# EVALUATION OF LIMPOGRASS [*Hemarthria altissima*] BREEDING LINES FOR USE IN FLORIDA FORAGE-LIVESTOCK SYSTEMS

By

MARCELO OSÓRIO WALLAU

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2013

© 2013 Marcelo Osório Wallau

To my grandparents, inspirers of love for ranching and great morals. To my parents, for their faith and devotion.

ACKNOWLEDGMENTS

Few people are as enthusiastic and intuitive for grasslands research as Dr. Lynn E. Sollenberger. Besides being a great researcher and professor, he is also a great advisor and friend that has taught us not just about forages, but also about values, life, and much more. I would like to extend a special thanks and appreciation for the amazing person he is. It was a great honor and pleasure being part of the Sollenberger group. A few years ago I had the opportunity to go as an exchange student to Texas Tech University, where I met Dr. Vivien Gore Allen, one of the most important persons in shaping my forage research career. With the same passionate and dedicated eyes of a life devoted to pasture research, she also took good care of her people. With a contagious eagerness, she encouraged me on pursuing a graduate degree and to come to the University of Florida. I am infinitely thankful for her influence. It is also important to mention the valuable input of my committee members, Dr. João Vendramini, Dr. Kenneth Quesenberry and Dr. Nicolas DiLorenzo, with whom I developed a good friendship across these years in Florida. It was a pleasure to work with such a distinct group of researchers.

This project would not have been achievable without the help of the great lab group we had including Kim Mullenix, Miguel Castillo, Chaein Na and Nick Krueger, who helped me from the field work to the statistics. André Aguiar, Eduardo Alava and Marta Kohmann, our adjunct members of the Sollenberger group, were also great companions and help for days when the work load was increased. Working together we made great progress. This group would not be complete without Dwight Thomas, whose services were of much value, and friendship incomparable, Richard Fethiere, our lab supporter and sports commentator, and Dr. Kenneth Woodard, from whom I learned how to reduce research error, enjoy the fellowship, and to be patient. In the second year of my experiment, I had a great deal of help from Dr. Carlos Augusto Gomide and Victor Costa, whose services and company were much appreciated. My good friend Eduardo Ribeiro, was also an important help in the statistics world, a horse yet to be broken. My great thanks for all these folks!

As a rancher, we know how to praise a good horse and a good friend. I am much obliged to have by my side Esteban Rios, Daniel Mullenix, Hermes Gerardo-Cuervo, Darren Henry, Steven Bingert, and Carlos Cañas, friends to ride the river with. I am thankful also for my friends from Animal Science, good company for barbecue and guitar playing, in special Anna Denicol, Rafael Bisinotto, Vitor and Paula Mercadante. I could not forget about my fellow Argentinian Gauchos, Alberto, Dolores, Vale, Belen, Oscar, Marcos and Paula, also great partners for a barbecue and a hand of “truco”.

I am really grateful for my family, for all the support while being in Florida and for the great foundation they gave me. Thanks to my parents, Carlos Wallau and Ana Maria Osório, my brothers Diego and Rodrigo, and my grandparents, Ingrid and Carlos Wallau and Eva and João Osorio (in memoriam). Also, thanks to my girlfriend Luiza Damboriarena, from whom the distance seemed infinite and the time an eternity. It is hard to be far from the loved ones.

Being away from home, in another country and not having family support can sometimes be hard. But having good friends along the way makes it a much easier and comfortable ride. Now, it is time to saddle up again, the cycle comes to an end and the courses diverge, but the friendship will never be forgotten. Thanks for all those people that made my stay here more enjoyable.

TABLE OF CONTENTS

LIST OF TABLES

Table page

LIST OF FIGURES

LIST OF ABBREVIATIONS

| | |
|---|---|
| [(W-Wo)/t] | Average growth rate |
| ADG | Average daily gain |
| AFRU | Agronomy Forage Research Unit |
| CP | Crude protein |
| CSM | Cotton seed meal |
| DM | Dry matter |
| DOM:CP | Digestible organic matter:crude protein ratio |
| dW/dt | Instantaneous growth rate |
| ha | Hectare |
| HI | High protein supplementation level |
| IVDDM | In vitro digestible dry matter |
| IVDOM | In vitro digestible organic matter |
| LA | Limpograss aeschynomene mixture |
| LAI | Leaf area index |
| LI | Light interception |
| LL | Lower layer |
| LO | Low protein supplementation level |
| RCREC | Range Cattle Research and Education Center |
| SH | Stubble height |
| TDN | Total digestible nutrients |
| UL | Upper layer |
| W | Biomass net accumulation |
| wk | Week |
| yr | Year |

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science

EVALUATION OF LIMPOGRASS [*Hemarthria altissima*] BREEDING LINES FOR USE IN FLORIDA FORAGE-LIVESTOCK SYSTEMS

By

Marcelo Osório Wallau

December 2013

Chair: Lynn E. Sollenberger
Cochair: João M. B. Vendramini
Major: Agronomy

Limpograss [*Hemarthria altissima* (Poir.) Stapf *et* C.E. Hubb.] is one of the most commonly used C4 grasses in wet soil environments in Florida. Its relatively high cold tolerance and digestibility reduce the forage shortfall in the winter and the need for supplemental feed. Virtually all of the 0.2 million ha of limpograss in Florida is planted to a single cultivar, ‘Floralta’ limpograss, that was released in 1984 (Quesenberry et al., 2004). Recently, new limpograss hybrids have been developed through breeding and and the best five in terms of persistence, productivity and nutritive value were identified in preliminary clipping and grazing trials. Additional evaluation of these hybrids is needed to determine which merit release as cultivars. The objective of this research was to identify one or more superior hybrids for cultivar release on the basis of their productivity, nutritive value, and persistence under grazing, and performance as stockpiled forage. Breeding lines 1, 4F, 10, 32, and 34 plus Floralta were evaluated under mob stocking to compare a combination of two grazing frequencies (initiation of grazing at 80 and 95% pre-grazing canopy light interception [LI]) and two post-grazing stubble heights (20 and 30 cm). Entry 10 had the longest grazing season, the least weed frequency, and accumulated more herbage (11.6 Mg ha$^{-1}$) than 32, 1, and 34 (≤

8.4 Mg ha$^{-1}$), but herbage accumulation was not different from 4F and Floralta (10.4 and 9.5 Mg ha$^{-1}$, respectively). Pre-grazing LI levels did not affect total-season herbage accumulation or harvested, but use of LI95 resulted in taller canopies with greater stem mass that were prone to lodging and trampling. In the stockpiling experiment, Entries 1, 4F, 10, and Floralta were fertilized with 50 or 100 kg N ha$^{-1}$ and stockpiled for 8, 12, or 16 wk. The longer period resulted in greater herbage harvested (7.8 vs. 9.3 Mg ha$^{-1}$ for 8 and 16 wk, respectively), but there was a relatively small decrease in digestibility (from 584 to 552 g kg$^{-1}$ at 8 and 16 wk, respectively). Entries 10 and 4F had greater herbage harvested (8.7 and 8.2 Mg ha$^{-1}$, respectively) than the others. After 1 yr of each of these experiments, Entries 10 and 4F appear to demonstrate improvement over Floralta in multiple traits of importance suggesting that among the breeding lines tested they are the ones that are most likely to be released as cultivars in the next few years.

# CHAPTER 1
# INTRODUCTION

Limpograss [*Hemarthria altissima* (Poir.) Stapf et C. E. Hubb.] is a stoloniferous, warm-season perennial forage grass that was collected in South Africa and brought to the USA in the 1960s. Three cultivars, 'Redalta', 'Greenalta', and 'Bigalta', were released by the Florida Agricultural Experiment Station in 1978 (Quesenberry et al., 1978). Redalta and Greenalta are diploid types that were never utilized to a significant extent by beef cattle (*Bos* sp.) producers in Florida because of low digestibility for livestock. Bigalta, a tetraploid cultivar, is high in digestibility, readily grazed by livestock, and used more widely than the other two, but producer adoption of Bigalta was limited by poor persistence under grazing (Quesenberry et al., 2004). A subsequent screening of additional limpograss plant introductions using mob stocking resulted in the release of 'Floralta', a tetraploid type that was more persistent under grazing than Bigalta yet with relatively high digestibility (Quesenberry et al., 1983; 1984).

The planted area of limpograss in Florida has increased more rapidly in the last 35 yr than any other perennial grass, increasing from zero to perhaps as much as 200, 000 ha statewide, with a high percentage of this area in South Florida. The reason for this large increase in planted area is the ability of limpograss to extend the grazing season. This is particularly the case in South Florida where many winters have few to occasionally no freezes. In this environment, limpograss continues to grow when moisture and temperature conditions are favorable, thus reducing winter feeding costs for beef cattle (Quesenberry et al., 2004). Another important characteristic of limpograss is its relatively high digestibility for a $C_4$ grass; it reaches 700 g $kg^{-1}$ in immature swards and declines slowly to 450 g $kg^{-1}$ when stockpiled and very mature (Carvalho, 1976;

Quesenberry et al., 2004). Commonly observed digestibility levels under grazing are in the range of 550 to 620 g $kg^{-1}$ (Holderbaum et al. 1992; Lima et al., 1999; Newman et al., 2002b).

A constraint to limpograss use is that crude protein concentration is sometimes below cattle requirements, making N supplementation necessary in order to obtain acceptable levels of livestock production (Holderbaum et al., 1991; Lima et al., 1999; Newman et al., 2002b). Crude protein concentration as low as 35 and as high as 120 g $kg^{-1}$ have been reported depending on limpograss physiological growth stage, fertilization, and grazing management (Quesenberry et al., 2004; Vendramini et al., 2008). Another limitation is that a significant proportion of the N in limpograss herbage is associated with the cell wall fraction of the plant, limiting its availability to livestock (Lima et al., 2001). Additionally, limpograss is not as persistent under grazing as bahiagrass (*Paspalum notatum* Flügge), and Floralta digestibility is often modestly lower than that of Bigalta (Quesenberry et al., 1983; 2004).

Recently, Quesenberry and his colleagues undertook the task of developing new limpograss cultivars by crossing the highly digestible Bigalta with the more persistent Floralta. The goal was to achieve superior cultivars with both high digestibility and persistence. Crosses were successful, and the large number of the lines that resulted was evaluated in terms of plant vigor, spread, and eventually yield under clipping. From this work, eight lines were selected that demonstrated the best overall performance. These eight lines and the two parents were included in an experiment conducted at the University of Florida Beef Research Unit near Gainesville during 2010 and 2011 (Wallau et al., 2012). Grasses were mob stocked every 2 or 4 wk from mid-May through mid-

October each year. Based on measurements of herbage harvested (by grazing), percentage cover of limpograss, and weed frequency, three of the eight breeding lines were found to be inferior and were eliminated from further testing.

The five remaining lines of limpograss require testing under a wider range of grazing management strategies prior to decisions regarding cultivar release. In addition, because limpograss is often used as stockpiled forage, it is important that potential new cultivars be assessed under this management. This thesis reports the results of research evaluating five breeding lines using four different grazing strategies (Experiment 1) and six different stockpiling management options (Experiment 2) during 2012. The main objectives of this work were to: 1) assess the persistence, productivity, and nutritive value of the breeding lines of limpograss under a wide range of grazing treatments; 2) identify differences in morphological traits among lines due to grazing strategies and measure how nutritive value and regrowth rate are affected by these grazing management practices; and 3) quantify the effect of length of stockpiling period on herbage harvested, nutritive value, and plant-part proportion of three breeding lines compared with Floralta. The overall goal is to contribute data that will aid in identifying the limpograss hybrid(s) that best meet the needs of Florida’s livestock industry and qualify for cultivar release.

# CHAPTER 2
# LITERATURE REVIEW

## Florida Forage-Livestock Systems

Grasslands occupy an estimated 4.5 million hectares in Florida, with approximately 1.8 million hectares of grazed forestland, 1.2 million hectares of native rangeland, and 1.4 million hectares of planted pastureland. This forage and grassland resource supports a large livestock industry. The number of beef cows (*Bos* sp.) in Florida in January 2011 was 926,000 (Florida Agricultural Statistics, 2011), and approximately 85% of Florida's pastureland is utilized for grazing in beef cow-calf operations. Of states east of the Mississippi River, Florida is currently fourth in number of beef cows, while nationally it is ranked 11$^{th}$. Florida is a major cattle and calf provider for the feedlot industry in the mid-western USA, with a calf crop of 870,000 head in 2010.

Most of the cattle are concentrated in the southern part of the state; eighty percent of beef cattle are raised south of a line from Daytona Beach to Tampa. In terms of economics, livestock contribute approximately 1.25 billion dollars per year to the Florida economy, with milk cash receipts of $439 million and beef cow and calf cash receipts of $502 million in 2010 (Florida Agricultural Statistics Service, 2011). The cow-calf production systems in the state are pasture based and utilize mainly subtropical and tropical grasses, such as bahiagrass (*Paspalum notatum* Flügge), limpograss [*Hemarthria altissima* (Poir.) Stapf *et* C. E. Hubb.], and bermudagrass [*Cynodon dactylon* (L.) Pers.], as the primary forage sources for grazing and hay.

## Origin, Evaluation, and Characteristics of Limpograss Cultivars

Limpograss is a stoloniferous perennial tropical grass originally from South Africa and India, where it was also associated with livestock production. It belongs to the *Poaceae* family, *Panicoideae* sub-family, and *Andropogonae* tribe. The species is predominant along streams at the center of origin and is adapted to lowlands, with wet and flooded soils. As a result, it is well suited to the poorly drained sandy soils of peninsular Florida (Quesenberry et al., 1984). The main morphological characteristics of limpograss are decumbent branching stems that can produce roots from the nodes, and small and narrow leaves (20 by 0.6 cm), which are mainly glabrous but have long hairs at the base. Plant height can reach up to 150 cm, and inflorescences are composed of several racemes that are almost cylindrical and appear singly or in groups from 2 to 4. At maturity, some cultivars will change leaf and stem pigmentation to a reddish or purple color (Quesenberry et al., 2004). Cold temperature tolerance is one feature that gives limpograss an advantage over other tropical grasses used in Florida. Observations made in Gainesville, FL, indicated little or no winter killing with temperatures of -10°C, but more damage was reported in Jay, FL when temperatures reached -13°C for more than 2 d consecutively (Quesenberry et al., 2004).

Following its introduction in 1964, evaluation programs were established in the beginning of the 1970s at the University of Florida in Gainesville, the USDA-NRCS Plant Materials Center at Arcadia, and the UF Range Cattle Research and Education Center (RCREC) at Ona, FL (Quesenberry et al., 2004). The first cultivars were selected for release from among 53 clones evaluated in greenhouse and small-plot clipping experiments (Ruelke et al., 1976). Twenty seven of these clones were evaluated under grazing with a defoliation interval of 5 wk. The best eight were tested under mob stocking with rest intervals of 3, 5, 7, and 9 wk (Quesenberry et al., 1978; 1983). Of these eight, ‘Redalta’ and ‘Greenalta’ limpograss, both diploids, were released in 1978 due to excellent persistence, although their digestibility was relatively low (Quesenberry et al., 1978). ‘Bigalta’ limpograss (tetraploid) had higher digestibility, but it was less persistent than Greenalta and Redalta. It was also released to producers by the Florida Agricultural Experiment Station in 1978 (Quesenberry et al., 1978) and was more widely used than Redalta and Greenalta in the beginning because of its higher digestibility. The relatively poor persistence under grazing of Bigalta limited its expansion.

Further evaluation was conducted of limpograss plant introductions, and another tetraploid accession was identified that showed similar to slightly lower in vitro digestible organic matter (IVDOM) concentration but superior persistence to Bigalta and greater digestibility than Greenalta and Redalta. At Ona, FL, plot studies indicated that the new accession was more cold tolerant than Bigalta, surviving temperatures of -10°C. It was released as ‘Floralta’ in 1984 (Quesenberry et al., 1984), and it rapidly became the most popular cultivar and remains the most widely planted limpograss in Florida today. The planted area of limpograss in the state has increased more rapidly in the last 35 yr than that of any other perennial grass, increasing from zero to perhaps as much as 200,000 ha statewide, with a high percentage of this area in South Florida (K. Quesenberry, personal communication).

Floralta has been found to be less persistent under grazing than grasses such as bermudagrass or bahiagrass (Quesenberry et al., 1984), therefore good management is key to its successful use. Floralta’s IVDOM is generally greater than other C4 grasses, even at advanced stages of maturity, which is why limpograss is frequently used for stockpiling. In immature swards, limpograss IVDOM can be close to 700 g $kg^{-1}$ and it slowly declines as plants mature (Carvalho, 1976; Quesenberry et al., 2004). However, crude protein (CP) concentrations are low for all cultivars with actual levels depending on management and fertilization. Also, it has been found that approximately 40% of limpograss N is associated with cell wall, thus it becomes available for use by animals only as cell wall is digested (Lima et al., 2001).

**Seasonality of Forage Production and Role of Limpograss in Production Systems**

Forage production varies widely throughout the year in Florida due to wide seasonal ranges in rainfall, daylength, and temperature. As daylength and temperature decrease in the fall, most tropical grasses become dormant and production of above-ground herbage is limited until the following spring. This reduces forage mass for grazing during the cold months and necessitates use of other strategies to address the forage shortfall. These include planting cool-season forages or feeding conserved forages (hay, haylage, or silage) and/or other supplements to cattle. Although effective, these practices increase production costs.

North Florida producers often use hay or plant winter-annual forages to address the gap in forage production. In the southern part of the state, winter-annual forages are less widely used because of the short cool season, and conserved forage is too expensive to feed on the very large ranches that characterize the region. Within this context, a warm-season grass that can be grazed year-round would be of great value. Limpograss is the most widely utilized warm-season perennial grass for providing grazed forage during the cool season in South Florida.

One of the reasons for the rapid increase in planted area of limpograss during recent decades is its relative cold tolerance that allows regrowth early in the spring and later in the fall. Depending on the region and the management, limpograss will still produce forage after the first frost event. In South Florida for example, where frost events are infrequent, Kretschmer and Snyder (1979) reported that N-fertilized Bigalta produced as much as 5 Mg DM $ha^{-1}$, or 40% of its annual yield, during winter. Quesenberry and Ocumpaugh (1980) found yields of 6 and 8 Mg DM $ha^{-1}$ when limpograss was fertilized with 75 kg N $ha^{-1}$at the end of summer and stockpiled for use in the late autumn or early winter in Gainesville, FL.

## Grazing Management of Limpograss

Good grazing management is one of the main factors required to optimize limpograss persistence and animal performance. Limpograss does not tolerate the same intensity of grazing as bahiagrass, and nutritive value varies vertically within the canopy and with different management strategies (Sollenberger et al., 1988; Holderbaum et al., 1991; Pitman et al., 1994; Brown and Adjei, 2001; Newman et al., 2002a; 2002b).

Limpograss use and response to management varies regionally throughout Florida. In South Florida, for example, where frosts events are relatively rare, limpograss can be used year-round and normally is grazed leniently during summer and often stockpiled in later summer for use in late fall and winter. Northern Florida farmers, however, tend to use limpograss only in the warm season and more intensively, resulting in different levels and distribution of production and nutritive value (Brown and Adjei, 2001).

For year-round grazing in South Florida, Kretschmer and Snyder (1979) suggested that a 20-cm stubble height should be maintained. This has not been substantiated by research elsewhere in the state, where better production and persistence has been obtained by maintaining a 40-cm height under continuous stocking, or a 25- to 35-cm stubble height under rotational stocking with a 4- to 6-wk rest period between grazing events (Newman et al., 2003b). Under continuous stocking, grazing to a short stubble reduced limpograss persistence and opened space for weeds such as vaseygrass (*Paspalum urvillei* Steud.) and common bermudagrass. Although continuous stocking of limpograss to maintain a 20-cm stubble height decreased the density of vaseygrass plants, common bermudagrass cover increased using this management (Newman et al., 2005). The same authors also tested 40- and 60-cm canopy heights and found that there was no difference between them for percentage of limpograss. Their conclusion was that 40 cm is the superior canopy height because there wais relatively little increase in frequency or cover of weed species but animal production was greatest (Newman et al., 2002b; 2003b; 2005).

Compared with bahiagrass, limpograss requires more lenient grazing to persist. However, undergrazing can lead to accumulation of stem material in the lower canopy, resulting in a decline in forage nutritive value and animal performance (Sollenberger et al., 1988; Holderbaum et al., 1992; Newman et al., 2002a). One alternative to avoid this problem is more frequent and closer grazing in the beginning of the season using rotational stocking. Sollenberger et al. (1988) suggested a 20- to 25-cm stubble height to reduce build up of stem, and a 4- to 5-wk regrowth interval to allow plants sufficient time to recover before a subsequent grazing.

**Limpograss Nutritive Value**

Schank et al. (1973) were among the first to report the relatively high IVDOM and slow rate of decline in IVDOM with increasing maturity of the tetraploid Bigalta. Carvalho (1976) determined that 2-wk-old Bigalta was similar to or slightly lower in IVDOM than

‘Pangola’ digitgrass (*Digitaria eriantha* Steud.), one of the higher quality $C_4$ grasses, but digitgrass IVDOM declined at a faster rate with maturity than did Bigalta. By 8 wk of regrowth, Bigalta had 50 to 170 g $kg^{-1}$ greater digestible OM than digitgrass and ‘Pensacola’ bahiagrass, respectively (Carvalho, 1976). As noted earlier, IVDOM of tetraploid types has consistently been greater than for diploids (Schank et al., 1973; Quesenberry et al., 1983). Bigalta generally is higher in IVDOM than Floralta, but the difference is much less than the difference between tetraploids and diploids (Quesenberry et al., 1983; Pitman et al., 1994). Limpograss IVDOM has been affected by N fertilization in a number of studies, increasing with increasing N rate (Lima et al., 1999; Quesenberry et al., 2004).

Reports of low CP in limpograss forage are widespread. For regrowth intervals of 2 to more than 20 wk, CP of Bigalta was less than that of Pensacola bahiagrass and Pangola digitgrass, decreasing to 60 g $kg^{-1}$ by 8 wk (Carvalho, 1976). Under continuous stocking, CP of the top 20 cm of a Floralta pasture was 47 g $kg^{-1}$ and that of esophageal extrusa of grazing steers was 58 g $kg^{-1}$ (Sollenberger et al., 1988). Across a wide range of N fertilizer rates, 6-wk regrowth of Floralta, Bigalta, and Redalta had CP concentrations below 70 g $kg^{-1}$ (Christiansen et al., 1988). Limpograss CP is much greater in the upper strata of the canopy in comparison with the lower strata (Holderbaum et al., 1992; Kretschmer et al., 1996). This may be the cause of protein deficiency in cattle grazing limpograss where extent of utilization of the pasture is relatively high (Sollenberger et al., 1999).

