i./ha; glyphosate at 1.12, 2.24, and 3.36 kg /ha; and a nontreated check. All treatments in both studies included a non-ionic surfactant at 0.25% (v/v).

Herbicides were applied aerially with a helicopter calibrated to deliver 93 L/ha. Herbicide treatments were applied in December 2008; weather conditions were 24 C air temperature, 6.6 kph wind speed, and 81% relative humidity under mostly clear skies on the day of application. Visual estimates of para grass control were recorded 1 month after treatment

(MAT) on a scale of 0 to 100%, where 0 = no control and 100 = complete control. In May 2009, impoundments were drained and burned by FWC staff to remove dead plant tissue. The flooded-impoundment area was flooded immediately after burning but the saturated-impoundment area was flooded 7 days after burning because both impoundments could not be flooded at same time due to water-pumping constraints. After flooding, one 3 by 3 m permanent quadrat was randomly placed into each plot to monitor native plant establishment. Control was estimated by visually assessing the reduction of para grass ground cover compared to the initial density in each plot at 2 and 8 months after burning and flooding (MAB-F) on a scale of 0 to 100%, as described previously. Native plant establishment was recorded at 2 and 8 MAB-F by counting the number of species in 3 by 3 m permanent quadrats inserted prior to flooding.

Total nonstructural carbohydrate (TNC) concentration

Four para grass plants were collected from Ona, Florida, and TMGWMA at monthly intervals for 2 years (Jan 2009 to Dec 2010). At each harvest, a 2700 cm^3 area was dug and soil was washed from the roots before being placed on ice for transport to 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 tissue was placed in a forced air dryer at 100 C for 2 h to halt enzymatic activity before adjusting the temperature to 60 C for 4 days. After attaining a constant weight, samples were ground and processed in the laboratory (Christiansen 1982).

Statistical analysis

Visual estimates of para grass control were subjected to analysis of variance using the PROC GLM procedure of SAS. Means were separated using Fisher's Protected LSD at $p \leq 0.05$. Data were checked for homogeneity of variance and normality. Native plant species establishment 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 TMGWMA) were pooled across years after performing Bartlett's 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 in SigmaPlot 11 to determine the effect of sampling date on TNC concentration in plant tissues.

RESULTS AND DISCUSSION

Imazapyr study

The imazapyr study was initially installed as a rate titration study. Although the aim of this study was to estimate imazapyr rate that would control at least 90% para grass, there were no significant differences in control among application rates; therefore, regression analysis was not utilized for these data.

The water level by treatment interaction ($p = 0.270$) was not significant 1 MAT;, therefore, data were pooled across initial water levels. At 1 MAT, imazapyr provided 70 to 88% control at all application rates (Table 1). At 6 MAT and 2 MAB-F (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 (nontreated 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 ($p = 0.400$) was not significant, and herbicide treatment was pooled across water levels. Para grass was reduced by at least 91% in all treatments, including the nontreated check, regardless of initial water level and flood timing (Table 1).

Table 1. Percent control (visual ratings) of para grass 1, 6 (2 MAB-F), and 12 MAT (8 MAB-F) in saturated and flooded impoundments after imazapyr treatment at T. M. Goodwin Waterfowl Management Area in 2008–2009[1].

			6 MAT[5] (2 MAB-F)		
Treatment	Rate	1 MAT[2,3,4]	Saturated	Flooded	12 MAT[3,5] (8 MAB-F)
	kg./ha	———% control———			
Nontreated	—	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)[6]		8	18		NS
LSD2 (0.05)		—	10		—

[1] Weed control rated on 0 to 100% scale; where 0 = no control and 100 = complete control.

[2] Abbreviations: MAT = month after treatment; MAB-F = month after burning–flooding.

[3] Results pooled across saturated and flooded impoundments at 1 MAT and 12 MAT (8 MAB-F) due to no water level by treatment interaction.

[4] Nontreated control not included in statistical analysis of 1 MAT.

[5] At 6 MAT and 12 MAT, % control represent % reduction of initial para grass ground cover.

[6] LSD1 separates means within column and LSD2 separates means across column within the same treatments.

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 rates was similar 1 MAT, regardless of the initial water depth (Table 2). 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 to 100% compared to the initial level of infestation. However, burning followed by immediate flooding of nontreated control plots resulted in at least 30% less para grass cover as compared to plots that were flooded 7 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%.