Total N in limpograss has been fractionated and N degradation in the rumen evaluated. Nitrogen associated with the NDF fraction was 540 g $kg^{-1}$ of total N for 8-wk

Bigalta regrowth (Brown and Pitman, 1991) and 380 to 430 g $kg^{-1}$ for 6-wk Floralta regrowth (Lima et al., 2001). Comparing limpograss and bahiagrass, limpograss had greater lag time for N degradation, slower N degradation rate, and much less ruminally degraded N (Brown and Pitman, 1991). These authors concluded that CP deficiency of cattle grazing limpograss is primarily a function of the low amount of CP present in the grass, more so than composition of the CP, but the long lag phase for CP degradation may play a secondary role.

The relationship between herbage IVDOM and CP concentrations, expressed as DOM/CP ratio, is important in determining an animal's N status (Moore, 1992). Because limpograss is both higher in IVDOM and lower in CP than most $C_4$ grasses, DOM/CP ratios of 8 to 10 are common (Holderbaum et al., 1991; Lima et al., 1999). These are levels typically associated with responses of cattle to N supplementation.

In rotationally stocked Floralta pastures during summer in Florida, the top half of the canopy had a stem plus sheath/leaf blade ratio of 2.1 compared to 7.3 in the bottom half (Holderbaum et al., 1992). Across layers, stem plus sheath averaged 40 g CP $kg^{-1}$ DM, while leaf blade CP was 100 g $kg^{-1}$. The large difference in leaf/stem ratio from top to bottom of the canopy and the large difference in CP between leaf and stem fractions implies that a shorter stubble height will lead to lower herbage CP concentration, higher DOM/CP ratio, and a greater likelihood of CP deficit in the diet of grazing animals.

### Animal Performance on Limpograss Pastures

Across a number of studies in the literature reviewed by Quesenberry et al. (2004), average daily gain of cattle grazing limpograss cultivars ranged from 0.33 to 0.67 kg $d^{-1}$ with a mean of 0.48 kg $d^{-1}$. There were no consistent differences in ADG between Bigalta and Floralta, although in one study cattle gains were 0.2 kg $d^{-1}$ greater for Bigalta than Floralta prior to deterioration of Bigalta stands (Pitman et al., 1994). Yearling beef steers grazing N-fertilized Floralta limpograss achieved gains of 0.33 kg $d^{-1}$, with values varying from 0.72 kg $d^{-1}$ in May to 0.18 kg $d^{-1}$ in August. Fistulated animals had greater extrusa CP and IVDOM compared with the whole canopy, explained by selectivity for leaf blade. During 3 yr of summer grazing, yearling beef steers gained 0.70 kg $d^{-1}$ on Floralta pastures overseeded with the annual legume aeschynomene (*Aeschynomene americana* L.) and 0.39 kg $d^{-1}$ on N-fertilized Floralta (180 kg N $ha^{-1}$ $yr^{-1}$; Rusland et al., 1988). Herbage from aeschynomene mixtures had a CP concentration of 113 vs. 82 g $kg^{-1}$ for the grass alone, and addition of aeschynomene to limpograss increased daily gain likely due in part to overcoming a CP deficiency.

Several studies evaluated animal performance to protein supplementation for cattle grazing limpograss. Holderbaum et al. (1991) and Newman et al. (2002b) found a positive response to supplementation and the latter suggested that there is a relationship between response to supplement and canopy height. Newman et al. (2002b) tested the average daily gain of crossbred heifers continuously stocked on limpograss pastures that were grazed to 20-, 40-, and 60-cm heights and heifers received either 0 or 640 g DM $d^{-1}$ of a corn-urea mixture with 440 g $kg^{-1}$ CP. They found greater ADG for 20- and 60-cm sward treatments when animals were supplemented compared with unsupplemented, but supplementation did not affect animal response for the 40-cm height. The ADG in unsupplemented treatments increased as height increased from 20 to 40 cm but decreased from 40 (644 g) to 60 cm (327 g). They suggested that buildup of stem in the 60-cm treatment may have reduced intake and forage nutritive value, therefore limiting gain. In contrast, the 40-cm treatment had lowerbulk density, providing greater opportunity for selection and greater ADG even without supplementation. Based on that, Newman et al. (2002b) concluded that grazing limpograss to a 40-cm canopy height (continuous stocking) results in the best compromise between production per animal and per unit area and also increases the likelihood of pasture persistence.

Sollenberger et al. (1988) tested the ADG of crossbred yearling steers grazing limpograss and bahiagrass under continuous stocking during 168 d (spring to mid-fall), in 2 yr and found no difference between the two grasses (0.38 and 0.33 kg $d^{-1}$ for bahiagrass and limpograss, respectively). However, there was a large variation in ADG throughout the season; generally gains were greater in the spring (up to 0.55 kg $d^{-1}$) and declined over the rest of the season (down to 0.15 $d^{-1}$ in the fall). The authors also reported an accumulation of stem material during mid- to late summer, which is consistent with reports from Holderbaum et al. (1992) and Newman et al. (2002b).

Holderbaum et al. (1991; 1992) hypothesized that the low ADG on limpograss pastures observed by Sollenberger et al. (1988) during mid-summer in North Central Florida was due to the low level of CP in limpograss. To test this, they measured the ADG of crossbred steers in limpograss pasture from July to October (84 d, 1987 and 1988) when supplemented with three different levels of N. Levels were no supplement (NP); 630 g $d^{-1}$ of a 21 g $kg^{-1}$ CP (corn-urea mixture) supplement (LO); and 730 g $d^{-1}$ of 50 g $kg^{-1}$ CP (corn-urea) supplement (HI). A mixed pasture of aeschynomene and limpograss was included for comparison purposes (LA).The ADG for NP steers (0.29 kg $d^{-1}$) was always lower than for LA, LO, and HI, and among these three there were no differences (0.53, 0.53, and 0.59 kg $d^{-1}$, respectively). Nevertheless, there was a decline in ADG for all supplemented and nonsupplemented treatments in late summer, suggesting that low CP is not the only factor affecting gain.

Looking at morphological characteristics, Holderbaum et al. (1992) divided the canopy equally in lower (LL) and upper (UL) layers and accounted for leaf blade and stem plus sheath fractions. They found that the greatest proportion of herbage mass in limpograss was in the LL, and proportion of herbage in the LL was even greater during periods of lower ADG. The UL blade fraction had consistently greater CP concentration (average of 96 g $kg^{-1}$ in 1987 and 118 g $kg^{-1}$ in 1988) than the other fractions. Lower layer stem CP averaged 29 and 35 g $kg^{-1}$ in 1987 and 1988, respectively. Herbage IVDOM was greater for the UL than for LL over all periods and years. This suggests that the low ADG during mid- and late summer are related to a higher proportion of stem in the canopy (around 77%) and its low nutritive value.

Lima et al. (1999), moreover, described the same positive response to N supplementation, and in addition they found that pasture N fertilization and N supplementation of animal diets yielded similar results in animal performance. Increasing N fertilizer applied to Floralta from 50 to 150 kg $ha^{-1}$ $yr^{-1}$ increased herbage CP concentration and decreased DOM/CP ratio. Daily gain of yearling beef heifers was much greater on pastures receiving the higher N rate, and these heifers did not respond to corn-urea supplement. Animals grazing pastures fertilized at the low N rate responded to the supplement. Across three experiments with yearling cattle grazing N-fertilized limpograss, increasing N rate from 50 through 180 kg $ha^{-1}$ resulted in greater CP concentration, lower DOM/CP, greater cattle BUN concentration, and increased daily gain (Quesenberry et al., 2004).

In contrast, Kretschmer and Snyder (1979) found no difference in animal performance with or without protein supplementation in South Florida. They attribute this to the greater opportunity for selection of leaves, therefore higher nutritive value of limpograss pastures in the region, primarily due to lenient grazing management and stockpiling.

## Stockpiled Forage

As stated before, limpograss herbage IVDOM declines slowly with increasing maturity, making limpograss well suited for stockpiling. A few studies have analyzed stockpiling date and period as well as fertilization effects on yield and nutritive value. Stockpiling date varies depending on the region. In South Florida, limpograss can be staged later (around mid-September) than in Central Florida (mid-August). In north Florida because of the early onset of cold weather, stockpiling is generally not as useful. There are better alternatives such as to plant cool-season annual forages to feed cattle.

Quesenberry and Ocumpaugh (1980) tested Bigalta, Redalta, and Greenalta nutritive value when stockpiled in North Florida starting in early August. They found that Bigalta was more suited to conservation, because even though the rate of decline in IVDOM was nearly the same for all cultivars, Bigalta had an advantage of, on average, 130 g $kg^{-1}$ greater digestibility over the other two cultivars. At the 14th week of stockpiling, Bigalta IVDOM values were 550 to 620 g $kg^{-1}$, dropping to 450 to 500 g $kg^{-1}$ by the 16th to 20th weeks.

Fertilizing the pastures is important for a stockpiling program. Limpograss responds to cool-season fertilization better than other tropical grasses and N fertilization also influences its nutritive value. In South Florida, Bigalta limpograss was staged on 17 September and fertilized with 112 kg N $ha^{-1}$ on different dates. Early to mid-October fertilization resulted in the best compromise between yield and IVDOM (Kretschmer and Snyder, 1979). Lima et al. (1999) found that limpograss CP was 97 and 115 g $kg^{-1}$ when fertilized with 50 and 150 kg N $ha^{-1}$, respectively. Nevertheless, stockpiled limpograss generally has lower CP concentration (30 to 50 g $kg^{-1}$ on average) than cattle requirements, which makes it necessary to use protein supplementation (Newman et al., 2009).

Different strategies can be used to overcome the problem of low CP in stockpiled limpograss. In south Florida, Vendramini and Arthington (2010) tested animal performance in stockpiled pastures with three levels of supplementation with cottonseed meal or part-time grazing of annual ryegrass (*Lolium multiflorum* Lam.) pastures. Supplementation treatments were 0 (control), 1.1 (CSM1), and 2.2 (CSM2) kg $head^{-1}$ $d^{-1}$ of cottonseed, fed three times per week, or access to annual ryegrass pastures for 24 h three times per week. Limpograss pastures were staged to 10-cm stubble height and fertilized with 56 kg N $ha^{-1}$ in late October and stockpiled for approximately 90 d before animals were assigned to the pastures. Evaluation period was from February to April 2007 and 2008. The CMS2 and ryegrass treatments had greater ADG (0.64 and 0.67 kg $d^{-1}$, respectively) compared with control and CMS1 treatments (0.14 and 0.44 kg $d^{-1}$, respectively). However, as extra area was required for the ryegrass treatment, gain per ha was lower for it than for CMS2 (188 vs. 322 kg $ha^{-1}$). In this experiment, the ryegrass pasture was economically viable only when the cost of establishment was lower than \$200 $ha^{-1}$.

In Central Florida, Davis et al. (1987) staged Bigalta on 10 October and fertilized with eight different N rates up to 400 kg N $ha^{-1}$. There was an increase in CP, IVDOM, K, and P concentration when fertilization rates were greater than 70 kg N $ha^{-1}$. They sampled monthly from December to April and found IVDOMD normally above 500 g $kg^{-1}$ and CP values always higher than 70 g $kg^{-1}$ for N rates > 135 kg $ha^{-1}$. However, in general, N fertilization recommendations to increase yield and nutritive value of limpograss pastures are around 100 kg N $ha^{-1}$ (Quesenberry et al., 2004).

## Origin of the New Hybrids

As was stated before, area planted to limpograss has increased greatly in the past few decades, and virtually all areas are planted with a single cultivar, Floralta. Relying on just one genotype on such a large area can be risky. If diseases or pests attack this cultivar and overcome any tolerance or resistance that it has, all limpograss in the region can be at risk. Therefore, it is of great importance to develop new hybrids, with similar or better characteristics than Floralta.

Among limpograsses, there still is room for improvement in nutritive value and persistence. There are genotypes with higher digestibility, such as Bigalta, and greater persistence, such as Greenalta and Redalta, than Floralta. With this in mind, Drs. Carlos Acuña, Kenneth Quesenberry, and Ann Blount, developed new limpograss hybrids by crossing the most digestible Bigalta with the more persistent Floralta. To accomplish this, racemes of both parents were bagged together in the greenhouse, without emasculation of either. Seed were harvested and germinated, yielding 51 plants, 39 with Bigalta as the female parent and 12 with Floralta as the female parent. New plants were grown in the greenhouse and sampled after 4- and 8-wk regrowth intervals to assess forage nutritive value. In 2006, all 51 hybrids and the parents were planted as single plants, in a randomized complete block design with two replications at the Agronomy Forage Research Unit (AFRU) northeast of Gainesville, FL, and at the

RCREC in Ona, FL. At AFRU, plots were allowed to grow until they reached 1.5 by 1.5-m in area, and they were harvested by clipping at five dates during the growing seasons of 2007 and 2008. Herbage dry matter harvested, nutritive value, and persistence were assessed. Data from AFRU and RCREC were then summarized and analyzed, and eight hybrids were selected for further evaluation under grazing. From those lines selected, four were Floralta x Bigalta crosses (1, 4F, 9, and 10) and four were Bigalta x Floralta (4B, 27, 32, and 34) crosses (female parent is listed first; K.H. Quesenberry, personal communication).

In July 2009, the eight selected lines plus the parents were planted at the Beef Research Unit, Gainesville, in 4- by 5-m plots arranged in a randomized complete block design with three replications. Plots were grazed at two frequencies, 2 and 4 wk, for 2 yr (2010 and 2011). Plots were mob stocked with Angus crossbred heifers to a 20-cm post-grazing stubble, from mid-May through mid-October each year. Persistence (described in terms of limpograss percentage ground cover and weed frequency at the beginning and end of each grazing season), herbage dry matter harvested, and nutritive value (IVDOM and CP) were quantified at each grazing event. Based on the overall results, three lines (4B, 9, and 27) showed poor performance and were discarded. Two lines were intermediate (32 and 34) and there were three elite lines (1, 4F, and 10) identified and selected for further evaluation in the experiments described in this thesis (Wallau et al., 2012).

## Use of Physiological Parameters as a Tool to Guide Initiation of Grazing Events

The idea of using plant physiological concepts in pasture management was developed with the need for better understanding of the plant-animal relationship and plant-plant interactions in a sward. The goal was to better explain herbage accumulation and animal performance responses. The development of parameters such as LI and leaf area index (LAI) and their utilization as management tools was an attempt to bring together physical and physiological properties of plant communities and how those are affected by grazing, harvesting, and different management techniques (Brown and Blaser, 1968; Da Silva and Nascimento Jr., 2007).

The use of light interception as a tool to guide grazing initiation is based on the theory that regrowth dynamics and plant morphology change during the growing season and as a result of differences among cultivars and management practices (Tainton, 1974; Fagundes et al., 2001; Da Silva and Nascimento Jr., 2007; Pedreira et al., 2009). Changes in growing conditions and weather characteristics (e.g., nutrient availability, light, temperature, etc.) during the season will alter the pasture growth rates, and using fixed resting periods can result in an early defoliation where the pasture did not achieve its potential, or late defoliation characterized by excessive stem and dead material accumulation. Either case can result in pasture degradation or losses in productivity (Pedreira et al., 2009). Therefore using a calendar-based criterion with a fixed resting period defined *a priori* to initiate grazing and not taking into account plant characteristics may not generate the best output in terms of productivity, nutritive value, and persistence. Fixed rest periods will likely result in largely different canopy characteristics at the start of grazing events throughout the growing season (Da Silva and Nascimento Jr., 2007).

**Theory and Related Concepts of the Use of Light Interception**

Light interception, as well as LAI, are two of the most widely utilized physiological parameters in grazing experiments. Those concepts were developed based on the sigmoid curve of pasture regrowth (Figure 2-1) described in a series of experiments by

Dr. R.W. Brougham, in New Zealand, during the 1950s and 1960s. Brougham (1958) showed how LAI, thus photosynthesis, changed over the time, and established the relations between LAI, LI, and herbage production and the interaction of those parameters with animal consumption (Bougham 1958; 1960; Harris, 1993).

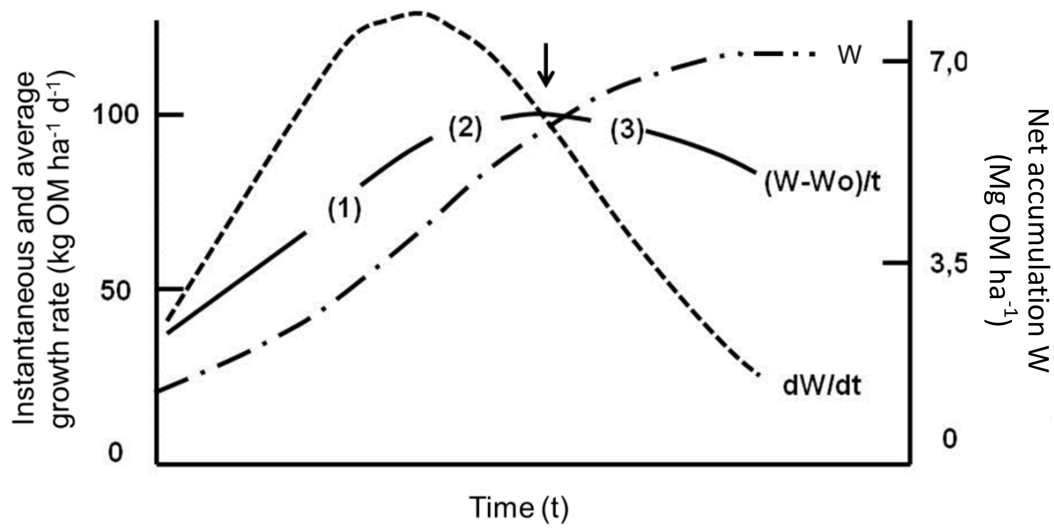


Figure 2-1. Effect of length of regrowth period on net accumulation (W), average growth rate [(W-Wo)/t] and instantaneous growth rate (dW/dt). Arrow indicates 95% light interception (adapted Parsons and Penning, 1988).

The sigmoid curve of regrowth (Figure 2-1) was described as having three marked phases (Brougham 1958; Parson and Penning, 1988). During the first phase, herbage accumulation rate increases curvilinearly and is highly dependent on plant reserves and/or residual leaf area (energy resources) and environmental factors (Brougham, 1958). The following phase is a linear growth (constant accumulation rates) when photosynthesis, aka herbage accumulation rate, is at a maximum and losses associated with senescence are still small. At this point, intra- and inter-specific competition become relevant, especially when the canopy approaches the critical LAI, i.e., when around 95% of the incident light is intercepted (see arrow in Figure 2-1). As regrowth continues there is an inversion on the average accumulation rate curve, and as it approaches the third phase, where nearly all light is intercepted, accumulation rates start decreasing and there is a buildup of stem and dead material. In other words, beyond 95% LI net growth slows significantly because leaves reach their lifespan and senescence rate of the old, shaded leaves in the bottom of the canopy increases and is equal to leaf appearance (Hodgson et al., 1981; Korte et al., 1982; Parson et al., 1988; Lemaire and Chapman, 1996).

The 95% LI level is considered to be the critical, or optimum LAI (Figure 2-2). Managing pastures at this level is a strategy based on the concept of optimizing grazing by always having the pasture in the maximum growth rate possible, therefore increasing total forage production (Parson et al., 1988; Lemaire et al., 2009). The use of 95% LI as grazing trigger will, based on this theory, interrupt the regrowth period when the average accumulation rate (balance between accumulation and senescence) is maximum and the pasture is at the best compromise level between nutritive value and herbage mass. Beyond this point, there is an increase in senescence and shading of the bottom leaves, therefore reduction of photosynthetic capacity, and the increase in biomass is minimal (Tainton, 1974; Parsons et al., 1988). In tropical grasses there is also an increased stem accumulation in this phase, reducing the nutritive value of the forage and negatively affecting the subsequent regrowth period by reducing amount of leaves in the bottom part of the canopy, limiting photosynthetic capacity, and delaying recovery from defoliation.

One aspect that is often overlooked but is extremely important in pasture management is utilization efficiency. Reduced utilization efficiency can be caused by difficulty of harvesting forage by grazing or even avoidance because of stem accumulation and increased fiber concentration. This can result in lodging and trampling of material due to excessively tall canopies, and senescence. Therefore it is important to time grazing based on sward morphology (height and stem percentage) in order to avoid deterioration. Morphological characteristics should not be separated from physiological parameters when making decisions on pasture management (Parsons and Penning, 1988; Gomide and Gomide, 2013).

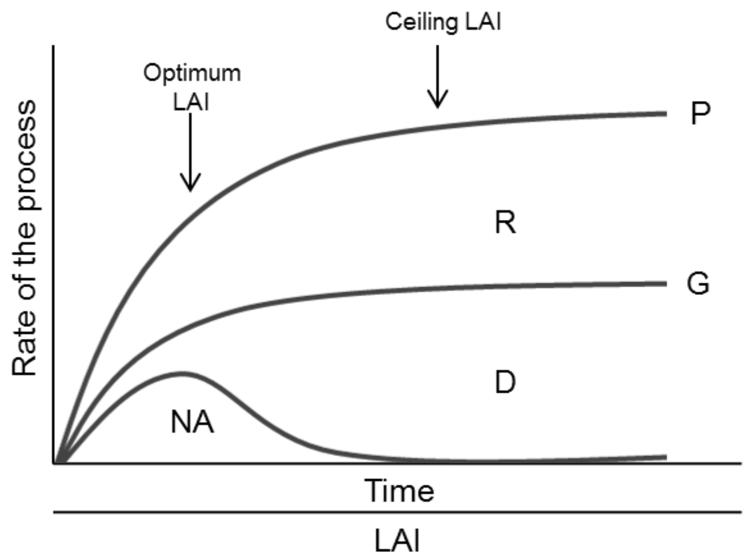


Figure 2-2. Relationship between rates of gross photosynthesis (P), respiration (R), gross tissue production (G), net herbage accumulation (NA) and tissue death (D) in a sward during regrowth (adapted from Parsons et al, 1988; Lemaire and Chapman, 1996).

**Evaluation of Light Interception as a Grazing Management Tool**

Early work with physiological parameters to study canopy structure and grazing relations were developed in temperate regions with C3 grasses or grass-legume mixtures (Brougham, 1960; Brown and Blaser, 1968; Korte et al., 1982; Hodgson, 1981; Parsons et al., 1988, Parsons and Penning, 1988). After those relationships were established, LI and LAI became popular strategies for research in tropical pastures (Da Silva and Nascimento Jr., 2007; Sbrissia et al., 2007; Gomide and Gomide, 2013).

Brazil has become the focal point for physiological experimentation in grazed tropical grass pastures. Most of the experiments are from the past 15 yr and focus on several cultivars of a few of the most used species in forage-livestock systems: *Brachiaria spp.*, guineagrass (*Panicum maximum* Jacq.), elephantgrass (*Pennisetum purpureum* Schumach) and bermudagrass [*Cynodon dactylon* (L.) Pers; Fagundes et al, 2001; Carnevalli et al., 2006]. Most experiments with LI measurements compared the 95% level with total light interception (100% or sometimes defined as 2 wk after 95% was reached) as treatments. Some also test a lower level such as 90%.

Carnevalli et al. (2006) tested guineagrass cv. Mombaça under grazing with four management strategies: a factorial of two LI levels (95 and 100%) and two stubble heights (30- and 50-cm) for a period of 411 d. The best results obtained in terms of herbage accumulated and herbage harvested were from plots grazed to a 30-cm residual height. The LI 100% treatment had greater litter losses and stem accumulation than LI 95%. The authors reported difficulty in reaching the target stubble on the plots assigned to the LI 100% treatments, especially the shorter stubble (30 cm). The treatment LI 100% and 30 cm stubble presented a higher proportion of leaf blade in the litter, possibly because of the trampling associated with the tall canopy when animals entered the plots.

With guineagrass cv. Tanzânia, Barbosa et al. (2007) tested three levels of LI (90, 95, and 100%) as the trigger for grazing initiation during a period of 309 d. Plots were grazed to 25- or 50-cm stubble height. Combinations of lower LI and high stubble increased the frequency of grazing cycles, therefore reducing resting period. However, the more frequent defoliation did not compensate for the higher accumulation on the more lenient treatments, that had in general the largest pre-grazing herbage mass. Leaf mass in the 90 and 95% LI were similar, denoting a higher stem elongation and mass accumulation after 90% LI was reached. Besides accumulating more herbage mass, plots assigned to a 100% LI had also high residual mass and stem and dead material fractions, reducing harvesting efficiency and utilization of the resources. The best results were achieved with the combination of 95% LI and 25-cm stubble. The lower level of LI resulted in underutilization of the full growing capacity of the pastures. The authors also reported difficulty in achieving the lower stubble (25 cm) on the least frequent grazing treatment (LI 100%), especially toward the end of the grazing season when stem and dead material had accumulated significantly. Both Carnevalli et al. (2006) and Barbosa et al. (2007) observed that 95% LI was achieved at a consistent height throughout the year in their experiments. They recommended a management of 90- and 70-cm canopy heights for initiation of grazing when associated with stubble heights of 30 and 25 cm, for Mombaça and Tanzânia guineagrass cultivars, respectively.

In *Brachiaria brizantha* cv. Xaraés pastures, Pedreira et al. (2009) used two LI criteria (95 and 100%) and a fixed regrowth interval (28 d) as determinants of when grazing should be initiated. All treatments were grazed to 15-cm stubble. The experiment was conducted over two seasons (spring and summer, 153 d). The authors reported a season effect on the herbage production and canopy height when pastures achieved 28 d of regrowth, but more similar values were obtained across the seasons when using the LI parameters. During the spring, when temperature and precipitation were lower, the 28-d treatment showed responses similar to the LI 95%, nonetheless in the summer, when growth conditions were more favorable, the responses were closer to those obtained at 100% LI level. Greater herbage accumulation was obtained in the treatment 100% LI due to a greater amount of stem material relative to 95% LI.

For sheep grazing perennial ryegrass (*Lolium perenne* L.) pastures, Tainton (1974) tested a combination of two grazing frequencies (95% LI and two weeks after this point was reached) and two exit heights (2.5 and 6.2 cm) on production and canopy morphological characteristics.  The 95% LI and 2 wk later treatments were not different in terms of herbage accumulation, but the 95%LI treatment had greater net herbage accumulation due to the marked increase (33%) in dead material on the more lenient treatment. According to the author, even the 95% LI treatment had an unexpected amount of dead material (18%). The lenient grazing induced a decrease in tiller number and increase in tiller mass (35% more compared to the more intensive management) and this was thought to contribute to the large amount of litter and stem material remaining after grazing.

Several studies (e.g., Sbrissia et al., 2007) indicate the effectiveness of using LI as a parameter to initiate grazing in tropical grasses, as it has already been proven as a tool for temperate species (Parsons et al., 1988, Parsons and Penning, 1988). The weak link is how to relate those parameters to simple, easily measurable, canopy characteristics (i.e., height) to be used in the field by farmers. Attempts had been made with different levels of success to relate optimum height and LI (Carnevalli et al., 2006; Barbosa et al., 2007, Sbrissia et al., 2007), but those characteristics are variable depending on the level of management applied, season, and genotype (Fagundes et al., 2001; Gomide and Gomide, 2013). Oversimplifying the equation and not taking into account differences in management practices, canopy characteristics, and harvesting efficiency can lead to incorrect interpretations and over-generalized recommendations.

## Literature Summary and Research Objectives

A major constraint to productivity of beef cattle production systems in Florida is the cool-season shortfall of forage for grazing. Area planted to limpograss in Florida has increased dramatically over the last 30 yr because it continues to produce herbage for grazing in South Florida during mild winters and winters with extended periods between frost events. Currently, nearly all limpograss area in South Florida is planted with cultivar Floralta. Total reliance on one cultivar is not optimal, thus development and testing of additional limpograsses is needed to broaden the genetic base and to address shortcomings of Floralta. Specifically, there are limpograsses with superior digestibility to Floralta, so the opportunity exists to increase forage digestibility. Additionally, Floralta is not as persistent under repeated grazing as some other important species in the region, so identifying lines with superior persistence is desirable.

New hybrids have been developed through breeding and screened for performance in small-plot clipping trials and to a limited extent under grazing. This has resulted in selection of five superior breeding lines for further evaluation. It is important to assess the performance of these lines under a wide range of grazing stress to identify those with greatest potential for use in Florida. In addition, because limpograss is often used as stockpiled forage, it is important that potential new cultivars be assessed under this management.

Thus, the current research project was designed to evaluate five limpograss breeding lines in terms of persistence, productivity, and nutritive value under various grazing and stockpiling management practices, with the ultimate goal to select the line or lines with greatest adaptation to Florida conditions. To achieve that goal, two experiments were carried out in 2012 and 2013, the first one focusing on different grazing management strategies and the second on stockpiling. Data contained in this thesis are from the 2012 year of each study, except for the weed frequency and limpograss cover, for which data from the first evaluation of 2013 is also presented.

# CHAPTER 3
# PERFORMANCE OF LIMPOGRASS BREEDING LINES UNDER A RANGE OF GRAZING MANAGEMENT STRATEGIES

## Overview of Research Problem

Limpograss [*Hemarthria altissima* (Poir.) Stapf et C.E. Hubb.] is a stoloniferous, warm-season perennial forage that was introduced to the USA from South Africa in the 1960s. It was found to be well adapted to Florida and is frequently used to extend the grazing season in regions of the state with poorly drained soils (Quesenberry et al, 2004). The first cultivars were released in 1978 ('Redalta', 'Greenalta', and 'Bigalta'; Quesenberry et al., 1978) and in 1984 ('Floralta'; Quesenberry et al., 1984). Because of superior nutritive value than Greenalta and Redalta, and greater persistence than Bigalta, only Floralta was adopted widely and is currently being used in Florida.

In the USA, limpograss is cultivated mainly in southern Florida, where winter temperatures are mild and frost events infrequent. Winter herbage production is the primary trait that has contributed to the adoption of limpograss by producers, and use of limpograss has provided much needed forage during the cool season and reduced livestock feeding costs. In the past 30 yr, the area planted to limpograss in Florida has grown faster than that of any other perennial forage grass species, and currently it is estimated that over 0.2 million ha are planted to Floralta (Quesenberry et al., 2004).

As area planted to limpograss grows, it is increasingly important for producers to have access to more than one genotype, because any pest or disease outbreak could have a major negative impact. Recent University of Florida research with limpograss has focused on developing new hybrids between Floralta and Bigalta. Preliminary clipping and grazing trials evaluated 51 breeding lines and identified five (informally named 1, 4F, 10, 32, and 34) with superior performance (Wallau et al., 2012). With an overall program goal of identifying the best limpograsses for cultivar release, the specific objective of this experiment was to investigate the forage productivity, persistence, and sward canopy characteristics of these five breeding lines vs. Floralta in response to different grazing management strategies.

## Materials and Methods

### Site Characteristics, Treatments, and Design

The experiment was conducted during 2012 at the University of Florida Beef Research Unit, northeast of Gainesville, FL (29° 38’ N, 82° 22’ W). The soil at the site is of the Pomona series of poorly drained sandy Spodosols (sandy, siliceous, hyperthermic Ultic Alaquods). Soil samples were taken during the time of land preparation and tested by the Extension Soil Testing Lab at the University of Florida. Soil pH in water was 5.3 and soil P, K, and Mg levels were 5.5, 36, and 109 mg $kg^{-1}$, respectively.

The study consisted of 24 treatments, arranged as a 6 x 2 x 2 factorial experiment in two replications of a randomized complete block design. The 48 experimental units were each 8 by 8 m in area. Treatments included six limpograss entries (1, 4F, 10, 32, 34, and Floralta), two pre-grazing canopy light interception levels (LI; 80 and 95%), and two post-grazing stubble heights (SH; 20 and 30 cm). From here forward the SH treatments will be referred to as SH20 and SH30 and the LI treatments as LI80 and LI95.

A pasture characteristic, i.e., canopy light interception, was chosen as the determinant of when a grazing event was initiated instead of a calendar-based, fixed regrowth interval. This was done because plant growth rates vary markedly during the growing season, resulting in widely divergent sward characteristics at the start of grazing when a fixed time interval is used to define grazing frequency. Greater consistency achieved by using a plant-based criterion may also aid in development of practical management guidelines for producers (i.e., target height for initiation of grazing for various breeding lines) because this height may be unique to a particular entry. Several authors have reported a high correlation between canopy height and LI (e.g., Carnevalli et al., 2006; Barbosa et al., 2007; Sbrissia et al., 2007), and they proposed specific pre-grazing canopy heights to achieve 95% LI for different pasture crops. They further suggested that these heights could be used by producers to determine when grazing should be initiated on farm. However, morphological characteristics tend to vary depending on management, season, and genotype, therefore height may not be consistently related to LI for all species and management practices (Gomide and Gomide, 2013).

The 95% LI level has been widely used in the literature as an “optimum” threshold for initiation of grazing because it represents the inflection point of the growth curve, where growth rates are maximum but before herbage accumulation rate starts decreasing (Lemaire and Chapman, 1996; da Silva and Nascimento Jr., 2007). Research with a number of $C_4$ grasses has shown that 95% LI at initiation of a grazing event is near optimal for sustaining high growth rates and good nutritive value throughout the season under rotational stocking (Donald, 1961, as cited by Lemaire and Chapman, 1996; Sbrissia et al., 2007; da Silva and Nascimento Jr., 2007). The lower LI level of 80% was chosen to provide more frequent grazing that reduces length of recovery periods after defoliation and applies more stress to the grasses than the 95% level (Lemaire and Chapman, 1996; da Silva and Nascimento Jr., 2007).

The stubble height treatments were selected based on previous rotational stocking studies with limpograss which led to recommendations of a 25- to 35-cm post-grazing stubble height (Quesenberry et al., 2004). The 30-cm height was intended to be near optimal, while the 20-cm height was chosen so that significant selection pressure was applied to assess grazing tolerance.

**Land Preparation and Establishment**

The experimental area had previously been a long-term bahiagrass (*Paspalum notatum* Flügge) pasture. It was sprayed with glyphosate at a rate of 5.6 kg a.i. $ha^{-1}$ on 5 July 2011. After bahiagrass plants died the area was plowed and then disked several times. Prior to planting, the seedbed was leveled and firmed using a drag. Plots were planted on 27 July 2011 using well-fertilized, mature, above-ground stems of the various limpograss entries. Stems were surface broadcast and plots were then disked to incorporate them into the soil, and the area was rolled to firm the seedbed.

Approximately 3 wk after planting (18 Aug. 2011), the plots were fertilized with 40 kg N, 5 kg P, and 35 kg K $ha^{-1}$. Dolomitic lime was applied at a rate of 2.24 Mg $ha^{-1}$ on 22 Aug. 2011. Plots were fertilized again on 6 Oct. 2011 with 40 kg N, 5 kg P, and 35 kg K $ha^{-1}$. All plots were sprayed for sedge control on 31 August 2011 with Basagran (bentazon) at a rate of 2.34 L $ha^{-1}$ and on 26 September 2011 with Outrider (sulfosulfuron) at a rate of 91 g $ha^{-1}$. Plots were allowed to grow without defoliation during the remainder of summer and fall 2011. On 17 Apr. 2012, plots were sprayed with Banvel (dicamba) at 2.4 L $ha^{-1}$ and then fertilized 1 d later with 45 kg N, 20 kg P, and 75 kg K $ha^{-1}$ to further support establishment.

Plots were staged by mowing to 10-cm stubble on 22 May 2012 and cut material was removed. To control existing vaseygrass (*Paspalum urvillei* Steud.) in the plots, glyphosate was applied with a wick. Additional N was applied at 40 kg $ha^{-1}$ on 4 June (all treatments), 17 July (all the LI80 treatments) and 27 July (all LI95), and 4 September (all treatments), for a total of 120 kg N $ha^{-1}$ $yr^{-1}$ for each experiment unit during the experimental period in 2012.

**Imposing Grazing Treatments**

Initiation of a grazing event was based on canopy LI. Measurements of LI to determine when grazing should occur on a given experimental unit began when visual appraisal indicated that the pasture was within 10 to 15 percentage units of the target LI. At that point, LI was measured approximately twice weekly. Whenever LI was within three percentage units of the target, grazing occurred the following day. Plots were mob-grazed using cross-bred yearling Angus heifers, weighing approximately 370 kg. Cattle were fasted overnight (for 12 h) before being assigned to pastures. Eight to twelve animals were allocated to each plot and allowed to graze until target stubble was reached (either 20 or 30 cm). Residence time in a pasture for a grazing event was 0.5 to 2 h. After reaching the target stubble, animals were transferred to another experimental unit or put on reserve pastures of primarily other $C_4$ grasses until they were needed again.

**Response Variables Measured**

**Light interception**

Light interception was measured using a 1-m long line quantum sensor (type SS1 for below canopy measurements and sunshine sensor type BF3 for full sunlight measurements) connected to a SunScan Canopy Analysis System model E-312-SS1-COM (Delta-T Devices, Cambridge, UK). Light interception was characterized at five representative sites per experimental unit between 1000 and 1500 h Eastern Daylight

Savings time. Below- and above-canopy incident photosynthetically active radiation (PAR) were measured simultaneously and the percentage of LI was determined by dividing the amount of light intercepted by the canopy (total incident PAR minus PAR reaching the soil surface) by the total incident PAR and multiplying by 100.

**Herbage mass, herbage accumulation, and herbage harvested**

Herbage mass was measured pre- and post-grazing for every grazing event. Herbage mass was quantified by clipping four representative 0.25-$m^2$ quadrats per experimental unit to a stubble height 10 cm less than the target exit height (i.e., 10 cm for the 20-cm treatment and 20 cm for the 30-cm treatment). Sampling to 10 cm below the target provides some margin for error should the exit stubble height be slightly less than the target, and it also minimizes carryover effects on the pasture that may occur if samples are clipped to heights that are much lower than the height to which the pasture is grazed.

Herbage mass samples were dried at 60°C to constant weight, and the average of the four sites used to represent the pasture. Herbage accumulation was calculated as the difference between post-grazing herbage mass of the previous grazing cycle (residual mass) and pre-grazing herbage mass of the current cycle. Herbage accumulation for all the grazing events was summed to determine total annual herbage accumulated. Herbage accumulation rate was calculated as herbage accumulation divided by number of days in the regrowth period. Herbage harvested was calculated as the difference between pre- and post-grazing herbage mass of the same grazing cycle, and summed across cycles to determine total season herbage harvested.

**Pre-graze canopy height and sward bulk density**

Canopy height were measured pre- and post-grazing for every grazing event. Pre-grazing height was used to characterize sward characteristics at a given level of light interception, while post-grazing height was quantified to determine when the target SH was achieved. Canopy height was measured using a ruler at 20 randomly selected locations per plot pre-grazing and at 10 locations post-grazing. Pre-grazing sward bulk density was assessed using measures of pre-grazing herbage mass and canopy height minus cutting height (target stubble height minus 10 cm). Bulk density was expressed in kg of DM $ha^{-1}$ $cm^{-1}$.

**Herbage nutritive value**

Samples for nutritive value were taken to represent the forage consumed by animals during a grazing event. Ten hand-plucked samples were taken per experimental unit immediately prior to each grazing event by clipping forage to the target stubble at random locations in the pasture. Those samples were composited within each experimental unit and dried at 60°C. All samples were ground to pass a 1-mm stainless steel screen in a Wiley mill (Model 4 Thomas-Wiley Laboratory Mill, Thomas Scientific, Swedeboro, NJ) and nutritive value was measured as in vitro digestible organic matter (IVDOM) and crude protein (CP) concentrations. Analysis for IVDOM was performed using a modification of the two-stage technique (Moore and Mott, 1974). For N analysis, samples were digested using a modification of the aluminum block digestion procedure of Gallaher et al. (1975). Nitrogen in the digestate was determined by semi-automated colorimetry (Hambleton, 1977), and CP concentration was calculated by multiplying total N by 6.25 (assuming 16% N in protein).

**Persistence**

Persistence was quantified in terms of percentage limpograss cover in the pasture and weed frequency. For both measurements, a 0.5- by 2-m aluminum frame divided into 0.1- by 0.1-m cells was used. The frame was placed at four locations in each experimental unit. The cover rating was made visually by the same observer, and percentage of limpograss was estimated in six 0.2- by 0.2-m quadrats per frame placement location (four locations times six observations per location for 24 observations per plot). Possible cover options included bare ground, limpograss, and weeds. Weed frequency was determined by indicating presence or absence of weeds (yes or no) in 20, 0.1- by 0.1-m quadrats per frame placement location (total of 80 measures per plot). Measurements were taken at the beginning of the grazing season in 2012 (June) before grazing treatments were first applied and again in May and June 2013.

An infestation of spittlebug [*Prosapia bicincta* (Say)] occurred toward the end of the 2012 growing season. Damage was evaluated visually on a scale from 0 (least damage) to 10 (most damage).

**Vertical distribution of sward components**

Assessing distribution of limpograss sward components is important because the spatial arrangement of limpograss leaf and stem may affect grazing animal response due to large differences in CP concentration between plant parts (Holderbaum et al., 1992; Pitman et al., 1994; Newman et al., 2002a, 2003a). Vertical distribution of sward components was evaluated prior to the third grazing event on all four grazing treatments of three of the five breeding lines (1, 4F, and 10) plus Floralta. Thus, there were 16 treatments and two replicates per treatment for this portion of the study. Entries included those that appeared to have greatest potential for subsequent cultivar release based on the results of the grazing experiment conducted during 2010 and 2011 (Wallau et al., 2012).

Samples were taken from two 0.25-$m^2$ quadrats per experimental unit. The herbage was harvested in two strata, the upper and lower half of the grazed portion of the sward. For example, if pre-grazing sward height was 60 cm and it was to be grazed to 20-cm stubble, the upper half was between 40 and 60 cm above soil surface, and the lower half was the portion between 20 and 40 cm. A sub-sample of herbage from each stratum was separated into leaf blade (leaf) and stem plus sheath (stem) fractions, and the fractions and the remaining non-separated sample were dried and weighed to determine leaf blade:stem ratio and total and plant part bulk density. For each stratum, IVDOM and CP were determined for leaf, stem, and total herbage fractions to describe vertical distribution of nutritive value in the canopy.

**Sward characteristics during different seasons of the year**

As number of grazing events and dates for specific grazing cycles were different among treatments, data were grouped in early, mid-, and late seasons to facilitate comparisons. Early season was the first grazing cycle for both LI levels, starting on 11 June and ending on 21 June. For calculation of herbage accumulation rate in this first season, the regrowth period was considered to begin on 22 May when the plots were staged by clipping to 10-cm stubble. Mid-season comprised the second and third grazing events for treatment LI80 and the second event for LI95, starting on 1 July and ending on 9 August. The late season included the fourth and fifth grazing cycles for treatment LI80 and the third and fourth cycles for treatment LI95, starting on 21 August and finishing on 12 October. Only Entry 10 was grazed for a fourth time for the LI95 treatment.

### Statistical Analyses

Data were analyzed using PROC GLIMMIX with grass entry, stubble height, and LI as fixed effects and block as random. Because pastures were grazed different numbers of times per growing season due to treatment definition, herbage accumulation, herbage harvested, and herbage nutritive value were assessed on a total-season basis and by early, mid-, and late season as described earlier. Season was considered a repeated measurement for the statistical analyses including season.

Limpograss cover and weed frequency were analyzed either by sampling date or as magnitude of change over time. Morphological (strata) and season data were analyzed as repeated measures with an autoregressive covariance structure. Mean separation for grass entries was accomplished using Fisher's least significance difference test and for stubble height and LI means using the F test. All means reported are least squares means.

## Results and Discussion

### Length of the Grazing Season

The grazing season started the week of 11 June and 18 June 2012 for the LI80 and LI95 treatments, respectively. The length of the grazing season was calculated as the number of days between the first and last grazing event, and it averaged 93 d with a range from 62 to 123 d. There were entry by LI and entry by SH interaction effects ($P$ = 0.007 and $P$ < 0.001, respectively; Table 3-1). Length of the grazing season was reduced by a spittlebug infestation that started on a few plots in mid-September and by early October was already widespread. Entry differences in tolerance to spittlebug and sward condition due to grazing treatment affected length of grazing season.

The entry x LI interaction occurred because length of grazing season was greater for LI80 than LI95 for all entries except 10 for which there was no LI effect (Table 3-1). At LI80, Entries 10, 4F, and Floralta had similar length of grazing season that was longer than for other entries, but at LI95 Entry 10 had the longest grazing season. Stubble height affected length of grazing season only for Entry 1. Entry 10 had the longest grazing season for both SH levels (Table 3-1).

Number of grazing events was generally three for LI95 except for Entry 10 that was grazed four times. Entries 10, 4F, and Floralta were grazed five times for treatment LI80 compared with Entry 1 (average of 4.5 times) and Entries 32 and 34 (four times each). Within a level of LI, stubble height and limpograss entry treatments resulted in pastures being ready to graze at a range of times. This feature is captured in Figure 3-1.

**Length of the Resting Period Between Grazing Events**

The average length of the resting period was influenced by SH ($P = 0.006$) and LI ($P < 0.001$) treatments. The LI80 plots were grazed more frequently, every 29 d on average, in comparison with LI95, where animals returned every 38 d. Both of these grazing frequencies are within a range of recommended management for limpograss under rotational stocking (Sollenberger et al., 1988; Newman et al., 2003b). The SH30 treatment had slightly shorter rest periods (32 d) than did SH20 (35 d). A similar response was obtained by Carnevalli et al. (2006) and Barbosa et al. (2007), both with guineagrass (*Panicum maximum* Jacq.), where rest periods were shorter with taller stubble height treatments due to greater residual leaf area than for shorter stubble heights.