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). We hypothesized that increasing water depth would negatively impact control of para grass with herbicides, but especially glyphosate. Results of both studies, however, indicate the effect of water depth at the time of herbicide application does not affect para grass control, except 1.68 kg/ha imazapyr in the glyphosate and imazapyr study at 1 MAT. Para grass control with imazapyr at 1.68 kg/ha was 18% lower under flooded as compared to saturated conditions. In the flooded impoundment para grass control with 1.68 kg/ha imazapyr was approximately 10% lower compared to 0.84 kg/ha imazapyr. Conversely, para grass control was similar following application of these two rates of imazapyr under saturated conditions 1 MAT. The reason for the different behavior of 1.68 kg/ha imazapyr in saturated versus flooded impoundments is not clear. However, the rate of plant death with this herbicide family is typically slow and 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. Overall, these studies indicate that leaf tissue above the water surface was sufficient to allow effective herbicide applications; therefore, it seems that para grass can be treated with glyphosate and/or imazapyr even when inundated. This is important because para grass can be treated during both dry and rainy seasons in Florida.

These data indicate that burning followed by flooding is important for effective para grass control. The primary stress induced by flooding is reduced oxygen availability in the soil solution (Kozlowski 1984). Under normal growing conditions, para grass has tolerance to flooding due to its hollow stolons and the constitutive high proportion of aerenchyma tissue (up to 60% of the root transverse area) in the roots (Baruch and Merida 1995). The development of adventitious rootlets under flooded conditions also promotes water and nutrient absorption (Baruch 1994). However, when aerial stolons are burned and subsequently flooded, the supply of atmospheric oxygen is eliminated and the plant is not able to initiate regrowth.

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

Table 2. Percent control (visual ratings) of para grass 1, 6 (2 MAB-F), and 12 MAT (8 MAB-F) from saturated and flooded impoundments after glyphosate and imazapyr treatments at T. M. Goodwin Waterfowl Management Area in 2008–2009[1].

		1 MAT2,3,4		6 MAT5 (2 MAB-F)		
Treatment	Rate	Saturated	Flooded	Saturated	Flooded	12 MAT3,5 (8 MAB-F)
	kg a.i./ha	% control				
Nontreated		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)6		6		20		NS
LSD2 (0.05)		6		21		—

[1] Weed control rated on 0 to 100% scale; where 0 = no control and 100 = total control.

[2] Abbreviations: MAT = month after treatment; MAB-F = month after burning–flooding.

[3] Results pooled across saturated and flooded impoundments at 12 MAT (8 MAB-F) due to no water level by treatment interaction.

[4] Nontreated control not included in statistical analysis of data at 1 MAT.

[5] At 6 MAT and 12 MAT, % control represent % reduction of initial para grass ground cover.

[6] LSD1 separates means within column and LSD2 separates means across column within the same treatments.

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 reinfestation of initially highly infested areas.

Native plant establishment

Reestablishment of plant species was observed in both impoundments regardless of herbicide treatments (data not shown). Alligator weed (*Alternanthera philoxeroides* [Mart.] Griseb.), cattail (*Typha latifolia* L.), pickerel weed (*Pontederia cordata* L.), pennywort (*Hydrocotyle* spp.), southern water grass (*Hydrochloa caroliniensis* P. Beauv.), spatter-dock (*Nuphar lutea* [L.] Sibth. & Sm.), *Sagittaria* spp., southern naiad (*Najas guadalupensis* [Spreng.] Magnus.), and spike rush (*Eleocharis* spp.) were the predominant species present in both impoundments after flooding. Minor plant species included muskgrass (*Chara* spp.), Egyptian paspalidium (*Paspalidium geminatum* [Forssk.] Stapf), 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) seemed to be greater in the saturated impoundment (flooded 7 days after burning) as compared to the flooded impoundment (flooded immediately after burning), possibly because delayed flooding provided sufficient time for seed germination of desirable plant species. Plant diversity and the number of a given species were expected to be substantially lower in the imazapyr treated plots. Both plant diversity and numbers were not different among herbicide treatments (data not shown), however, possibly because 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.