### Post-grazing Light Interception

There was a LI by SH ($P < 0.001$) and entry by LI ($P = 0.002$) interaction for post-grazing LI. The LI by SH interaction occurred because for LI80 there was no difference in post-grazing LI between SH levels (60 and 56% for SH20 and SH30, respectively; SE = 2.6), but post-grazing LI was greater for SH30 (64%) than for SH20 (50%) in LI95. Within SH30, post-grazing LI was higher for LI95 than for LI80 (64 vs. 56%, respectively), but the opposite was observed for SH20 (50 vs. 60%, respectively), possibly because of the increased trampling that occurred trying to achieve a shorter SH when the initial canopy height was taller (LI95). The interaction of entry by LI occurred because post-grazing LI was greater for Entry 1 at LI80 than at LI95 (61 vs. 50%, respectively; Table 3-2), but the opposite happened for Entry 10 (56 vs. 69%, respectively). There was no difference between LI levels for Entry 4F and Floralta. Within LI80, Floralta had the lowest post-grazing LI (53%), but it was not different than Entry 10. At LI95, Entry 10 had greater post-grazing LI (69%) than the other entries.

### Herbage Accumulated, Herbage Accumulation Rate, and Herbage Harvested

For total annual herbage accumulation, there was LI by SH interaction and an entry effect ($P = 0.034$ and 0.010, respectively). Interaction occurred because herbage accumulation was greater for 20- than 30-cm SH for LI80, but SH did not affect the response for LI95 (Table 3-3). There was a trend ($P = 0.09$) toward greater herbage accumulation for LI 95 than LI80 when SH was 30 cm, but there was no effect of LI when SH was 20 cm (Table 3-3).

Entry 10 had greater total annual herbage accumulation than Entries 1, 32, and 34, but did not differ from 4F and Floralta (Table 3-4). Herbage accumulation reported for limpograss in the literature varies rather widely, ranging from around 8 to 16 Mg ha$^{-1}$, depending on the region and management (Quesenberry et al., 1984; Sollenberger et al., 1988; Pitman et al., 1994; Newman et al., 2009). Values found in this experiment are within the range of those reported in the literature and comparable to those from a previous experiment where these lines were tested (Wallau et al., 2012). In that study, Entry 10 herbage accumulation was 10.1 Mg $ha^{-1}$ $yr^{-1}$ and was greater than Entry 1 but not different than Entries 4F, 32, 34, and Floralta when grazed to a 20-cm stubble every 2 or 4 wk.

Herbage accumulation rate for the whole season was calculated as the total herbage accumulation divided by the length of the growing season, with growing season length calculated as the period from staging (22 May) to the last grazing event. Herbage accumulation rate was affected by LI x SH interaction ($P$ = 0.031; Table 3-3). Interaction occurred because there was no effect of SH for LI95 (100 and 102 kg DM $ha^{-1}$ $d^{-1}$, for SH20 and SH30, respectively), but for LI80 herbage accumulation rate was greater for SH20 than SH30 (91 vs. 69 kg DM $ha^{-1}$ $d^{-1}$, respectively).

Herbage harvested was affected by entry ($P$ = 0.009) and LI by SH interaction ($P$ = 0.016) effects (Table 3-3). Interaction occurred because SH20 had greater herbage harvested than SH30 when LI was 80 (9.1 vs. 6.5 Mg $ha^{-1}$, respectively), but there was no effect of SH for LI95. When SH was 20 cm, LI80 had greater herbage harvested than LI95 (9.1 vs. 7.3 Mg DM $ha^{-1}$, respectively; $P$ = 0.05), but there was no effect of LI for SH30. Because of the greater amount of stem and taller canopy for LI95 before grazing began, there was much greater incidence of lodging and animal trampling than for LI80. When LI was 95%, cattle were reluctant to continue grazing after the tops of plants were removed because of the high proportion of stem in the lower stratum of the canopy, especially on SH20 plots. If animals were maintained on these pastures for longer periods of time in an attempt to achieve the target stubble, they would lie down or walk around the plot, increasing the amount of herbage lodged and trampled and negatively affecting regrowth during the subsequent grazing cycle.

The sampling procedure used in 2012 was not capable of quantifying the amount of lodged and trampled forage that end up below the target SH. This approach was modified for the 2013 grazing season to better account for this wasted herbage. The same challenge in low stubble height treatments was reported by Carnevalli et al. (2006) and Barbosa et al. (2007). They found it problematic to achieve guineagrass (cv. Mombaça and Tanzânia, respectively) stubble heights of 30 and 25 cm, respectively, when grazing was initiated at an LI of ~100%. The problem was most pronounced toward the end of the grazing season when stem and dead material had built up in the lower part of the canopy. Carnevalli et al. (2006) also reported that an LI level of nearly 100% at initiation of grazing created conditions where lodging was more likely to occur.

Differences observed in herbage accumulated and harvested (total season and per grazing cycle) between SH20 and SH30 within the LI80 treatment occurred despite there being no difference in pre-grazing height (59 and 60 cm, respectively). Differences in herbage harvested likely occurred because SH20 had a greater proportion of pre-grazing herbage mass removed. Treatment LI80-SH30 also had a shorter regrowth period. Lack of difference between SH levels for LI95 in herbage harvested and accumulated during the season and per period was likely because the longer regrowth period allowed time for both treatments to approach a ceiling leaf area index (not measured) and production.

Herbage accumulated and harvested were not different for Entries 10, 4F, and Floralta (Table 3-4). Entry 10 accumulated around 30% more forage than Entries 1, 32, and 34, and had from 30 to 40% more herbage harvested. The rank and absolute values of herbage accumulated and harvested obtained in 2012 were generally consistent with results from a preliminary study conducted in 2010 and 2011 at the same research station (Wallau et al., 2012). The 2010-11 study data showed significant differences of 10 and 4F from Floralta for herbage harvested but not for herbage accumulated.

### Pre-grazing Canopy Height and Sward Bulk Density

There was LI x SH interaction for canopy height ($P$ = 0.024; Table 3-5). The LI95 swards were 11 to 16 cm taller at initiation of grazing than LI80 swards regardless of level of SH. Interaction occurred because there was no SH difference in canopy height for LI80, but SH20 pastures were shorter than SH30 pastures when they reached LI95 (70 vs. 76 cm, respectively).

Bulk density on a total season basis was affected by SH ($P$ = 0.003) and LI ($P$ = 0.049) main effects. Pasture grazed to a shorter stubble height (20 cm) had a higher bulk density (69 kg $ha^{-1}$ $cm^{-1}$; SE = 3.2) than those grazed to 30 cm (62 kg $ha^{-1}$ $cm^{-1}$). Pastures under high grazing intensity tend to shift toward a shorter canopy with high bulk and tiller density as a phenotypic plasticity response for grazing avoidance (Chapman and Lemaire, 1993; Sbrissia et al., 2007). For a large range of forage species, bulk density values were between 100 and 200 kg $ha^{-1}$ $cm^{-1}$ (Sollenberger and Burns, 2001), and limpograss stands were around 180 kg $ha^{-1}$ $cm^{-1}$ (Holderbaum et al., 1992). Values found in this current experiment were much lower than in the Holderbaum et al. (1992) experiment, but they are within ranges previously reported. Newman et al. (2002b) also found an increase in bulk density as continuously stocked limpograss pastures were maintained at shorter canopy heights. In that study, the 2-yr average bulk density for pastures maintained at 20 cm was 109 kg $ha^{-1}$ $cm^{-1}$, while it was around 63 kg $ha^{-1}$ $cm^{-1}$ for those kept at 40 and 60 cm.

Bulk density was greater in LI95 plots (69 kg $ha^{-1}$ $cm^{-1}$; SE = 3.2) than LI80 (63 kg $ha^{-1}$ $cm^{-1}$), in spite of LI80 having a shorter canopy height. This is likely an effect of the increased stem accumulation on LI95 plots, especially in the lower portion of the canopy (described later in Chapter 3). An increased competition for light decreases the number of tillers and increases canopy height (Sbrissia et al., 2007). In the case of limpograss, taller tillers requires greater structural strength and therefore increases the bulk density (Newman et al., 2003a). Stobbs (1973) also reported increased bulk density with maturity for *Chloris gayana* Kunth and *Setaria anceps* (Schumach.) Stapf & C.E. Hubb., especially in lower canopy layers. High bulk density can result in a reduction in number of tongue sweeps, bite volume, bite weight, and selectivity, with the ultimate result being a reduction in animal performance (Stobbs, 1975; Burns and Sollenberger, 2001). Extremely low bulk densities, on the other hand, can decrease bite weight to a point where it cannot be compensated for by increasing bite frequency, therefore negatively affecting animal performance. Newman et al. (2002b) reported higher average daily gain of steers continuously stocked on limpograss pasture maintained at 40 cm (0.64 kg $d^{-1}$) than at 20 cm (0.45 kg $d^{-1}$), and the 40-cm swards had lower bulk density. Average daily gain decreased again (quadratic response) for pastures maintained at 60 cm (0.33 kg $d^{-1}$), even though that bulk density decreased further more. This response was associated with an increase in stem accumulation, lodging and trampling on the 60-cm treatment, factors that could have reduced accessibility to leaves (Newman et al., 2002b; 2003a).

During the experimental period, 277 LI and corresponding canopy height measurements were obtained. Those data points were integrated into a linear regression analysis to verify the correlation between them. The observed coefficient of determination was fairly low ($r^2 = 0.39$), denoting a poor correlation between the parameters. Contrary to results reported for other grass species (Carnevalli et al., 2006; Barbosa et al., 2007), using canopy height as a proxy for LI in order to initiate grazing at 95% LI does not seem to be a valid technique with limpograss.

**Nutritive Value**

Average total season herbage CP concentration was affected by the main effects of LI and SH ($P = 0.002$ and $P = 0.016$, respectively). Herbage CP was greater for LI80 (89 g $kg^{-1}$; SE = 2.3) than LI95 (81 g $kg^{-1}$), probably a consequence of the shorter length of rest period for LI80. As there was no difference in herbage accumulated between LI treatments, it is unlikely that there were any differences in magnitude of dilution effects on CP concentration. Plots grazed to SH30 had greater CP concentration compared with SH20 (88 vs. 82 g $kg^{-1}$, respectively; SE = 2.3), likely due to less stem material lower in the canopy being sampled for SH30 vs. SH20. Levels of CP were less than those reported by Wallau et al. (2012), but in that experiment grazing intervals were more frequent at 2 and 4 wk.

The average herbage IVDOM concentration was 578 g $kg^{-1}$, and the response was not affected by any treatment or interaction. Concentrations in this experiment were greater than those reported for the same entries by Wallau et al. (2012), but they are within a range reported for limpograss in the literature (Holderbaum et al., 1992; Newman et al., 2002b). The lack of LI effect, i.e., maturity, supports the often stated concept that limpograss maintains high levels of digestibility over a wide range of maturity (Rusland et al., 1988; Holderbaum et al., 1992; Quesenberry et al., 2004). Digestibility of limpograss pastures on a 42-d rotational stocking system (35-d resting period, 7-d grazing) varied from 504 to 573 g $kg^{-1}$ when sampled from mid-July to mid-September (Holderbaum et al., 1992). Moore (1992) reported that almost 70% of the limpograss samples submitted to the Florida Extension Forage Testing Program presented total digestible nutrient concentrations above 510 g $kg^{-1}$. Total season IVDOM and CP for each entry is reported on Table 3-6.

## Sward Characteristics During Different Seasons

Vertical distribution of plant parts and chemical composition were evaluated for pre-grazing canopies at the third grazing event of the season. Dates at which plots were grazed for the third time differed among treatments because of varying lengths of regrowth period.

### Sward composition

Leaf percentage was affected by stratum ($P < 0.001$), SH ($P = 0.028$), and LI x entry interaction ($P = 0.027$). Leaf percentage in the upper stratum was 39% vs. 23% in the lower stratum (SE = 1.4). Leaf percentage in the lower stratum was not as low as reported in other studies in the literature. Holderbaum et al. (1992) and Newman et al. (2003a) found from 15 to 33% of leaf in the upper strata and close to 10% in the lower. The SH30 treatment had 34% leaf vs. 29% for the SH20 (SE = 1.4). The LI x entry interaction (Table 3-7) occurred because 4F had 12 percentage units greater leaf proportion for LI80 than LI95 (38 vs. 26%, respectively), but there was no LI difference for any other entry. Entry 4F had a greater proportion of leaves within LI80 (38%) than either Entry 10 or Floralta, but it was not different than Entry 1 (Table 3-7). Within LI95, Entry 10 had a greater proportion of leaves than 4F (33 vs. 26%), but it was not different from 1 and Floralta. Proportion of leaves has been reported to be directly correlated to bite weight, especially in the upper part of the sward where the animal has more access and ability to select (Stobbs, 1973). Greater bite weight has positively affected animal performance (Sollenberger and Burns, 2001).

With limpograss, Newman et al. (2003a) found an inconstant effect of canopy height on leaf percentage, and Holderbaum et al. (1992) showed no interaction of periods of lower average daily gain with decreased leaf:stem ratio. Newman et al. (2003a) suggested that for cattle grazing limpograss leaf proportion in the diet is more a function of accessibility and selection for leaves than the actual proportion of leaves in the grazed horizon. Pitman et al. (1994) found that extrusa samples of esophageally-fistulated animals grazing limpograss was 13 g $kg^{-1}$ greater in CP concentration than in the leaf component of the sward of the high stocking rate treatment (4 vs. 8 animals $ha^{-1}$), and suggested that despite the low CP in limpograss, selective grazing can provide a higher nutritive value diet. The advantage of selection for a better nutritive value diet decreases as the sward matures, because the advantages of selectivity are offset by the disadvantages of lower bite weight reducing total intake (Stobbs, 1973)

Leaf:stem ratio was greater ($P < 0.001$; SE = 0.05) in the upper than lower stratum (0.71 vs. 0.31). There was a trend ($P = 0.059$) for greater leaf:stem for SH30 (0.58; SE = 0.05) than for SH20 pastures (0.44). There was an entry x LI interaction effect (*P* = 0.05; SE = 0.13) for leaf:stem ratio. Entry 4F had a leaf:stem of 0.77 for LI80 but 0.37 for LI 95. Leaf:stem ratio was not affected by LI for any of the other entries, nor was LI80 generally favored over LI95. Leaf:stem ratio in rotationally stocked limpograss can be three to six times greater in the upper stratum than in the lower (average of 0.48 and 0.14, respectively; Holderbaum et al., 1992). This vertical difference can lead to CP deficiency in the diet when cattle graze to a lower stubble height (Quesenberry et al., 2004).

Leaf, stem, and total pre-grazing herbage mass were affected by LI x stratum interaction (Table 3-8). Within LI level, the upper stratum had less leaf, stem, and total mass than the lower stratum. In the upper stratum, there was no effect of LI on leaf, stem, or total herbage mass, however those same responses were greater in the lower stratum for LI95 than for LI80. Greater leaf mass in the lower stratum was not due to larger leaf:stem ratio, which was 0.31 in the lower vs. 0.71 in the upper stratum, but to more than two times greater herbage mass in the lower than upper stratum.

The lower stratum had greater bulk density than the upper (Table 3-8) for both LI levels. There was no difference for bulk density in the upper stratum between LI80 and LI95 (30 vs. 37 kg $ha^{-1}$ $cm^{-1}$), but bulk density was around 65% greater for LI95 in the lower stratum (72 vs. 118 kg $ha^{-1}$ $cm^{-1}$). Similar to the current study, Holderbaum et al. (1992) reported values of bulk density that were two to three times greater in the lower layer of the canopy compared with the upper (269 vs 224 kg $ha^{-1}$ $cm^{-1}$ for Year 1, and 243 vs 85 kg $ha^{-1}$ $cm^{-1}$ for Year 2). The increase in bulk density from LI80 to LI95 is probably due to the stem accumulation in the bottom part of the LI95 canopy due to the longer resting period (Stobbs, 1973). Besides having a larger herbage accumulation, treatments assigned to LI95 built up more stem material in the lower canopy which can result in a decline in forage nutritive value and animal performance (Sollenberger et al., 1988; Holderbaum et al., 1992; Newman et al., 2002b) and wasting  of forage due to animal refusal and lodging.

**Nutritive value of sward components**

Leaf CP was affected by stratum ($P < 0.001$; SE = 1.5) and entry x LI interaction ($P = 0.003$), and IVDOM was affected by LI x stratum ($P = 0.016$) and a strong trend toward entry x stratum interaction ($P = 0.051$). All entries had greater leaf CP concentration at LI80 than LI95, ranging from 135 to 152 g $kg^{-1}$ and 81 to 111 g $kg^{-1}$, respectively (Table 3-9). The interaction between entry by LI occurred because Floralta had lower leaf CP concentration (81 g $kg^{-1}$) within LI95 than Entries 1, 4F, and 10. The upper stratum of the canopy had greater leaf CP than the lower stratum (127 vs. 117 g $kg^{-1}$, respectively). Leaf CP was consistently greater for upper layer than lower layer for Holderbaum et al. (1992) across the grazing season and over 2 yr. In that study, the average (four evaluations in 2 yr) leaf CP concentration on rotationally stocked limpograss grazed every 35 d was 106 and 95 g $kg^{-1}$ for upper and lower strata, respectively. Newman et al. (2003a) found significant but smaller differences, around 130 and 120 g $kg^{-1}$ for upper and lower strata leaf CP, respectively. Pitman et al. (1994) indicated that leaf CP concentration was directly related to average daily gain of steers continuously stocked in Bigalta and Floralta limpograss, because despite the low CP in the total herbage selective grazing can provide diets of much higher nutritive value. In that study, CP in the upper stratum was around 30 and 35 g $kg^{-1}$ for Floralta and Bigalta, respectively, but leaf CP was more than double and esophageal samples for Bigalta were 7 g $kg^{-1}$ greater in CP than green leaves. Esophageal samples from cattle grazing Floralta at high stocking rate (8 vs. 4 animals $ha^{-1}$) was 13 g $kg^{-1}$ higher than sampled leaf CP concentration.

Entries 10 and 4F had greater leaf IVDOM concentration (594 and 595 g $kg^{-1}$) than Entry 1 (564 g $kg^{-1}$) in the upper stratum and greater leaf IVDOM than Floralta (607 g $kg^{-1}$ for both Entries 10 and 4F vs. 572 g $kg^{-1}$ for Floralta) in the lower stratum (Table 3-9). Within entry, only Entry 1 leaf IVDOM concentration was affected by stratum, with lower stratum IVDOM greater than upper stratum (586 vs. 564 g $kg^{-1}$, respectively). For LI by stratum interaction, leaf IVDOM varied only from 577 to 612 g $kg^{-1}$, but within LI80 it was greater for lower than upper layer (612 vs. 592 g $kg^{-1}$, respectively; Table 3-10), and within the lower stratum it was greater for LI80 than LI95.

Stem CP was affected by LI ($P < 0.001$), SH ($P = 0.020$), and stratum ($P < 0.001$), while IVDOM was affected by LI x stratum interaction ($P = 0.044$). The upper stratum of the canopy had greater stem CP than the lower stratum (64 vs. 48 g $kg^{-1}$, respectively, SE = 3.4). Additionally, CP in stem was greater for LI80 than LI95 (70 vs. 42 g $kg^{-1}$; SE = 3.3) and for SH30 than SH20 (60 vs. 52 g $kg^{-1}$; SE = 3.3). It is clear that any management that causes animals to graze more mature herbage or lower in the canopy is going to have a major negative effect on diet CP, especially in light of the large proportion of stem in the lower canopy.

Stem IVDOM was greater in the upper than lower stratum for both levels of LI, and within the lower stratum it was greater for LI80 than for LI95 (600 vs. 570 g $kg^{-1}$, respectively; SE = 9.9). Similar values in magnitude and type of response were found by Holderbaum et al. (1992), where lower stratum stem IVDOM ranged from 503 to 550 g $kg^{-1}$, whereas upper stratum ranged from 568 to 628 g $kg^{-1}$. Upper layer stem plus sheath fraction was either higher than all other fractions (combinations of leaf or stem and upper or lower) or not different from them across the season. The authors attributed the high digestibility of the stem plus sheath fraction in comparison with leaf to the high proportion of sheath in the first fraction. According to Akin et al. (1977), digestibility of the top two thirds of the sheath in bermudagrass [*Cynodon dactylon* (L.) Pers.] can be as high as or higher than the leaf.

**Persistence**

There was an entry effect ($P$ = 0.007) on weed frequency In June 2012 before grazing treatments were imposed. Weed frequency prior to imposing grazing treatments was greatest for Entry 32 and least for Floralta (Table 3-11).

By June 2013, limpograss cover was affected by entry x SH interaction ($P$ = 0.036) and LI ($P$ = 0.020). The LI80 treatment had a greater percentage of limpograss cover (63%; SE = 3.5) than LI95 (54%), probably due in part to the more upright growth morphology of the LI95 treatment which resulted in a greater proportion of bare ground between tillers. Thus this response was likely less related to greater weed invasion and more related to greater bare ground between tillers in LI95. A similar plant response likely resulted in SH 20 having a greater limpograss ground cover than SH30 (63 vs. 54%, respectively) after 1 yr of grazing. Values for cover had a large variation, especially when analyzing between the entries. The entry x SH interaction occurred because Entries 1 and 34 had less cover at SH30 than at SH20 (Table 3-12). Within levels of SH, Entries 1, 4F and 10 had the greatest cover at SH20, but were not different than Floralta and 32 at SH 30, except for Entry 10 that was greater than 32. The entry by LI interaction was due to reduced cover for Floralta from LI80 to LI95. Analyzing by

LI level, Entries 32 and 34 always had the least percentage of cover, but they were not different than Floralta at LI95 (Table 3-12).

It is expected that grazing frequency and intensity (i.e., LI and SH) would affect weed frequency and consequently cover, leading to less cover being associated with a greater presence of weeds (Newman et al., 2003b). However, in the current study there was no influence of LI or SH on weed frequency. Therefore, the observed cover effects of SH and LI treatments are probably more related to canopy morphology than specifically the presence of weeds. By June 2013, weed frequency was affected only by entry ($P < 0.001$). Weed frequency was less in Entries 10 and 1 than in Floralta, 32, and 34 (Table 3-11). Entry 4F was different only from 34, which had the highest weed frequency.

The change in persistence-related responses (i.e., limpograss cover and weed frequency) between June 2012 and June 2013 was compared. There were effects of entry x LI interaction ($P = 0.046$) and a trend toward entry x SH ($P = 0.078$) interaction on change in limpograss cover. There were entry ($P < 0.001$) and LI ($P = 0.043$) main effects on change in weed frequency. Treatment LI80 had a greater increase in weed frequency than LI95 (20 vs. 8%, respectively; SE = 4.1). The entry effect was associated with a very large increase in weed frequency for Entry 34 (43%) and Floralta (28%) compared with a decrease in weed frequency for Entries 10 (-2%) and 1 (-8%; Table 3-11).

The trend toward interaction between entry and SH occurred because cover for Entry 34 decreased from SH20 to SH30 (Table 3-13). Within SH20, Entries 1, 4F, and 10 had the least decrease in cover (0, -1, and -2 %, respectively) compared with the others (ranging from -21 to -29%), but only Entry 34 had a significant reduction (-51%) at SH30. Analyzing the entry by LI effect, the interaction was due to a greater reduction in cover between 2012 and 2013 for Floralta at LI95 (-30%) than at LI80 (-5%; Table 3-13). Within LI80, Entries 32 and 34 had the most reduction in cover, and at LI95, Floralta also had a greater reduction than Entries 1, 4F, and 10. Entry 1, although not being the most productive, is one of the most competitive.

Newman et al. (2003b) reported that increased grazing intensity of limpograss (i.e., shorter canopy height in continuous stocking) decreased vaseygrass population, but it increased common bermudagrass invasion. Comparing continuous vs. rotational stocking effects on established limpograss pastures infested with vaseygrass, there was a greater decrease in vaseygrass (-15 percentage units) and increase in limpograss (6 percentage units) cover under continuous stocking compared with rotational stocking (-3 and -8 percentage units, for vaseygrass and limpograss cover, respectively; Newman et al., 2005). In the current study, the most prevalent weeds in the first year were bahiagrass (*P. notatum*), vaseygrass, and yellow nutsedge (*Cyperus esculentus*). In 2013 there was a significant increase in the occurrence dollarweed (*Hydrocotyle* spp.), prickly lettuce (*Lactuca serriola*), and marsh bedstraw (*Galium palustre*) in the plots, and dogfennel (*Eupatorium capillifolium*), and common bermudagrass at the plot margins.

**Spittlebug Damage**

Pastures were affected by an infestation of two-lined spittlebug [*Prosapia bicincta* (Say)] that started in mid-September and by 10 Oct. 2012 was widespread. The last grazing event was 12 October, and immediately thereafter the plots were rated for insect damage, mowed, and sprayed with esfenvalerate at a rate of 700 ml a.i. $ha^{-1}$. Damage ratings ranged from 1 (least damage) to 10 (most damage), based on visual estimation of dead/brown material. Damage ratings were affected by entry ($P = 0.001$) and LI x SH interaction ($P = 0.046$). Damage was most severe in the LI95/SH30 treatment (Table 3-14). There was no effect of LI when SH was 20, nor was there an effect of SH when LI was 80. Entry 10 had less damage than Floralta, 32, and 34, but it was not different from 1 and 4F (Table 3-15). Spittlebug generally thrives in high moisture and low light environments. The greater infestation on the LI95/SH30 treatment would be expected, because it created a favorable situation for the development of spittlebug (Valério, 2008). As this was not an assay designed to test for insect tolerance, further experimentation is recommended. However, this result suggests that one of the objectives of the breeding program was achieved, i.e., to increase the diversity of the germplasm available and enhance pest tolerance.

## Seasonal Analysis

As number of grazing events and their distribution throughout the grazing season varied according to LI treatment, grazing events were grouped in three seasons: early, mid-, and late. This grouping of the data allowed for all treatments to have data in each season. In this section, only season effects or interactions with season will be discussed.

### Total herbage accumulation and herbage accumulation rate

Total herbage accumulation per season and herbage accumulation rate were affected by the LI x season interaction ($P < 0.001$ and $P = 0.013$, respectively; Table 3-16), and there was SH x season interaction for total herbage accumulated per season ($P = 0.035$; Table 3-17).

Both responses were greater during mid-season for LI80 (Table 3-16). Greater total herbage accumulation in that season was associated with both greater herbage accumulation rate and the occurrence of two grazing events during that season for all LI80 treatments. Total herbage accumulation was greatest for LI95 during the late-season in spite of lesser herbage accumulation rate than in early-season. Greater total herbage accumulation in late season was due to some LI95 treatments having more than one grazing event in that season while all treatments had only one grazing event in early and mid-season. The LI95 treatment had greater total herbage accumulation than LI80 in early and late season, but LI80 responses were greater than LI95 in mid-season. Herbage accumulation rate differed between LI levels only during early and late season and favored LI95 in both.

Relating these data with the regrowth curve proposed by Parsons and Penning (1988), the LI80 would likely fall in Phase 1, where herbage accumulation rate is still increasing exponentially and did not yet reach the maximum. Theoretically, grazing at LI80 does not allow expression of the full potential of the plant to produce biomass and results in lower herbage accumulation than when allowed to grow to LI95 (Barbosa et al., 2007; Sbrissia, 2007). As noted elsewhere in this chapter, however, there were canopy structure, lodging, and animal behavior challenges associated with LI95 that make it an undesirable option for limpograss pastures.

The SH x season interaction on total herbage accumulation occurred because there was an SH effect only during late season when SH20 had greater herbage accumulation than SH30 (3570 vs. 2670 kg $ha^{-1}$, respectively; Table 3-17). Comparing within level of SH, early season herbage accumulation was less than mid-season for both SH levels, and the mid-season was most productive for SH30.

**Nutritive value**

There was an LI x season interaction effect on both IVDOM (*P* = 0.005) and CP (*P* <0.001). Digestibility was greater for LI80 then for LI95 in the early (595 vs. 575 g $kg^{-1}$, respectively) and mid- (602 vs. 579 g $kg^{-1}$, respectively) seasons, but there was no LI effect in late season (561 vs. 576 g $kg^{-1}$, respectively). Within a level of LI, the only difference was for LI80 where late-season IVDOM was less than the other seasons (Table 3-18).

Herbage CP decreased as the year progressed for both LI levels (Table 3-16), going from 157 to 67 g $kg^{-1}$ for LI80 and 118 to 54 g $kg^{-1}$ for LI95. For all seasons, LI80 had higher CP concentration than LI95 because of the less mature swards. A possible explanation for the high CP values for the early season, especially for the LI80 treatment, is that regrowth period (from staging to first grazing) was around 3 wk, therefore the herbage was relatively immature, and in addition the plots were fertilized with 40 kg N $ha^{-1}$ 1.5 wk after staging. Values for limpograss CP are low throughout the literature (e.g., Sollenberger et al., 1988; Holderbaum et al., 1991; Pitman et al., 1994; Brown and Adjei, 2001), normally below the 70 g $kg^{-1}$ minimum for maintenance of a non-lactating, non-pregnant heifer (Moore, 1992). Few studies report values as high as those obtained in the early and mid-season. Newman et al. (2002b), in continuously stocked limpograss pasture, harvested only the top 5 cm of the canopy to represent animal diets and reported values from 86 to 120 g $kg^{-1}$ of CP and digestibility of 509 to 603 g $kg^{-1}$. These concentrations are closer to those obtained in this study. The authors commented that this “unexpected high nutritive value” could be associated with moderate drought stress that slowed herbage accumulation rates, principally in the second year of the experiment. No moisture stress occurred in 2012 when the current experiment was ongoing. Vendramini and Arthington (2010) reported even higher values for limpograss winter growth (February to April), with CP and IVDOM reaching up to 144 and 618 g $kg^{-1}$, respectively.

## Important Findings and Implications

Based on the first year of data from this study, it is possible to see an advantage favoring Entries 10 and 4F relative to the industry standard Floralta in many of the traits evaluated. Entries 10 and 4F are clearly superior to the tested hybrids 32 and 34. Specifically, Entry 10 and 4F had as great or greater herbage accumulation and herbage harvested than all other entries, and Entry 10 had a longer grazing season for all combinations of treatments than most of the other entries. Entry 10 had an advantage in measures of persistence in comparison with 4F, and 10 showed greater tolerance to a spittlebug infestation that occurred near the end of the first year of defoliation. Entry 1, although not being among the most productive entries, had excellent limpograss cover response and one of the lowest weed frequencies. In terms of nutritive value, there were no consistent differences among entries although 4F generally was at or very near the top of the range in digestibility.

The LI treatments did not differ in total season herbage accumulated or harvested, but plots assigned to LI80 were grazed more frequently and a greater number of times during the season than LI95 plots. A taller canopy height and greater herbage bulk density were characteristic of LI95 vs. LI 80. These morphological attributes generated some constraints to grazing efficiency because the forage was prone to lodging and trampling, and animals were reluctant to graze further after removing the plant tops. The use of 95% light interception as a trigger for grazing (Kasanga and Monsi, 1954; Donald, 1961, as cited by Lemaire and Chapman, 1996; da Silva and Nascimento Jr., 2007), has significant limitations for use with limpograss likely due to upright stem growth and relatively small, erect leaves that characterize this species.

Base on previous studies (Wallau et al., 2012) and the first year of the current research, the entries that are most likely to be released as new limpograss cultivars in the next few years are 4F and 10. Entries 32 and 34 did not show sufficient adaptation to grazing and should be discarded. Entry 1 appears to have desirable persistence traits, but it has not shown similar levels of herbage accumulation as 10 and 4F. Experimentation is being conducted on performance of cattle grazing selected entries, and these data along with one additional year of results from the current study should provide greater clarity regarding the merits of various hybrids for cultivar release.

Table 3-1. Length of the grazing season as affected by limpograss entry x light interception (LI) interaction and by limpograss entry x post-grazing stubble height (SH) interaction. Data are means across two levels of either LI or SH and two replicates (n = 4).

| Entry | LI (%) | | *P* value | SH (cm) | | *P* value |
|---|---|---|---|---|---|---|
| | 80 | 95 | | 20 | 30 | |
| | ------------ days ------------- | | | ------------ days ----------- | | |
| 1 | 96 b[†] | 76 b | <0.001 | 99 b | 73 d | <0.001 |
| 4F | 122 a | 73 c | <0.001 | 101 b | 94 b | 0.193 |
| 10 | 113 a | 115 a | 0.791 | 115 a | 113 a | 0.561 |
| 32 | 86 c | 76 b | 0.053 | 81 c | 81 c | 1.000 |
| 34 | 90 bc | 77 b | 0.011 | 85 c | 82 c | 0.461 |
| Floralta | 117 a | 78 b | <0.001 | 102 b | 94 b | 0.090 |
| SE | 4.7 | | | 4.7 | | |

[†] Means within a column followed by the same letter are not different at $P < 0.05$.

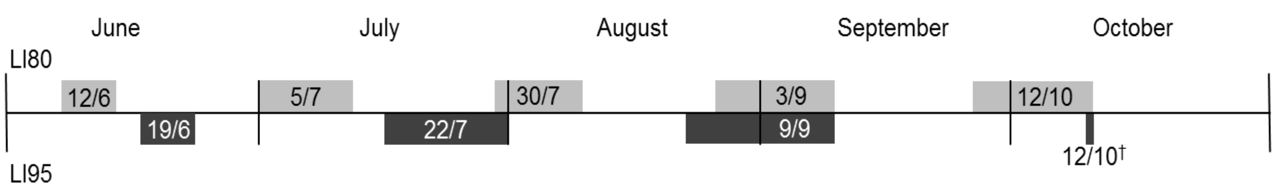


Figure 3-3. Timescale showing differences in median date and in range of initiation of grazing for each grazing event for treatments of pre-grazing light interception (LI) 80 and 95. Numbers inside the rectangles indicate median date when plots of a given LI were grazed and size of the rectangle indicates length of time over which initiation of that numbered event occurred ([†]on 10/12, only Entry 10 plots were grazed).

Table 3-2. Effect of limpograss entry by pre-grazing light interception (LI) interaction on post-grazing LI. Data are means across two post-grazing stubble heights and two replicates (n = 4).

| Entry | LI (%) 80 | LI (%) 95 | *P* value |
|---|---|---|---|
| | ----------------%------------- | | |
| 1 | 61 a[†] | 50 b | 0.007 |
| 4F | 61 a | 55 b | 0.090 |
| 10 | 56 ab | 69 a | 0.003 |
| Floralta | 53 b | 54 b | 0.710 |
| SE | 3.6 | | |

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

Table 3-3. Total limpograss herbage accumulated, herbage accumulation rate, and herbage harvested during the grazing season as affected by the pre-grazing light interception (LI) x post-grazing stubble height (SH) interaction. Data are means across six entries and two replicates (n = 12).

| LI (%) | SH (cm) 20 | SH (cm) 30 | *P*-value |
|---|---|---|---|
| | Herbage accumulated (kg DM $ha^{-1}$) | | |
| 80 | 10.7 | 7.7 | 0.002 |
| 95 | 9.5 | 9.2 | 0.772 |
| *P*-value | 0.166 | 0.090 | |
| SE | 0.9 | | |
| | Herbage accumulation rate (kg DM $ha^{-1}$ $d^{-1}$) | | |
| 80 | 91 | 69 | 0.009 |
| 95 | 100 | 102 | 0.716 |
| *P*-value | 0.223 | <0.001 | |
| SE | 7.5 | | |
| | Herbage harvested (kg DM $ha^{-1}$) | | |
| 80 | 9.1 | 6.5 | 0.007 |
| 95 | 7.3 | 7.9 | 0.470 |
| *P*-value | 0.053 | 0.115 | |
| SE | 0.87 | | |

Table 3-4. Total annual limpograss herbage accumulated and herbage harvested for six entries during 2012. Data are means across two grazing intensities, two grazing frequencies, and two replicates (n = 8).

| Entry | Herbage accumulated | Herbage harvested |
|---|---|---|
| | -------------------- Mg ha$^{-1}$ ----------------- | |
| 10 | 11.6 a† | 9.9 a |
| 4F | 10.4 ab | 8.9 ab |
| Floralta | 9.5 abc | 7.9 abc |
| 32 | 8.4 bc | 7.1 bc |
| 1 | 8.0 c | 6.4 c |
| 34 | 7.8 c | 6.0 c |
| SE | 0.9 | 0.9 |

† Means within a column followed by the same letter are not different at $P < 0.05$.

Table 3-5. Pre-grazing limpograss canopy height as affected by the pre-grazing light interception (LI) x post-grazing stubble height (SH) interaction. Data are means across six entries and two replicates (n = 12).

| | SH (cm) | | |
|---|---|---|---|
| LI (%) | 20 | 30 | *P*-value |
| | ---------- cm ---------- | | |
| 80 | 59 | 60 | 0.535 |
| 95 | 70 | 76 | 0.001 |
| *P*-value | <0.001 | <0.001 | |
| SE | 1.7 | | |

Table 3-6. Total grazing season in vitro digestible organic matter (IVDOM) and crude protein (CP) for each of the limpograss entries. Data are means across two levels of pre-grazing light interception, two levels of post-grazing stubble height, and two replicates (n = 8).

| Entry | IVDOM | CP |
|---|---|---|
| | --------- g kg$^{-1}$ ---------- | |
| 10 | 590 | 81 |
| 1 | 586 | 90 |
| 4F | 577 | 82 |
| 34 | 574 | 81 |
| Floralta | 573 | 90 |
| 32 | 566 | 87 |
| SE | 12.9 | 4 |

Table 3-7. Effect of pre-grazing light interception level (LI) x entry interaction on leaf percentage and leaf:stem ratio. Data are means across two post-grazing stubble heights and two replicates (n = 4).

| Entry | LI (%) | | *P* value |
|---|---|---|---|
| | 80 | 95 | |
| | Leaf (%) | | |
| 1 | 36 ab[†] | 32 ab | 0.218 |
| 4F | 38 a | 26 b | 0.005 |
| 10 | 29 b | 33 a | 0.281 |
| Floralta | 27 c | 29 ab | 0.632 |
| SE | 3.8 | | |
| | Leaf:stem ratio | | |
| 1 | 0.63 ab | 0.48 a | 0.278 |
| 4F | 0.77 a | 0.37 a | 0.006 |
| 10 | 0.43 b | 0.54 a | 0.437 |
| Floralta | 0.40 b | 0.45 a | 0.724 |
| SE | 0.13 | | |

[†] Means within a column followed by the same letter are not different at $P < 0.05$.

Table 3-8. The effect of pre-grazing light interception (LI) x canopy stratum interaction on limpograss leaf, stem, and total herbage mass (kg $ha^{-1}$) in the upper and lower strata of the sward canopy and on total herbage bulk density (kg $ha^{-1}$ $cm^{-1}$). Data are means across two levels of post-grazing stubble height, four entries, and two replicates (n = 16).

| LI (%) | Stratum | | *P* value |
|---|---|---|---|
| | Upper | Lower | |
| | Leaf mass (kg $ha^{-1}$) | | |
| 80 | 291 | 365 | 0.087 |
| 95 | 262 | 478 | <0.001 |
| *P* value | 0.561 | 0.029 | |
| SE | 50 | | |
| | Stem mass (kg $ha^{-1}$) | | |
| 80 | 410 | 1296 | <0.001 |
| 95 | 452 | 1707 | <0.001 |
| *P* value | 0.774 | 0.007 | |
| SE | 143 | | |
| | Total mass (kg $ha^{-1}$) | | |
| 80 | 701 | 1660 | <0.001 |
| 95 | 713 | 2185 | <0.001 |
| *P* value | 0.945 | <0.001 | |
| SE | 178 | | |
| | Bulk density (kg $ha^{-1}$ $cm^{-1}$) | | |
| 80 | 30 | 72 | <0.001 |
| 95 | 37 | 118 | <0.001 |
| *P* value | 0.56 | <0.001 | |
| SE | 11.4 | | |

Table 3-9. Canopy stratum x entry interaction effect on limpograss leaf herbage in vitro digestible organic matter concentration (IVDOM) and pre-grazing light interception (LI) x entry interaction on limpograss leaf herbage CP. The IVDOM data are means across two levels of post-grazing stubble height (SH), two levels of LI, and two replicates (n = 8), and the CP data are means across two levels of SH, two strata, and two replicates (n = 8).

| Entry | IVDOM | | *P* value | CP | | *P* value |
|---|---|---|---|---|---|---|
| | Stratum | | | LI (%) | | |
| | Upper | Lower | | 80 | 95 | |
| | ------------------------ g $kg^{-1}$ ------------------------ | | | | | |
| 1 | 564 b[†] | 586 ab | 0.030 | 135 a | 109 a | 0.004 |
| 4F | 595 a | 607 a | 0.176 | 152 a | 101 a | <0.001 |
| 10 | 594 a | 607 a | 0.152 | 138 a | 111 a | 0.003 |
| Floralta | 586 ab | 572 b | 0.131 | 149 a | 81 b | <0.001 |
| SE | 15 | | | 8.3 | | |

[†] Means within a column followed by the same letter are not different at $P < 0.05$.

Table 3-10. Pre-grazing light interception (LI) x canopy stratum interaction effect on limpograss leaf and stem in vitro digestible organic matter concentration (IVDOM). Data are means across four entries, two levels of stubble height, and two replicates (n = 16).

| LI (%) | Stratum | | *P* value |
|---|---|---|---|
| | Upper | Lower | |
| | Leaf IVDOM (g $kg^{-1}$) | | |
| 80 | 592 | 612 | 0.005 |
| 95 | 577 | 574 | 0.617 |
| *P* value | 0.189 | 0.002 | |
| SE | 11 | | |
| | Stem IVDOM (g $kg^{-1}$) | | |
| 80 | 626 | 600 | 0.007 |
| 95 | 622 | 570 | <0.001 |
| *P*-value | 0.678 | 0.005 | |
| SE | 10 | | |

Table 3-11. Percentage weed frequency as affected by limpograss entry measured in June 2012 and 2013 and the change in weed frequency between years. Data are means across two levels of pre-grazing light interception, two levels of post-grazing stubble height, and two replicates (n = 8).

| Entry | Weed frequency | | Change in weed frequency |
|---|---|---|---|
| | 2012 | 2013 | |
| | ---------------------------%--------------------------- | | |
| 1 | 41 bc | 33 c | -8 d |
| 4F | 38 bc | 51 bc | 13 bc |
| 10 | 34 bc† | 32 c | -2 cd |
| Floralta | 29 c | 57 b | 28 ab |
| 32 | 57 a | 66 b | 9 bcd |
| 34 | 46 ab | 89 a | 43 a |
| SE | 7 | 9.2 | 10 |

† Means within a column followed by the same letter are not different at $P < 0.05$.

Table 3-12. Effect of entry by post-grazing stubble height (SH) and entry by pre-grazing light interception (LI) interactions on percentage of limpograss cover in June 2013. Data are means across two levels of either LI or SH and two replicates (n = 4).

| Entry | SH (cm) | | *P* value | LI (%) | | *P* value |
|---|---|---|---|---|---|---|
| | 20 | 30 | | 80 | 95 | |
| | --------------%------------- | | | --------------%------------ | | |
| 1 | 75 a† | 57 ab | 0.047 | 72 a | 60 a | 0.169 |
| 4F | 75 a | 60 ab | 0.093 | 75 a | 59 a | 0.066 |
| 10 | 76 a | 73 a | 0.777 | 77 a | 71 a | 0.484 |
| 32 | 47 b | 59 b | 0.818 | 49 b | 48 b | 0.914 |
| 34 | 50 b | 19 c | 0.001 | 29 c | 39 b | 0.323 |
| Floralta | 56 b | 64 ab | 0.345 | 73 a | 46 b | 0.004 |
| SE | 8.5 | | | 8.5 | | |

† Means within a column followed by the same letter are not different at $P < 0.05$.

Table 3-13. Effect of entry by post-grazing stubble height (SH) and entry by pre-grazing light interception (LI) interactions on percentage unit change in limpograss cover between June 2012 and June 2013. Data are means across two levels of either LI or SH and two replicates (n = 4).

| Entry | SH (cm) | | *P* value | LI (%) | | *P* value |
|---|---|---|---|---|---|---|
| | 20 | 30 | | 80 | 95 | |
| | --------------------percentage unit change------------------ | | | | | |
| 1 | 0 a[†] | -13 a | 0.119 | -3 a | -10 a | 0.408 |
| 4F | -1 a | -10 a | 0.289 | 2 a | -13 a | 0.074 |
| 10 | -2 a | -3 a | 0.891 | -1 a | -3 a | 0.830 |
| 32 | -27 b | -16 a | 0.228 | -22 b | -21 b | 0.842 |
| 34 | -29 b | -51 b | 0.013 | -47 c | -33 b | 0.103 |
| Floralta | -21 b | -13 a | 0.379 | -5 a | -30 b | 0.006 |
| SE | 8.3 | | | 8.3 | | |

[†] Means within a column followed by the same letter are not different at $P < 0.05$.

Table 3-14. Pre-grazing light interception (LI) x post-grazing stubble height (SH) interaction effect on rating of spittlebug damage to limpograss. Data are means across six entries and two replicates (n = 12).

| LI (%) | SH (cm) | | *P* value |
|---|---|---|---|
| | 20 | 30 | |
| 80 | 3.9[†] | 4.2 | 0.582 |
| 95 | 4.3 | 5.8 | 0.002 |
| *P* value | 0.464 | 0.001 | |
| SE | 0.45 | | |

[†] The rating scale was 1 to 10 with 1 = least damage, and 10 = most damage, based on dead material.