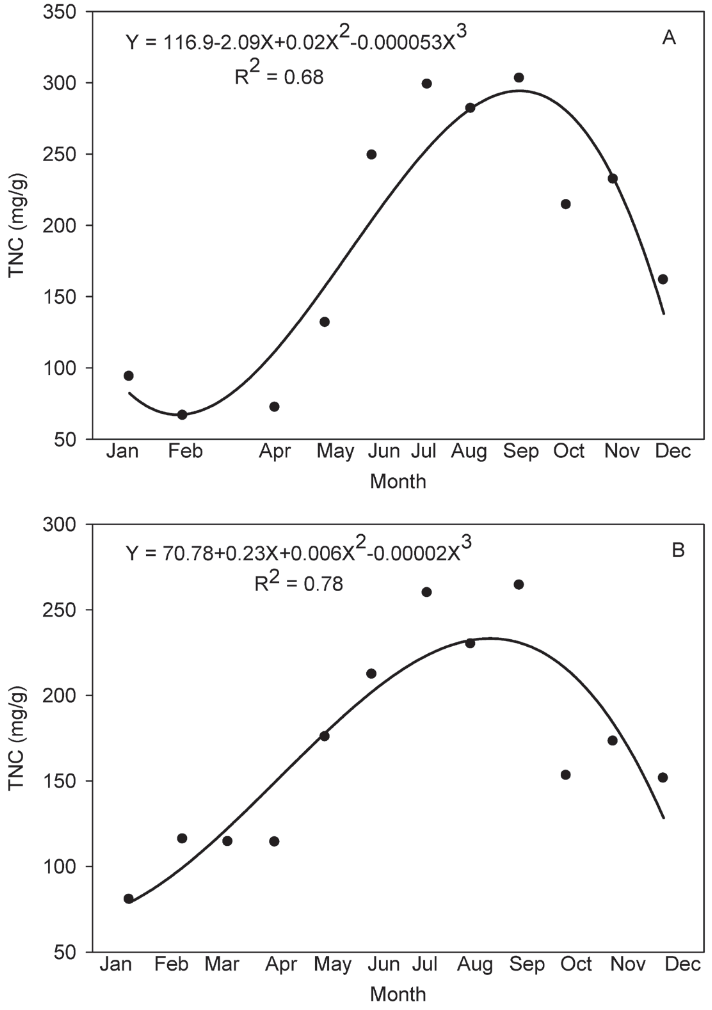

Figure 1. Seasonal variation in total nonstructural carbohydrate concentration (TNC) in para grass stolon (A) and crown (B) tissues pooled over 2 years at Ona, FL.

Total nonstructural carbohydrate (TNC)

Date of sampling had a cubic effect on TNC concentration in para grass stolon and crown tissues at both locations (Figures 1 and 2). In both stolon and crown tissues, TNC concentrations were lowest between February and April and increased to a maximum between July and September at both locations. The TNC concentration began to decline from October to December at both locations in both plant tissues (Figures 1 and 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 lowest during late-winter to early-spring due to the dormant period of plant growth. During this period, para grass growth ceases due to frost, and it is possible that stolon tissues began to degrade following a frost event; therefore, stolon TNC concentration would continue to decrease. When regrowth 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 (Jun through Sep). 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, 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).

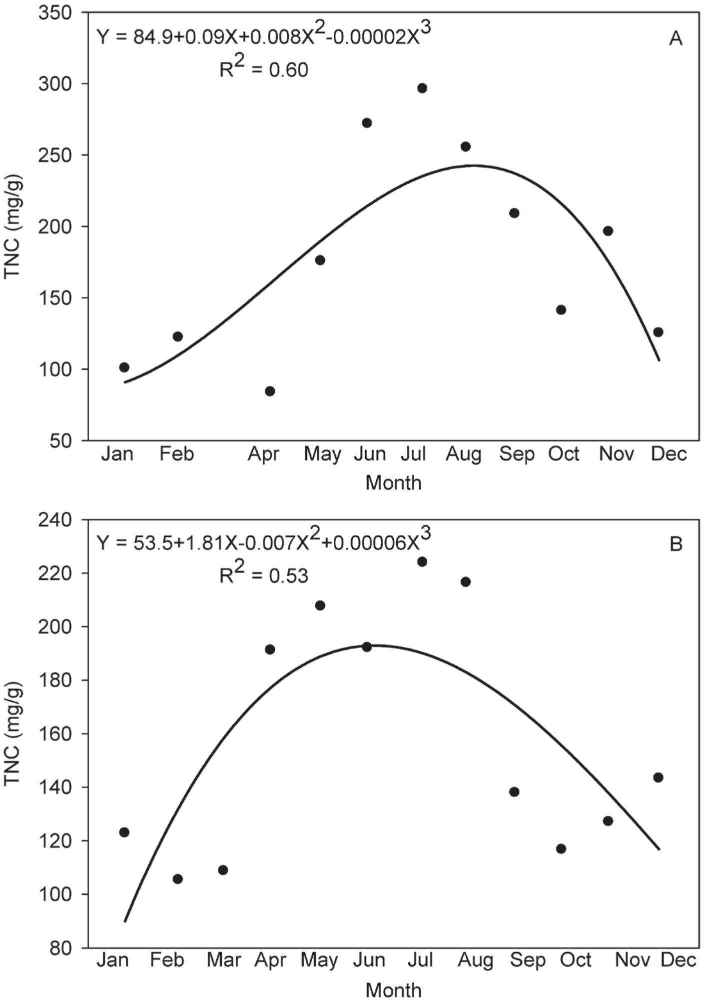

Figure 2. Seasonal variation in total nonstructural carbohydrate concentration (TNC) in para grass stolon (A) and crown (B) tissues pooled over 2 years at T. M. Goodwin Waterfowl Management Area, Fellsmere, FL.

Temperature and 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, which could possibly explain the variation in carbohydrate concentrations among the two locations in this study.

These results show that para grass may be more susceptible to herbicide applications in early summer (early May to Jun) 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 a single application date (late fall). However, the effect of these herbicides on para grass control may differ with regard to application timing, and therefore the effect of glyphosate and imazapyr application timing on para grass control needs to be evaluated.

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