Table 3-15. Limpograss entry effect on rating of spittlebug damage. Data are means across two levels of pre-grazing light interception, two levels of post-grazing stubble height, and two replicates (n = 8).

| Entry | Damage rating† |
|---|---|
| 34 | 6.1 c‡ |
| 32 | 4.8 b |
| Floralta | 4.8 b |
| 1 | 4.4 ab |
| 4F | 3.9 ab |
| 10 | 3.4 a |
| SE | 0.55 |

† The rating scale was 1 to 10 with 1 = least damage, and 10 = most damage, based on dead material.
‡Means within a column followed by the same letter are not different at P < 0.05.

Table 3-16. Effect of pre-grazing light interception (LI) x season of the year interaction on total limpograss herbage accumulated and herbage accumulation rate. Data are means across six entries, two post-grazing stubble heights, and two replicates (n = 24).

| Season | LI (%) | | *P* value |
|---|---|---|---|
| | 80 | 95 | |
| | Total herbage accumulated (kg ha$^{-1}$) | | |
| Early | 1530 ac† | 3160 b | <0.001 |
| Mid | 4720 a | 3270 b | <0.001 |
| Late | 2290 b | 3950 a | <0.001 |
| SE | 320 | | |
| | Herbage accumulation rate (kg ha$^{-1}$ d$^{-1}$) | | |
| Early | 72 b | 111 a | <0.001 |
| Mid | 90 a | 101 ab | 0.177 |
| Late | 59 b | 91 b | <0.001 |
| SE | 7.8 | | |

† Means within a column followed by the same letter are not different at P < 0.05.

Table 3-17. Effect of post-grazing stubble height (SH) x season interaction on limpograss herbage accumulated. Data are means across six limpograss entries, two levels of pre-grazing light interception, and two replicates (n = 24).

| Season | SH (cm) | | *P* value |
|---|---|---|---|
| | 20 | 30 | |
| | Herbage accumulated (kg DM ha$^{-1}$) | | |
| Early | 2240b[†] | 2450b | 0.505 |
| Mid | 4170a | 3830a | 0.292 |
| Late | 3570a | 2670b | 0.006 |
| SE | 320 | | |

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

Table 3-18. Effect of pre-grazing light interception (LI) x season interaction on limpograss in vitro digestible organic matter (IVDOM) and crude protein (CP) concentrations.

| Season | IVDOM | | *P* value | CP | | *P* value |
|---|---|---|---|---|---|---|
| | LI (%) | | | LI (%) | | |
| | 80 | 95 | | 80 | 95 | |
| | ------- g kg$^{-1}$ ------ | | | ------- g kg$^{-1}$ ------ | | |
| Early | 595 a[†] | 575 a | 0.025 | 157 a | 118 a | <0.001 |
| Mid | 602 a | 579 a | 0.010 | 92 b | 81 b | 0.002 |
| Late | 561 b | 575 a | 0.094 | 67 c | 54 c | <0.001 |
| SE | 0.87 | | | 0.36 | | |

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

# CHAPTER 4
# POTENTIAL OF LIMPOGRASS BREEDING LINES FOR USE IN STOCKPILING SYSTEMS FOR LATE-SEASON GRAZING

## Overview of Research Problem

Seasonality of forage production is one of the main challenges facing livestock production systems. The lack of forage for grazing in the off season requires supplementation as hay, silage, or concentrate, and use of these feed sources, which generally come from off the farm, increases the costs of livestock production. In central and south Florida, forage quantity limitations most often occur during winter, when temperatures are sufficiently low and day length short to induce dormancy in many of the commonly used warm-season perennial grass species but not cold for an extended time period that would allow cool-season grasses to become a practical forage source. Extending the length of the grazing season can delay or reduce the need for supplementation. This can be achieved by using cold tolerant species/cultivars that remain productive after temperatures and daylength start decreasing or by stockpiling forage for late-season use.

Stockpiling limpograss is a strategy that is already being used in Florida, especially in the southern part of the state. There, mild winter temperatures favor growth later in the season, so limpograss pastures can be utilized until late-September and then stockpiled, or even grazed year-round if conditions allow (Kretschmer and Snyder, 1979). Other than its production during the winter time, the primary reason for using limpograss for stockpiling is that herbage in vitro digestible organic matter (IVDOM) concentration is generally greater than that of other commonly used C4 grasses at advanced stages of maturity. Values for IVDOM in stockpiled limpograss are generally around 550 to 620 g kg$^{-1}$ (Carvalho, 1976; Quesenberry et al., 2004). However, CP concentrations are low with actual levels depending on management and fertilization, but most of the time protein supplementation is required when feeding stockpiled limpograss (Newman et al., 2009).

Recent breeding efforts have resulted in the development of several limpograss hybrids that may have potential for use in Florida. Because stockpiling is a widely used management strategy for limpograss in Florida, there is need for evaluation of the potential of these breeding lines under stockpiling management prior to cultivar release. The objective of this study was to assess the potential of three limpograss breeding lines (1, 4F, and 10) for use as stockpiled forage and compare them with the current industry standard, 'Floralta' limpograss. The lines were tested at two levels of N fertilizer and three lengths of stockpiling period to determine the effects of these treatments on herbage harvested, plant-part proportion, and nutritive value.

## Materials and Methods

### Site Characteristics

This experiment was conducted at the University of Florida Beef Research Unit in an area adjacent to Experiment 1. The soil is a Smyrna fine sand (sandy, siliceous, hyperthermic, Aeric Alaquods), and a group of eight limpograss breeding lines plus Floralta and 'Bigalta' limpograss were planted there in 2009. The area was utilized subsequently for the initial grazing evaluation of the breeding lines that led to selection of the entries to be used in the grazing experiment described in Chapter 3 (Wallau et al., 2012). The initial plots accommodated two grazing frequencies and three replicates of each line, and experimental units measured 5 by 5 m. Soil pH was 6.2, and Mehlich-1 extractable P, K, Mg, and Ca were 13, 175, 101, and 654 mg $kg^{-1}$, respectively.

The last grazing event in the initial experiment at this site was in October 2011 and after this the plots were closed to cattle through the winter of 2011-2012. For the current stockpiling experiment, plots were utilized that were planted to entries 1, 10, 4F, and Floralta and that had a good limpograss stand in the summer of 2012. These 5 by 5 m plots were divided into 1.5 by 1.5 m experimental units to which the stockpiling experiment treatments were assigned.

**Treatments and Experimental Design**

The study consisted of 24 treatments, arranged as a 4 x 3 x 2 factorial experiment in three replications of a randomized complete block design. The breeding lines used in this trial were 1, 10, and 4F, and the cultivar Floralta served as the control. Treatments were two N fertilization rates (50 and 100 kg ha$^{-1}$) and three stockpiling periods (8, 12, and 16 wk). The recommended N fertilization rate for stockpiling limpograss is around 100 kg N ha$^{-1}$ (Quesenberry et al., 2004). However, many Florida pastures receive less or even no N, so the choice of a level less than 100 kg N ha$^{-1}$ takes this into account. Overall the goal was to keep N rates as low as possible and still achieve the desired forage production and nutritive value. Stockpiling periods were chosen based on previous research that indicated a period of 8 to 10 wk should be allowed in order for the pastures to accumulate sufficient biomass for autumn-winter use (Quesenberry and Ocumpaugh, 1980). According to the same authors, the best date to start stockpiling limpograss in North Florida is early August. Starting at this time provides relatively similar environmental conditions as would occur in South Florida when initiation of stockpiling is approximately mid-September.

Prior to initiation of stockpiling, the pastures were grazed occasionally throughout the spring and summer of 2012 to a 20-cm stubble height.  Plots were mowed on 1

August to 20 cm for staging and N fertilizer was applied according to treatment rate on 10 August. Based on soil test results, on 17 Aug. 2012 all plots were fertilized with 18 kg $ha^{-1}$ of P and 33 kg $ha^{-1}$ K. The 8-, 12-, and 16-wk stockpiling periods ended on 28 September, 29 October, and 30 November, respectively, and samples were taken on those dates to quantify herbage harvested and nutritive value. In addition, hand-plucked samples to determine nutritive value only were taken 4 and 6 wk after staging from the 8-wk treatment plots to expand the range of the data beyond the 8- to 16-wk period.

## Response Variables Measured

### Herbage harvested and herbage accumulation rate

At the end of the stockpiling period for each experimental unit, one 0.25-$m^2$ quadrat was clipped using battery-powered shears to a 20-cm stubble from the center of the experimental unit. The samples were dried at 60°C to constant weight, and weighed to determine herbage harvested. Herbage accumulation rate during the stockpiling period was calculated as herbage harvested divided by length of the stockpiling period.

### Nutritive value

Nutritive value, expressed as CP and IVDOM concentrations, was determined on total harvested herbage from the quadrat sample used to quantify herbage harvested and on plant-part samples (leaf and stem) described below. All samples were ground to pass a 1-mm stainless steel screen in a Wiley mill (Model 4 Thomas-Wiley Laboratory Mill, Thomas Scientific, Swedeboro, NJ) and analyzed for CP and IVDOM. In addition, hand-plucked samples were taken at 4 and 6 wk after stockpiling began from the plots assigned to the 8-wk stockpiling period treatment. These samples were taken midway between the 0.25-$m^2$ area that would eventually be sampled for herbage harvested and the plot margin. These data will provide additional information regarding the change in N and IVDOM concentrations of the stockpiled forage as a function of time.

Analysis for IVDOM was performed using a modification of the two-stage technique (Moore and Mott, 1974). For N analysis, samples were digested using a modification of the aluminum block digestion procedure of Gallaher et al. (1975). Nitrogen in the digestate was determined by semi-automated colorimetry (Hambleton, 1977), and CP concentration was calculated by multiplying total N by 6.25 (assuming 160 g N $kg^{-1}$ protein).

The digestible organic matter to CP ratio (DOM:CP) was calculated by dividing the herbage IVDOM by herbage CP. This ratio is important because it describes an animal’s N status. When the ratio is above 7, animals are likely to require and respond to protein supplementation (Moore, 1992).

**Morphological characteristics**

Average non-extended sward height (referred to as canopy height) was measured with a ruler at five sites per plot at the end of the stockpiling period. At 12 and 16 wk, the limpograss canopy had lodged, thus both non-extended and extended canopy heights (referred to as extended stem length) were measured. A lodging index was calculated as the ratio between extended stem length and non-extended canopy height. Bulk density was calculated by dividing the herbage harvested by the average non-extended canopy height minus cutting stubble height (20 cm).

For each harvesting date, four hand-plucked samples were taken to a 20-cm height on each plot and composited. The composite sample was separated into leaf blade and sheath + stem fractions for the 8-wk treatment, and leaf blade, sheath + stem, and dead material fractions for 12- and 16-wk treatments. There was negligible dead material above the cutting height at 8 wk, so this fraction was not quantified, but it increased over time. All samples were dried at 60°C to constant weight and weighed.

### Statistical Analysis

Data were analyzed using PROC GLIMMIX with N fertilization level, stockpiling period, and entry as fixed effects and block as a random effect. All reported means are least square means. Mean separation was accomplished for grass entry using Fisher's least significance difference test, for N rate means using the F test, and for length of stockpiling period using polynomial contrasts (linear and quadratic). The extra hand-plucked samples taken at 4 and 6 wk were analyzed for IVDOM and CP and grouped with 8 wk nutritive value data. They were analyzed using PROC MIXED with sampling date as a repeated measure using an autoregressive covariance structure.

## Results and Discussion

### Herbage Mass Harvested and Accumulation Rate

Herbage mass harvested was affected by length of the stockpiling period ($P < 0.001$) and entry ($P = 0.024$) main effects. Entries 4F and 10 had the greatest herbage harvested (8.7 and 8.2 Mg ha$^{-1}$, respectively; Table 4-1). Floralta was the least productive entry (6.4 Mg ha$^{-1}$) but not statistically different than Entry 1 (7.4 Mg ha$^{-1}$). There was a linear ($P < 0.001$) effect of length of stockpiling period on herbage harvested. Plots harvested at 8 wk accumulated 6 Mg ha$^{-1}$, and herbage harvested increased to 7.8 Mg ha$^{-1}$ at 12 wk and 9.3 Mg ha$^{-1}$ at 16 wk (Table 4-2). Herbage harvested is expected to plateau with time, but the length of the stockpiling period may not have been long enough to observe this effect (e.g., Brown and Blaser, 1968; Parsons and Penning, 1988), or the weather conditions in 2012 may have contributed to the response observed, because few days (10 d) between October and November had temperatures below 10°C.

Herbage accumulation rate was also significantly affected by length of the stockpiling period ($P$ = 0.007) and entry ($P$ = 0.010) main effects. Entries 4F and 10 had the greater average herbage accumulation rate over the stockpiling period (106 and 101 kg DM $d^{-1}$, respectively; Table 4-1) compared with Floralta (78 kg DM $d^{-1}$), but Entry 1 average accumulation rate (91 kg DM $d^{-1}$) was not different than that of any other entry. There was a linear ($P$ = 0.002) effect of stockpiling period on herbage accumulation rate. The 8-wk treatment had the greatest herbage accumulation rate (107 kg DM $d^{-1}$; Table 4-2), and it decreased over time to 92 and 82 kg DM $d^{-1}$ for 12- and 16-wk periods, respectively.

**Canopy Height and Extended Stem Length**

Non-extended canopy height was affected by entry ($P$ = 0.002) and stockpiling period ($P$ = 0.001) main effects. Entry 10 had a taller sward (82 cm) than all other entries, which ranged from 73 to 75 cm. The stockpiling period had a linear ($P$ < 0.001) effect on canopy height. There was a general decrease in canopy height over time, from 81 cm at 8 wk to 74 and 72 cm at 12 and 16 wk, respectively. The decrease in non-extended canopy height occurred because stem angle became more nearly horizontal lower in the canopy but the upper portion of the stem grew erect. To characterize this effect, extended canopy height was measured and a “lodging index” was calculated as the ratio between the extended stem length and the non-extended canopy height. For the 8-wk treatment, this change in stem orientation had not yet occurred and extended stem length was the same as non-extended canopy height.

Extended stem length was affected by entry by stockpiling period interaction (*P* = 0.016). Interaction occurred because extended stem length increased from 8 to 12 wk for all entries except Entry 1, and from 12 to 16 wk for all entries but Floralta (Table 4-3). There was a linear and quadratic response of extended stem length to stockpiling period for Entries 1 and Floralta, and only a linear effect for Entries 4F and 10. The quadratic effect for Entries 1 and Floralta was due to no further increase in extended stem length beyond 12 wk. Extended stem length did not vary among entries at 8 wk. Floralta had longer stems at 12 wk than 4F and 1, but their length was not different from stems of Entry 10. At 16 wk, Entry 4F had the longest stems, but they were not different than Entry 10. Floralta stem length was intermediate, longer than Entry 1 but not different than 10.

The lodging index was 1.0 for all entries for the 8-wk stockpiling period, but it was greatest for Floralta (1.68) at 12 wk, and greater for Floralta and 4F than Entry 1 at 16 wk. Lodging index also increased over time in a linear and quadratic manner for all entries but Entry 10 for which the effect was linear. The quadratic effect was significant because the magnitude of increase in the index from 12 to 16 wk was smaller than from 8 to 12 wk for Entries 1 and 4F, and for Floralta there was no further increase after 12 wk. Entry 1 showed no difference between 12 and 16 wk (Table 4-3), and in general Entry 1 seems to be a lower growing type than the other entries evaluated.

Canopy characteristics of stockpiled forage can affect both herbage accumulation and later utilization by the animal (Santos et al., 2009). A high lodging index can result in reduced harvesting efficiency and wasted material. For Santos et al. (2009), lodging index of *Brachiaria decumbens* cv. Basilisk was positively related to an increase in total herbage mass, stem mass, and dead material mass; and it was negatively related with leaf blade mass. Thus, in their experiment, a greater lodging index was associated with traits that would likely lead to decreased intake and reduced nutritive value.

As a result of this increase in true stem length, maintenance of canopy height, and increase in herbage (especially stem) harvested, there was a linear ($P < 0.001$) increase of herbage bulk density in response to increasing length of stockpiling period. Bulk density increased from 100 kg ha$^{-1}$ cm$^{-1}$ at 8 wk to 145 kg ha$^{-1}$ cm$^{-1}$ at 12 wk and 180 kg ha$^{-1}$ cm$^{-1}$ at 16 wk. This increase in bulk density may create some constraints to ingestive behavior of animals grazing stockpiled limpograss (Sollenberger and Burns, 2001), particularly because it is also associated with decreased leaf proportion and accessibility (Stobbs, 1973; Newman et al., 2003b). These features of a mature sward canopy are to be expected because stockpiling is not a strategy to maximize forage quality but to provide low cost forage at a time when other forages are not actively growing.

**Plant-part Proportion**

Live leaf percentage was affected by entry ($P = 0.009$), N fertilization rate ($P = 0.047$), and stockpiling period ($P < 0.001$). Entries 1 and 10 had a greater leaf percentage (18 and 17%, respectively; Table 4-4) than 4F (14%), but none of the entries was different from Floralta (16%). Increasing N fertilization from 50 to 100 kg ha$^{-1}$ increased leaf percentage from 15 to 17%. This effect was not large enough to cause differences in herbage CP due to N rate. Leaf proportion in the canopy responded both linearly and quadratically to stockpiling period (both at $P < 0.001$; Table 4-5). There was a general decrease in leaf percentage over time, from 20% at 8 wk to 15% at 16 wk, but the quadratic contrast occurred because leaf percentage was even lower value at 12 than 16 wk (12%).

Leaf mass was affected only by stockpiling period (*P* = 0.048) and there was a quadratic effect (*P* = 0.018). Higher leaf mass was observed at 8 (1190 kg $ha^{-1}$) and 16 wk (1280 kg $ha^{-1}$) than at 12 wk (950 kg $ha^{-1}$; Table 4-6). This unexpected response can be attributed to low temperatures and a frost event observed on 30 October. Temperatures increased thereafter resulting in development of new leaves and increasing both leaf mass and proportion at the 16-wk harvest (1280 kg $ha^{-1}$ and 15%, respectively). A similar effect was observed by Mislevy and Martin (2007) who reported that CP and IVDOM increased from a harvest 2 wk after a frost to a harvest that occurred 4 wk after frost. The authors attributed this change to developing tillers at the base of the swards.

Live stem percentage was also affected by N fertilization rate (*P* = 0.047) and entry by stockpiling period interaction (*P* = 0.049). Stem mass, however, was affected only by entry (*P* = 0.011) and stockpiling period (*P* < 0.001) main effects. Nitrogen fertilization reduced the percentage of stem in the sward from 78%, when plots were fertilized with 50 kg N $ha^{-1}$, to 76% at the 100 kg N $ha^{-1}$ rate (SE = 0.6). Percentage of stem was lower for Entry 1 at 8 wk and higher for Entry 4F at 16 wk (Table 4-7). There was a linear decrease in stem proportion over time for all entries, and only Entry 1 had a significant quadratic effect. Stem mass, however, increased linearly over time (*P* < 0.001). At 8 wk, stem mass was below 5 Mg $ha^{-1}$, but it increased to over 6 Mg $ha^{-1}$ at 12 wk and to almost 7 Mg $ha^{-1}$ at 16 wk. This response of decreasing both stem and leaf proportion despite increasing herbage mass is a consequence of the dead material accumulation with increasing stockpiling period ($P < 0.001$ for both mass and proportion). Dead material accounted for 10% (760 kg $ha^{-1}$) and 11% (1060 kg $ha^{-1}$) of total herbage harvested at 12 and 16 wk, respectively (Table 4-5 and Table 4-6). Dead material proportion and mass were affected by linear (both at $P < 0.001$) and quadratic ($P < 0.001$ and $P = 0.009$, respectively) effects. There was an overall increase in dead material mass and proportion over time, but extent of change was smaller between 12 and 16 wk than between 8 and 12 wk.

Leaf to stem (L:S) ratio was influenced by the length of stockpiling period ($P < 0.001$), N fertilization level ($P = 0.042$), and entry ($P = 0.008$) main effects. Entry 4F had the lowest L:S ratio (0.17) among all entries, with L:S for Entries 1, 10, and Floralta ranging from 0.21 to 0.24 (Table 4-4). Increasing N fertilization from 50 to 100 kg $ha^{-1}$ increased L:S ratio from 0.20 to 0.22 (SE = 0.01). The polynomial contrast showed a linear and quadratic response ($P = 0.03$ and $P < 0.001$, respectively) of L:S ratio to length of stockpiling period. There was a general decrease over time, but ratio was the highest at 8 wk (0.25) and lowest at 12 wk (0.17), with 16 wk presenting an intermediate value (0.21). This response is consequence of the low percentage of leaves at 12 wk as described earlier.

## Nutritive Value

### Digestibility

When evaluated for stockpiling periods of 8 to 16 wk, IVDOM was affected by entry and stockpiling period main effects ($P < 0.001$ for both). Entry 4F had the highest IVDOM (590 g $kg^{-1}$; Table 4-8) compared with Entries 1, 10, and Floralta, which did not differ from each other and had IVDOM ranging from 548 to 559 g $kg^{-1}$. Digestibility was greater for the 8-wk treatment (584 g $kg^{-1}$; Table 4-9) than for 12- (548 g $kg^{-1}$) and 16-wk periods (552 g $kg^{-1}$). The polynomial contrast showed linear and quadratic ($P < 0.001$ for both) responses of IVDOM to stockpiling period, so although IVDOM decreased with increasing stockpiling period to 12 wk, it remained relatively constant thereafter. Remarkably, even at 12 and 16 wk of maturity, average limpograss IVDOM did not decrease below 548 g $kg^{-1}$. High IVDOM across a wide range of maturities was found in other limpograss studies (Carvalho, 1976; Davis et al., 1987; Arthington and Brown, 2005). The similar values for IVDOM between 12 and 16 wk could be associated with the increase in leaf mass reported earlier from 12 to 16 wk, but the effect of this was ameliorated due to a larger increase in stem mass and dead material at the base of the sward.

Carvalho (1976) analyzed change in IVDOM with increasing maturity for different C4 species including limpograss. He found similar IVDOM concentration as in the current study for 8- and 12-wk limpograss herbage (589 and 533 g $kg^{-1}$, respectively), but in that experiment IVDOM continued to decline at a lower rate through 16 wk (516 g $kg^{-1}$) and eventually to 452 g $kg^{-1}$ at 22 wk. Compared with bahiagrass (*Paspalum notatum* Flügge), limpograss IVDOM was 155 to 170 g $kg^{-1}$ higher at all regrowth periods, and bahiagrass IVDOM at 22 wk was 226 g $kg^{-1}$ (Carvalho, 1976). Quesenberry and Ocumpaugh (1980) reported Bigalta limpograss IVDOM above 620 and 550 g $kg^{-1}$ when stockpiled up to 14 wk following staging on 1 August during 2 yr of study. The authors observed significant decreases in IVDOM at later dates (January to March) than the period evaluated in the current experiment. Arthington and Brown (2005) used 10-wk-old limpograss hay in a feeding trial and reported IVDOM of 575 g $kg^{-1}$.

Mislevy and Martin (2007) evaluated the stockpiling properties of different cultivars of bahiagrass, bermudagrass [*Cynodon dactylon* (L.) Pers.], stargrass (*C. nlemfluensis* Vanderyst), and limpograss (Floralta) in south Florida. They tested an unfertilized treatment and compared it with application of 50-30-60 kg N-P-K ha$^{-1}$. Harvests occurred at four dates including at first frost and 1, 2, and 4 wk after the frost event. Plots were staged on 1 October, fertilized later in the month, and time to the first harvest varied each year, depending on the frost, but the average stockpiling period was around 9 wk. Limpograss accumulated more herbage than the other species, 4.5 Mg ha$^{-1}$ with fertilizer application and 1.5 Mg ha$^{-1}$ without fertilizer. Limpograss IVDOM averaged 577 and 600 g kg$^{-1}$ for unfertilized and fertilized treatments, and did not differ for most of the harvest periods. While limpograss did not decrease IVDOM after the first frost, other species tested showed a decrease of 82, 86, and 57 g kg$^{-1}$, for bahiagrass, bermudagrass, and stargrass, respectively. At the fourth week after frost, Floralta's digestibility was the highest of all grasses, 544 g kg$^{-1}$, whereas the others ranged from 379 to 503 g kg$^{-1}$ for the fertilized treatment.

According to Moore (1992) total digestible nutrients (TDN) required for beef cattle ranges from 540 to 620 g kg$^{-1}$, depending on the animal class and physiological state. In his report of forage analysis results from the Florida Extension Forage Testing Program, he indicated that the vast majority of samples for species other than limpograss had TDN concentrations ranging from 480 to 510 g kg$^{-1}$, whereas 68% of limpograss samples had TDN above 510 g kg$^{-1}$.

Stockpiled limpograss in vitro digestible dry matter (IVDDM) concentrations were evaluated by Davis et al. (1987) in response to eight levels of N-P-K fertilization (in a ratio of 9-1-4) in central Florida. Pastures were staged to 2.5 cm in October and received fertilization based on N levels of 0, 34, 68, 100, 135, 168, 200, and 400 kg N $ha^{-1}$. Harvests were from December to April. Digestibility in December was between 500 and 600 g $kg^{-1}$ for all levels of fertilization and in January for all but 0 kg N $ha^{-1}$. The February harvest (around a 17-wk stockpiling period) had the lowest IVDDM, dropping to below 500 g $kg^{-1}$ and not being affected by fertilization level.

**Crude protein**

Crude protein was affected by entry ($P = 0.008$) and stockpiling period main effects ($P < 0.001$), but it was not affected by N fertilization ($P = 0.111$). Entry 4F had the lowest CP concentration (27 g $kg^{-1}$; Table 4-8), while Entries 1 (33 g $kg^{-1}$), 10 (32 g $kg^{-1}$), and Floralta (33 g $kg^{-1}$) did not differ. There were linear and quadratic effects ($P < 0.001$ and $P = 0.001$, respectively) of increasing length of stockpiling period on limpograss CP. Crude protein concentrations decreased from 39 g $kg^{-1}$ at 8 wk to 28 and 27 g $kg^{-1}$ at 12 and 16 wk (Table 4-9).

All levels of CP are much below cattle requirements and below most reports in the literature. Limpograss hay without N fertilization cut at 10-wk regrowth had CP concentration of approximately 30 g $kg^{-1}$ (Arthington and Brown, 2005). This concentration was inferior to that of bahiagrass, bermudagrass and stargrass. Following initiation of stockpiling on 10 October, limpograss CP concentration in December was greater than in the current experiment, ranging from approximately 90 g $kg^{-1}$ with 0 N to almost 150 g $kg^{-1}$ at 400 kg N $ha^{-1}$ (Davis et al., 1987). Although CP decreased over time in their study, it never reached below 70 g $kg^{-1}$ even at 0 N. Like Davis et al. (1987) and unlike the current experiment, Kretschmer and Snyder (1985) reported a response of stockpiled limpograss CP to N fertilization. After staging the Bigalta pastures on 15

September, plots received 50, 100, or 150 kg N $ha^{-1}$ on either 22 September or 2 November and were harvested on 18 December. Crude protein concentration had a quadratic response to N fertilization level, varying from around 35 to 80 g $kg^{-1}$, and reaching a maximum at approximately 120 kg N $ha^{-1}$. The authors reported that the September fertilization had superior yield and N uptake, but CP and IVDOM responded to a greater degree when fertilized in November than September. Mislevy and Martin (2007) also reported that stockpiled limpograss CP was affected by fertilizer application (zero vs. 50-30-60 kg N-P-K $ha^{-1}$). Herbage CP decreased slightly from 101 g $kg^{-1}$ at time of a frost event to 92 g $kg^{-1}$ 4 wk after frost in the fertilized treatment, and from 84 to 78 g $kg^{-1}$ without fertilization. The lack of CP response to N fertilization in the current study is likely due to the narrow range (50 kg $ha^{-1}$) and relatively low N rates applied relative to those in which a response to N was observed.

Like the response in the current study, Carvalho (1976), Quesenberry and Ocumpaugh (1980), and Davis et al. (1987) reported the same trend of decreasing limpograss CP with increasing maturity during fall through winter. Carvalho (1976) fertilized limpograss with 74 kg N $ha^{-1}$ and evaluated changes in nutritive value with increasing maturity. He found low CP in limpograss relative to bahiagrass and digitgrass (*Digitaria eriantha* Steud.), but only at 22 wk of regrowth was CP lower than 40 g $kg^{-1}$. Bigalta limpograss, staged on 1 August, decreased CP below 50 g $kg^{-1}$ by early October (8 wk) and remained low for the for the rest of the experimental period (Quesenberry and Ocumpaugh, 1980).

Kretschmer et al. (1996) tested initial and late fertilization dates and different N rates on stockpiled Bigalta limpograss. Plots were staged on 2 September and initial fertilization was applied either on 22 September or 2 November, at 50 or 150 kg N $ha^{-1}$ rate. Late fertilizer (0, 50 or 150 kg N $ha^{-1}$) was applied on December 18 (total of 12 treatments). Plants were cut to a 10-cm stubble height and separated into 25-cm segments from the top to the base and analyzed for IVDOM and CP. Late (December) fertilization increased CP for both initial fertilization dates, with a slight advantage for the November over September fertilization. Protein concentration in the top segments were at least twice as great as the lower ones, indicating that late N fertilizer application is translocated to the meristematic region, where probably some regrowth is occurring. Digestibility values were very high for both treatments (ranging from 575 to 665 g $kg^{-1}$) and varied little among treatments and within the plant profile. In addition to large vertical heterogeneity in CP, the authors showed IVDOM was nearly constant and remained high all the way to the base of the canopy. This was a consequence of greater leaf proportion in the upper stratum and two to three times greater CP concentration in leaves than stems, while, in contrast, IVDOM did not vary widely between leaf and stem or vertically within a plant part (Holderbaum et al., 1992).

**Digestible organic matter:crude protein ratio**

The DOM:CP ratio was affected by entry and stockpiling period (both $P < 0.001$). Entry 4F had a ratio of 21.3, higher than all other entries that ranged from 17.6 to 18.6 (Table 4-8). The polynomial contrasts showed both linear ($P < 0.001$) and quadratic ($P = 0.032$) effects of length of stockpiling period on DOM:CP. The ratio at 8 wk was lower (15.5) than for both subsequent periods (20.7 and 21.5 for 12 and 16 wk, respectively), and the rate of decrease was smaller from 12 to 16 wk, resulting in the quadratic effect (Table 4-9).

The highest IVDOM was for Entry 4F (590 g $kg^{-1}$) and it also had the lowest CP (27 g $kg^{-1}$) and the least proportion of leaves (13.6%) in the canopy. Lower CP is often associated with greater herbage harvested as was observed for Entry 4F. However, herbage harvested for Entry 10 was not different than for 4F, but DOM:CP ratio was 4.5 units higher. Floralta and Entry 1 responded similarly for both herbage harvested and herbage DOM:CP.

The very high DOM:CP ratio of limpograss in this study and previously reported in the literature (e.g., Holderbaum et al., 1992) is due to particular characteristics of the species. Specifically, stem IVDOM can be as high or nearly as high as that of leaves, but stem CP may only be half as great as leaf CP. These patterns of plant part chemical composition and IVDOM response, along with the high percentage of stem in limpograss herbage harvested, explain the very high DOM:CP observed.

Moore and Kunkle (1995) suggested that the DOM:CP ratio should remain below 7 to sustain intake and animal performance, and cattle grazing forages with ratios greater than 7 are likely to require N supplementation. Moore (1992) reported that 81% of the limpograss samples sent to the Florida Extension Forage Testing Program had TDN:CP ratios above 8 due to the high digestibility and relative low CP. He indicated that animals grazing forages with TDN:CP ratio above 8 are likely to require and respond to protein supplementation.

Holderbaum et al. (1991) compared performance of steers grazing limpograss fertilized with 120 kg N $ha^{-1}$ with that on mixed pasture of limpograss and aeschymomene (*Aeschynomene americana* L.). Animals on pure limpograss stands received either no supplementation, or were fed a 210 or 500 g CP $kg^{-1}$ supplement, in order to provide 90 or 120 g CP $kg^{-1}$ of diet, respectively. Average DOM:CP for limpograss pastures was 8.7, and for the mixture with the legume was 6.9. Average daily gain was least for animals grazing limpograss without supplementation (0.29 kg $d^{-1}$). There was no difference between the 210 or 500 g CP $kg^{-1}$ supplement treatments (0.53 and 0.59 kg $d^{-1}$, respectively), or between the supplement treatments and the limpograss-aeschynomene mixture (0.52 kg $d^{-1}$). In another experiment, supplementing heifers rotationally stocked on limpograss pastures with a 400 g $kg^{-1}$ CP mix increased average daily gain from 0.06 to 0.41 kg $d^{-1}$ when those pastures were fertilized with 50 kg N $ha^{-1}$ and herbage DOM:CP averaged 9.7 and 8.4, respectively (Lima et al., 1999). In the same study, no difference in animal performance was observed between supplemented and non-supplemented treatments when the pastures received 150 kg N $ha^{-1}$ and herbage DOM:CP averaged 7.7, indicating a critical level of DOM:CP somewhere in the range of 8 to 10. Clearly, herbage from all treatments in the current study was well above this range, and CP supplementation would be needed.

**Early-stockpiling period nutritive value**

Hand-plucked samples were taken at 4 and 6 wk of stockpiling in the plots designated to the 8-wk stockpiling period treatment. To evaluate the evolution of nutritive value early in the stockpiling period, data for IVDOM and CP for 4, 6, and 8 wk were grouped and analyzed as repeated measurements.

Herbage IVDOM was affected by the entry main effect ($P$ = 0.001) and N level by date interaction ($P$ = 0.002). Entry 4F had greater IVDOM (626 g $kg^{-1}$) than either Entry 1 or Floralta (603 and 594 g $kg^{-1}$), but it was not different than Entry 10 (613 g $kg^{-1}$). Entries 1 and 10 did not differ in IVDOM

The interaction between date and N level for IVDOM occurred because digestibility was greater at 4 wk for the higher N fertilization rate (623 vs. 606 g $kg^{-1}$ for 100 and 50 kg N $ha^{-1}$, respectively; SE = 7.8), but there was no difference observed thereafter. Within N levels, IVDOM was greater at 6 wk (633 g $kg^{-1}$) than at 4 wk (606 g $kg^{-1}$) for the 50 kg N $ha^{-1}$ rate, while the lowest IVDOM was observed at 8 wk (583 g $kg^{-1}$). At the 100 kg N $ha^{-1}$ rate, greater IVDOM was observed for the first two dates (627 and 620 g $kg^{-1}$ for 4 and 6 wk, respectively) and it decreased to 586 g $kg^{-1}$ at 8 wk.

Crude protein was affected by entry by date interaction ($P$ = 0.004) and N fertilization ($P$ = 0.025) effects. Herbage from plots fertilized with 100 kg N $ha^{-1}$ had a slightly greater CP concentration compared with 50 kg N $ha^{-1}$ (53 vs. 48 g $kg^{-1}$; SE = 3.9). This difference, as noted in the previous section, disappeared after 8 wk. For all entries, CP concentration decreased from 4 to 8 wk. The decline had both linear and quadratic terms for Entries 1, 4F, and 10, and was linear for Floralta (Table 4-10). The quadratic effect was due to the more rapid decrease from 4 to 6 wk in comparison with 6 to 8 wk. Entry 1 had the highest CP at 4 wk (79 g $kg^{-1}$), and at 6 wk (53 g $kg^{-1}$) it was greater than all but Floralta (52 g $kg^{-1}$). There were no differences among the limpograss entries at 8 wk. Entry 10 was the only entry that did not decline in CP between 6 and 8 wk (38 vs 42 g $kg^{-1}$, respectively).

Crude protein concentration in limpograss is generally lower than other commonly used grasses (e.g., bahiagrass, bermudagras, digitgrass). Values for this experiment, although comparable to some in the literature, were relatively low and decreased faster than in most other studies (e.g., Carvalho, 1976). In that experiment, limpograss CP concentration was above 100 g $kg^{-1}$ only for the first 5 wk, decreasing to around 70 g kg$^{-1}$ at 9 wk (Carvalho, 1976). The same author reported IVDOM concentrations above or around 600 g kg$^{-1}$ for the first 8 wk of regrowth for limpograss. Four-week limpograss hay, without fertilization, used for a feeding trial had CP concentration of around 80 g kg$^{-1}$, and CP of 10-wk-old hay decreased to approximately 30 g kg$^{-1}$ (Arthington and Brown, 2005). On the other hand, Quesenberry and Ocumpaugh (1980) reported that Bigalta limpograss CP dropped below 50 g kg$^{-1}$ only after 8 wk of growth. Crude protein was also higher for 8-wk stockpiled Bigalta limpograss (Davis et al., 1987); they reported CP concentrations of 90 g kg$^{-1}$ with 68 kg N fertilizer ha$^{-1}$ and > 120 g kg$^{-1}$ when fertilization rates were above 100 kg N ha$^{-1}$.

**Plant part nutritive value**

Leaf blade and stem plus sheath fractions from the 8-, 12-, and 16-wk stockpiling periods were analyzed for CP and IVDOM. Leaf CP was affected by entry ($P = 0.037$; SE = 2.2) and stockpiling period effects ($P < 0.001$; SE = 1.9), but N fertilization level did not affect leaf CP ($P = 0.172$). Entry 4F (71 g kg$^{-1}$) had lower leaf CP than Entries 1 and Floralta (77 g kg$^{-1}$), but Entry 10 leaf CP was not different than any of the other entries (74 g kg$^{-1}$). There were linear ($P < 0.001$) and quadratic ($P = 0.02$) effects of length of stockpiling period on leaf blade CP, with concentrations decreasing from 81 g kg$^{-1}$ at 8 wk to 72 and 71 g kg$^{-1}$ at 12 and 16 wk, respectively.

Leaf blade IVDOM was affected by length of stockpiling period ($P < 0.001$) and there were both linear and quadratic effects ($P = 0.003$ and $P < 0.001$, respectively). There was a decrease in leaf digestibility from 569 g kg$^{-1}$ at 8 to 539 g kg$^{-1}$ at 12 wk ($P = 0.061$) and then an increase to 618 g kg$^{-1}$ at 16 wk. The increase in leaf IVDOM was probably due to new leaves that grew with the mild temperatures observed in November after frosts prior to the 12-wk harvest in October. A similar effect was reported by

Mislevy and Martin (2007) who reported an increase in CP and IVDOM between 2 and 4 wk after a frost event due to warming temperatures and new growth during that time. According to the authors, the increase in both parameters (23 and 13 g $kg^{-1}$, respectively) could be related to the appearance of new tillers and leaves due to warmer temperatures after the frost.

Stem CP was affected only by stockpiling period and showed a linear decrease ($P$ = 0.002) from 22 g $kg^{-1}$ at 8 wk to 17 g $kg^{-1}$ at 16 wk. Stem IVDOM was affected by the three-way interaction of entry x N fertilization level x stockpiling period ($P$ = 0.007). As the N fertilization main effect was not significant, the entry x stockpiling period interaction was evaluated for each level of N. At 50 kg N $ha^{-1}$, the entry by stockpiling period interaction was significant ($P$ = 0.034). The general tendency was for stem IVDOM to decline over time, but the interaction occurred because for Entry 10, the 12-wk concentration (536 g $kg^{-1}$) was lower than for 8 and 16 wk (576 and 569 g $kg^{-1}$). For all stockpiling periods, stem digestibility of Entry 4F (ranging from 620 to 580 g $kg^{-1}$) was greater than for Floralta at 12 and 16 wk (549 and 546 g $kg^{-1}$, respectively), and Entry 1 had the most marked decline (from 585 to 512 g $kg^{-1}$ at 8 and 16 wk, respectively). Within 100 kg $ha^{-1}$ N fertilization rate there was entry and stockpiling date main effects ($P$ < 0.001 for both). Stem digestibility was higher for 4F (602 g $kg^{-1}$) than for any other entry and those entries ranged from 552 to 559 g $kg^{-1}$. The polynomial contrast for stockpiling period was linear ($P$ < 0.001), and stem IVDOM decreased from 594 g $kg^{-1}$ at 8 wk, to 562 g $kg^{-1}$ at 12 wk and 548 g $kg^{-1}$ at 16 wk. Kretschmer at al. (1996) also reported very high digestibility values for stockpiled limpograss. For a staging date of 15 September, the authors tested the effect of a range of combinations of early and late fertilization dates and rates (described earlier in the text). Limpograss plants were harvested on 9 January and divided in segments of 25-cm increments from a 10-cm stubble height. Considering the bottom three segments (out of 5) as being constituted primarily by stems, IVDOM concentrations ranged only from 576 to 622 g $kg^{-1}$. Kretschmer at al. (1996) observed that delaying N fertilization of stockpiled limpograss until November resulted in higher digestibility values for the entire canopy profile but decreased herbage accumulation.

## Important Findings and Implications

Both Entries 4F and 10 were more productive than Floralta, and appear to be promising lines for use as stockpiled forage. Entry 4F had the highest digestibility, but at the same time the lowest CP and highest DOM:CP and stem accumulation of the other entries. In comparison, Entry 10 produced as much as 4F, but did not show any improvement over Floralta in terms of nutritive value. Morphological characteristics (e.g. increased stem accumulation) of Entry 4F may create constraints for animal consumption. Entry 10 appeared to provide the best compromise between production and nutritive value, if considering that protein supplementation can add significant cost and that the level of digestibility observed is sufficient to carry most livestock classes through the winter. Increasing N fertilization to levels beyond those tested by this experiment could help enhance CP concentration of stockpiled limpograss and reduce the quantity of protein supplement needed, but the cost of fertilization vs. supplementation must be compared to determine if this approach is economical.

Table 4-1. Herbage harvested and herbage accumulation rate of four stockpiled limpograss entries in 2012. Data are means across two N fertilization levels, three stockpiling periods, and three replicates (n = 18).

| Entry | Herbage harvested ($Mg\ ha^{-1}$) | Herbage accumulation rate ($kg\ ha^{-1}\ d^{-1}$) |
|---|---|---|
| 4F | 8.7 a[†] | 106 a |
| 10 | 8.2 a | 101 a |
| 1 | 7.4 ab | 91 ab |
| Floralta | 6.4 b | 78 b |
| SE | 0.8 | 8.6 |

[†] Means within a column followed by the same letter are not different at $P < 0.05$.

Table 4-2. Effect of stockpiling period on herbage mass harvested and herbage accumulation rate. Data are means across four limpograss entries, two N fertilization rates, and three replicates (n = 24).

| Stockpiling period (wk) | Herbage harvested ($Mg\ ha^{-1}$) | Herbage accumulation rate ($kg\ ha^{-1}\ d^{-1}$) |
|---|---|---|
| 8 | 6.0 | 107 |
| 12 | 7.8 | 92 |
| 16 | 9.3 | 83 |
| SE | 0.7 | 7.4 |
| Contrast[†] | L** | L** |

[†] Orthogonal polynomial contrast for the effect of stockpiling period on herbage harvested and herbage accumulation rate; L = linear, Q = quadratic; * and ** indicate $P < 0.05$ and $< 0.01$, respectively.

Table 4-3. Entry x stockpiling period interaction effect on limpograss extended stem length and lodging index. Means are averages of two N fertilization levels and three replicates (n = 6).

| Entry | Stockpiling period (wk) | | | Contrast† |
|---|---|---|---|---|
| | 8 | 12 | 16 | |
| | Extended stem length (cm) | | | |
| 1 | 77 a‡ | 99 b | 99 c | L**Q* |
| 4F | 73 a | 104 b | 123 a | L** |
| 10 | 89 a | 107 ab | 118 ab | L** |
| Floralta | 79 a | 117 a | 112 b | L**Q** |
| SE | | 5.4 | | |
| | Lodging index§ | | | |
| 1 | 1 a | 1.25 c | 1.39 b | L**Q* |
| 4F | 1 a | 1.45 b | 1.69 a | L**Q* |
| 10 | 1 a | 1.31 bc | 1.55 ab | L** |
| Floralta | 1 a | 1.68 a | 1.62 a | L**Q** |
| SE | | 0.09 | | |

† Orthogonal polynomial contrast effect for stockpiling period on nutritive value parameters; L = linear, Q = quadratic; , * and ** indicate *P* < 0.05 and < 0.01, respectively.
‡ Means within a column and response variable followed by the same lower case letter are not different at P < 0.05.
§ Ratio between extended stem length and canopy height.

Table 4-4. Limpograss entry effect on leaf percentage and leaf:stem (L:S) ratio in herbage harvested. Data are means across three stockpiling periods, two N fertilization levels, and three replicates (n = 18).

| Entry | Leaf (%) | L:S ratio |
|---|---|---|
| 1 | 18 a† | 0.24 a |
| 4F | 14 b | 0.17 b |
| 10 | 17 a | 0.22 a |
| Floralta | 16 ab | 0.21 a |
| SE | 1.2 | 0.02 |

† Means within a column followed by the same letter are not different at *P* < 0.05.

Table 4-5. Effect of stockpiling period on leaf and dead material proportions. Data are means across four entries, two N fertilization levels, and three replications (n = 24).

| Period | Leaf | Dead material |
| --- | --- | --- |
| | ------------------------- % ---------------------------- | |
| 8 | 20 | 0 |
| 12 | 12 | 10 |
| 16 | 15 | 11 |
| SE | 1 | 0.7 |
| Contrast† | L** Q** | L**, Q** |

† Orthogonal polynomial contrast for stockpiling period effect on herbage harvested and herbage accumulation rate; L = linear, Q = quadratic, * and ** indicate $P < 0.05$ and $< 0.01$, respectively.

Table 4-6. Effect of stockpiling period on leaf, stem, and dead material mass. Data are means across four entries, two N fertilization levels, and three replications (n = 24).

| Period | Leaf | Stem | Dead material |
| --- | --- | --- | --- |
| | ------------------------ kg ha$^{-1}$ ---------------------- | | |
| 8 | 1190 | 4830 | 0 |
| 12 | 950 | 6050 | 760 |
| 16 | 1280 | 6930 | 1060 |
| SE | 133 | 995 | 98 |
| Contrast† | Q* | L** | L**, Q** |

† Orthogonal polynomial contrast effect for stockpiling period on herbage harvested and herbage accumulation rate; L = linear, Q = quadratic, * and ** indicate $P < 0.05$ and $< 0.01$, respectively.

Table 4-7. Effect of entry by stockpiling period interaction on stem percentage. Data are means across two N fertilization levels and three replicates (n = 6).

| Entry | Stockpiling period | | | Contrast† |
|---|---|---|---|---|
| | 8 | 12 | 16 | |
| | ----------------------%--------------------- | | | |
| 1 | 77 b‡ | 79 ab | 73 b | L*Q* |
| 4F | 82 a | 78 a | 77 a | L** |
| 10 | 81 a | 76 b | 74 b | L** |
| Floralta | 81 a | 77 ab | 72 b | L** |
| SE | | 1.6 | | |

† Orthogonal polynomial contrast effect for stockpiling period on herbage harvested and herbage accumulation rate; L = linear, Q = quadratic, * and ** indicate $P < 0.05$ and $< 0.01$, respectively.
‡ Means within a column followed by the same letter are not different at $P < 0.05$.

Table 4-8. Limpograss entry effect on herbage in vitro digestible organic matter (IVDOM) and crude protein (CP) concentrations and digestible organic matter:crude protein (DOM/CP) ratio. Data are means across three stockpiling periods, two N fertilization levels, and three replicates (n = 18).

| Entry | IVDOM | CP | DOM:CP |
|---|---|---|---|
| | ---------------- g kg$^{-1}$ ------------- | | |
| 1 | 550 b† | 33 a | 17.8 b |
| 4F | 590 a | 27 b | 23.1 a |
| 10 | 559 b | 32 a | 18.6 b |
| Floralta | 548 b | 33 a | 17.6 b |
| SE | 7.3 | 1.9 | 1.3 |

† Means within a column followed by the same letter are not different at $P < 0.05$.

Table 4-9. Effect of stockpiling period on limpograss herbage in vitro digestible organic matter (IVDOM) and crude protein (CP) concentrations and digestible organic matter:crude protein (DOM:CP) ratio. Data are means across four entries, two N fertilization levels, and three replications (n = 24).

| Stockpiling period (wk) | IVDOM | CP | DOM:CP |
|---|---|---|---|
| | ---------------- g $kg^{-1}$ ------------- | | |
| 8 | 584 | 39 | 15.5 |
| 12 | 548 | 28 | 20.7 |
| 16 | 552 | 27 | 21.5 |
| SE | 6.3 | 1.7 | 1.2 |
| Contrast† | L**, Q** | L**,Q** | L**,Q* |

† Orthogonal polynomial contrast effect for stockpiling period on nutritive value parameters; L = linear, Q = quadratic; , * and ** indicate *P* < 0.05 and < 0.01, respectively.

Table 4-10. Limpograss entry by length of stockpiling period interaction effect on herbage crude protein (CP) concentration. Data are means across two N fertilization rates and three replications (n = 6)

| Entry | Stockpiling period (wk) | | | Contrast† |
|---|---|---|---|---|
| | 4 | 6 | 8 | |
| | ------------------ g $kg^{-1}$ ------------------- | | | |
| 1 | 79 a‡ | 53 a | 41 a | L**Q* |
| 4F | 65 b | 42 b | 33 a | L**Q* |
| 10 | 60 b | 38 b | 42 a | L**Q* |
| Floralta | 61 b | 52 a | 39 a | L** |
| SE | | 4.7 | | |

† Orthogonal polynomial contrast effect for stockpiling period on nutritive value parameters; L = linear, Q = quadratic; , * and ** indicate *P* < 0.05 and < 0.01, respectively.
‡ Means within a column and response variable followed by the same letter are not different at *P* < 0.05.

# CHAPTER 5
# SUMMARY AND CONCLUSIONS

Limpograss [*Hemarthria altissima* (Poir.) Stapf *et* C.E. Hubb.] use in Florida has increased rapidly over the past 30 yr, especially in the southern part of the state, where it is estimated that over 0.2 million ha are planted to cv. Floralta. With basically just one cultivar available in the market, it can be vulnerable to an outbreak of pests or diseases. Moreover, current cultivars have limitations that might be addressed in a breeding program. Specifically, Bigalta typically has greater digestibility than Floralta, but Floralta is much more persistent under grazing. Therefore, there remains room for improvement in limpograsses. With the final goal of making available another limpograss cultivar for Florida cattlemen, Dr. Quesenberry and his colleagues at the University of Florida developed hybrids by crossing the more digestible Bigalta with the more persistent Floralta. Initially, 51 hybrids resulted from their work, and after a series of clipping and grazing trials the five best performing breeding lines were selected. The objective of this research was to test those lines, informally named 1, 4F, 10, 32, and 34 under different grazing management treatments (Chapter 3) and stockpiling strategies (Chapter 4) to assess their productivity, persistence, and nutritive value.

## Limpograss Breeding Line Performance Under Grazing

Limpograss breeding lines (1, 4F, 10, 32, and 34) and Floralta were evaluated under mob-stocking comparing the factorial combinations of two pre-grazing canopy light interception levels (LI; 80 and 95%) that defined initiation of grazing events, and two post-grazing stubble heights (SH; 20 and 30 cm). The average length of the grazing season was 93 d, and longer for Entry 10 at LI95 (115 d), but not different from 4F and Floralta at LI80 (122 and 117 d, respectively, and 113 d for Entry 10). In general, plots assigned to LI80 were grazed more frequently therefore more times than those to LI95 (average of 4.6 and 3.2 grazing events, respectively).

Herbage accumulation was greater for Entry 10 (11.6 Mg ha$^{-1}$) than for Entries 1, 32 and 34 (≤ 8.4 Mg ha$^{-1}$) but was not different than 4F and Floralta (10.4 and 9.5 Mg ha$^{-1}$, respectively). Herbage accumulated, accumulation rate, and harvested were lower for LI80/SH30 than for all other treatment combinations. There was a greater incidence of lodging and trampling on the LI95 treatments because greater stem accumulation, taller canopy height, and greater herbage bulk density in LI95 than LI80 imposed constraints for the animals to graze, especially when targeting SH20. Another contributing factor to achieving SH20 was that this treatment had greater bulk density than SH30.

Nutritive value was not affected by entry, but CP was greater for LI80 (89 g kg$^{-1}$) than LI95 (81 g kg$^{-1}$). Digestibility did not vary greatly and average IVDOM was 578 g kg$^{-1}$. The lack of LI effect, i.e., maturity, supports the often stated concept that limpograss maintains high levels of digestibility over a wide range of maturity.

Leaf percentage was greater in the upper layer of the sward than in the lower layer (39 vs. 23%, respectively), and the SH30 treatment had 34% leaf vs. 29% for the SH20. Leaf and stem mass were greater in the lower than the upper stratum. In the upper stratum, there was no effect of LI on leaf, stem, or total herbage mass, however those same responses were greater in the lower stratum for LI95 than for LI80.

All entries had greater leaf CP concentration at LI80 than LI95, ranging from 135 to 152 g kg$^{-1}$ and 81 to 111 g kg$^{-1}$, respectively, and the upper stratum of the canopy had greater leaf CP than the lower stratum (127 vs. 117 g kg$^{-1}$, respectively). Entries 10 and 4F had greater leaf IVDOM concentration (594 and 595 g $kg^{-1}$) than Entry 1 (564 g $kg^{-1}$) in the upper stratum and greater leaf IVDOM than Floralta (607 g $kg^{-1}$ for both Entries 10 and 4F vs. 572 g $kg^{-1}$ for Floralta) in the lower stratum. Stem CP was greater in the upper than in the lower stratum (64 vs. 48 g $kg^{-1}$), for LI80 than LI95 (70 vs. 42 g $kg^{-1}$) and for SH30 than SH20 (60 vs. 52 g $kg^{-1}$). Stem IVDOM was generally high for all treatments, but it was greater for LI80 than for LI95 (600 vs. 570 g $kg^{-1}$, respectively).

Weed frequency was less in Entries 10 and 1 than in Floralta, 32, and 34. The change in persistence-related parameters from before treatments were imposed to 1 yr later showed that weed frequency increased in LI80 compared to LI95 (20 vs. 8%, respectively), and there was a very large increase in weed frequency for Entries 34 (43%) and Floralta (28%) compared with a decrease in weed frequency for Entries 10 (-2%) and 1 (-8%).

At the end of the 2012 grazing season, a spittlebug infestation affected the experimental pastures. A visual rating was assigned to each plot based on the extent of the damage. Treatment LI95/SH30 had the most severe damage and Entry 10 had less damage than Floralta, 32, and 34, but it was not different from 1 and 4F.

Based on the first year of data, Entries 4F and 10 showed significant improvement on several of the traits measured in comparison to the industry standard Floralta, and are clearly superior to Entries 32 and 34. Using LI parameters to initiate grazing seems not to be appropriate for limpograss pastures, because the “optimum” level (95% LI) results in canopy characteristics that are unfavorable for animal harvesting and may, therefore, negatively affect performance.

## Use of Limpograss Breeding Lines as Stockpiled Forage

Entries 1, 4F, 10, and Floralta were fertilized with 50 or 100 kg N ha$^{-1}$ and stockpiled for 8, 12, or 16 wk beginning on 1 August. There was a linear increase over the stockpiling period in herbage harvested (7.8 vs. 9.3 Mg ha$^{-1}$ for 8 and 16 wk, respectively) and a decrease in herbage accumulation rate (107 vs. 82 kg DM d$^{-1}$ for 8 and 16 wk, respectively). Entries 4F and 10 had the greatest herbage harvested (8.7 and 8.2 Mg ha$^{-1}$, respectively) and Floralta the least (6.4 Mg ha$^{-1}$).

Nitrogen fertilization affected stem percentage (78 vs. 76% for 50 and 100 kg N ha$^{-1}$, respectively) and leaf percentage (15 vs. 17% for 50 and 100 kg N ha$^{-1}$, respectively), but the difference was not great enough to influence total herbage CP. Leaf percentage declined with time from 20% at 8 wk to 15% at 16 wk, while leaf mass increased slightly. Stem mass increased over time from below 5 Mg ha$^{-1}$ at 8 wk to almost 7 Mg ha$^{-1}$ at 16 wk, but the relative proportion of stem declined over the period due to increased dead material accumulation (11% at 16 wk).

Digestibility was greater at 8 wk (584 g kg$^{-1}$) than at 12 (548 g kg$^{-1}$) and 16 wk (552 g kg$^{-1}$), but the reduction was not large. Entry 4F had the highest IVDOM concentrations (590 g kg$^{-1}$) compared with the others, ranging from 548 to 559 g kg$^{-1}$, but 4F had the lowest CP (27 g kg$^{-1}$) while Floralta, 1, and 10 had CP concentrations around (33 g kg$^{-1}$).

Both Entries 4F and 10 were more productive than Floralta and appear to have good stockpiling qualities. However, beside the fact that Entry 4F had the greatest digestibility, Entry 10 appeared to provide a better compromise between production and nutritive value (especially CP concentration), that may help reduce protein supplementation costs.

## Implications of the Research

The last limpograss cultivar released in Florida was Floralta in 1984, and since then nearly all area planted to limpograss in the state was planted to Floralta. There is a need to diversify this genetic pool and improve some traits such as digestibility and persistence.  So far, most of the goals of this program seem attainable because at least two of the hybrids generally outperform Floralta in most important aspects including productivity, persistence, nutritive value, and possibly insect tolerance. From a cattleman's perspective, it is important to have alternative cultivars available on the market in order not to be dependent on just one genetic line. The new hybrids appear capable of improving cattle performance while reducing production costs due to greater persistence. The decision of which entry or entries to release will be a challenging one. Entry 10 appears to be the most consistent performer among the breeding lines, and it is the most likely candidate for cultivar release. Entry 4F also has many desirable traits, although it may not be as persistent as Entry 10. Entry 1 is less productive than Entries 10 or 4F, but it appears to have good persistence and nutritive value. Clearly, Entries 32 and 34 should not be released due to lack of persistence. Data are being collected from each of the two experiments for a second year in 2013, and they will provide additional guidance for eventual cultivar release decisions.

## LIST OF REFERENCES

Akin, D.E., E.L. Robinson, F.E. Barton, and D.S. Himmelsbach. 1977. Changes with maturity in anatomy, histochemistry, chemistry, and tissue digestibility of bermudagrass plant parts. J. Agr. Food Chem. 25:179-186.

Arthington, J.D., and W.F. Brown. 2005. Estimation of feeding value of four tropical forage species at two stages of maturity. J. Anim. Sci. 83:1726-1731.

Barbosa, R.A., N. Júnior, V. Pacheco, B. Euclides, S.C. da Silva, A.H. Zimmer, and R.A.A. Torres Jr. 2007. Capim-tanzânia submetido a combinações entre intensidade e freqüência de pastejo. Pesqui. Agropecu. Bras. 42(3): 329-340.

Brougham, R.W. 1958. Interception of light by the foliage of pure and mixed stands of pasture. Aust. J. Agric. Res. 1:39-52.

Brougham, R.W. 1960. The ralationship between Critical leaf area, total chlorophyll content and maximum growth rate of some pasture and crop plants. Ann. of Bot. 24:463-474.

Brown, R.H., and R.E. Blaser. 1968. Leaf area index in pasture growth. Herb. Abst. 38:1-9.

Brown, W.F., and M.B. Adjei. 2001. Urea and (or) feather meal supplementation for yearling steers grazing limpograss (*Hemarthria altissima* var. 'Floralta') pastures. J. Anim. Sci. 79:3170-3176.

Brown, W.F., and W.D. Pitman. 1991. Concentration and degradation of fiber fractions in selected tropical grasses and legumes. Trop. Grasslands 25:305-312.

Carnevalli, R.A., S.C.D.A. Silva, A.A.O. Bueno, M.C. Uebele, F.O. Bueno, J. Hodgson, G.N. Silva, and J.P.. Morais. 2006. Herbage production and grazing losses in *Panicum maximum* cv . Mombaça under four grazing managements. Trop Grasslands 40:165–176.

Carvalho, J.H. 1976. Plant age and its effect upon forage quality. Master Thesis, University of Florida, Gainesville.

Chapman, D., and G. Lemaire. 1993. Morphogenic and structural determinations of plant regrowth after defoliation. p. 95-104. Proc Int Grassl Cong, 17$^{th,}$ Palmerston North, New Zealand, 8-21 February 1993.

Christiansen, S., O.C. Ruelke, W.R. Ocumpaugh, K.H. Quesenberry, and J.E. Moore. 1988. Seasonal yield and quality of 'Bigalta', 'Redalta' and 'Greenalta' limpograss. Trop. Agric. 65:49-55.

Da Silva, S.C., and D. Nascimento Jr. 2007. Avanço na pesquisa com plantas forrageiras tropicais em pastagens: características morfofisiológicas e manejo do pastejo. Rev. Bras. Zootecn. 36:121-138.

Davis, C.E., V.D. Jolley, G.D. Mooso, L.R. Robison, and R.D. Horrocks. 1987. Quality of stockpiled Bigalta limpograss forage at varying fertility levels. Agron. J. 79:229-235.

Fagundes, J.L., S.C. Da Silva, C.G.S. Pedreira, A.F. Sbrissia, R.A. Carnevalli, C.A.B. Carvalho, and L.P.M. Pinto. 1999. Índice de área foliar, interceptação luminosa e acúmulo de forragem em pastagens de Cynodon spp. sob diferentes intensidades de pastejo. Sci. Agr. 56:1141–1150.

Florida Agricultural Statistics Service. 2011. Florida agriculture by numbers 2011. Florida Department of Agriculture and Consumer Services., Tallahasse, FL. http://www.nass.usda.gov/Statistics_by_State/Florida/index.asp

Gallaher, R.N., C.O. Weldon, and J.G. Futral. 1975. An aluminum block digester for plant and soil analysis. Soil Sci. Soc. Amer. Proc. 39:803-806.

Gomide, J.A., and C.A.M. Gomide. 2013. Morfofisiologia de gramíneas forrageiras. p. 31-50. *In* T.F. Bernardes et al. (ed.) Forragicultura: Ciência, Tecnologia e Gestão dos Recursos Forrageiros.

Hambleton, L.G. 1977. Semiautomated method for simultaneous determination of phosphorus, calcium and crude protein in animal feeds. J AOAC Int. 60:845-852.

Harris, W. 1993. The contributions of Dr. Raymond Wilkie Brougham to grassland science and management. Rev. Pastos 13:3-51.

Hodgson, J. 1981. Variations in the surface characteristics of the sward and the short-term rate of herbage intake by calves and lambs. Grass Forage Sci. 36:49-57.

Holderbaum, J.F., L.E. Sollenberger, J.E. Moore, W.E. Kunkle, and A.C. Hammond. 1991. Protein supplementation of steers grazing limpograss pasture. J. Prod. Agric. 4:437-441.

Holderbaum, J.F., L.E. Sollenberger, K.H. Quesenberry, J.E. Moore, and C.S. Jones, Jr. 1992. Canopy structure and nutritive value of rotationally-grazed limpograss pasture during mid-summer to early autumn. Agron. J. 84:11-16.

Korte, C.J., B.R. Watkin, and W. Harris. 1982. Use of residual leaf area index and light interception as criteria for spring-grazing management of a ryegrass-dominant pasture. New Zealand J. Agric. Res. 25:309-319.

Kretschmer, A.E., and G.H. Snyder. 1979. Production and quality of limpograss for use in the subtropics. Agron. J. 71:37-43.

Kretschmer, A.E., and G.H. Snyder. 1985. Effect of late N fertilization rates on Bigalta limpograss yield, N contents, and digestibility.Soil Crop Sci. Soc. Fla. Proc. 44:193-197.

Kretschmer, A.E., G.H. Snyder, and T.C. Wilson. 1996. Effects of fall application dates and rates of N on N and IVOMD in Bigalta limpograss segments. Soil Crop Sci. Soc. Fla. Proc. 55:116-120.

Lemaire, G., and D. Chapman. 1996. Tissue flows in grazed plant communities. p. 3-36. *In* J. Hodgson and A.W. Illius (ed.) The ecology and management of grazing systems. CABI, Wallingford, UK.

Lemaire, G., S.C. Da Silva, M. Agnusdei, M. Wade, and J. Hodgson. 2009. Interactions between leaf lifespan and defoliation frequency in temperate and tropical pastures: a review. Grass Forage Sci. 64:341-353.

Lima, G.F.C., L.E. Sollenbeger, and J.E. Moore 2001. Nitrogen concentration in cell wall of warm-season perennial grasses.p. 376-377. Piracicaba, SP, Brazil: Brazilian Soc. of Anim. Husbandry.

Lima, G.F.C., L.E. Sollenberger, W.E. Kunkle, J.E. Moore, and A.C. Hammond. 1999. Nitrogen fertilization and supplementation effects on performance of beef heifers grazing limpograss. Crop Sci. 39:1853-1858.

Mislevy, P., and F.G. Martin. 2007. Yield and nutritive value of stockpiled grasses as influenced by cultural practices and a freeze. Forage and Grazinglands PMN International. Retrieved 9 Aug. 2013. http://www.plantmanagementnetwork.org/pub/fg/research/2007/freeze/

Moore, J.E. 1992. Matching protein and energy supplements to forage quality. p. 31-44 Proc. 3rd Annual Florida Ruminant Nutrition Symposium. B. Harris and B. Haskins (ed). Univ. of Florida, Gainesville, FL

Moore, J.E., and G.O. Mott. 1974. Recovery of residual organic matter from in vitro digestion of forages. J. Dairy Sci. 57:1258-1259.

Moore, J.E., and W.E. Kunkle. 1995. Improving forage supplementation programs for beef cattle. p. 65-74. In: 6th Annual Florida Ruminant Nutrition Symposium. Univ. Florida, Gainesville."

Newman, Y.C., L.E. Sollenberger, W.E. Kunkle, and C.G. Chambliss. 2002b. Canopy height and nitrogen supplementation effects on performance of heifers grazing limpograss. Agron. J. 94:1375-1380.

Newman, Y.C., L.E. Sollenberger, W.E. Kunkle, and D.B. Bates. 2002a. Crude protein fractionation and degradation parameters of limpograss herbage. Agron. J. 94:1318-1386.

Newman, Y.C., J.M.B. Vendramini, L.E. Sollenberger, and K.H. Quesenberry. 2009. Limpograss (*Hemarthria altissima*): overview and management. University of Florida IFAS Extension. Retrieved 13 Nov. 2011 http://edis.ifas.ufl.edu/ag330

Newman, Y.C., and L.E. Sollenberger. 2005. Grazing management and nitrogen fertilization effects on vaseygrass persistence in limpograss pastures. Crop Sci. 45:2038-2043.

Newman, Y.C., L.E. Sollenberger, A.M. Fox, and C.G. Chambliss. 2003a. Canopy characteristics of continuously stocked limpograss swards grazed to different heights. Agron. J. 95:1246-1252.

Newman, Y.C., L.E. Sollenberger, A.M. Fox, and C.G. Chambliss. 2003b. Canopy height effects on vaseygrass and bermudagrass spread in limpograss pastures. Agron. J. 95:390-394.

Parsons, A.J., and P.D. Penning. 1988. The effect of the duration of regrowth on photosynthesis, leaf death and the average rate of growth in a rotationally grazed sward. Grass Forage Sci. 43:15–27.

Parsons, A.J., I.R. Johnson, and J.H.H. Williams. 1988. Leaf age structure and canopy photosynthesis in rotationally and continuously grazed swards. Grass Forage Sci. 43:1-14.

Pedreira, B.C. e, C.G.S. Pedreira, and S.C. da Silva. 2009. Herbage accumulation during regrowth of Xaraés palisadegrass submitted to rotational stocking strategies. Rev. Bras. Zootec. 38:618–625.

Pitman, W.D., R.V. Machen, and K.R. Pond. 1994. Grazing evaluation of Bigalta and Floralta limpograss. Crop Sci. 34:210-214.

Quesenberry, K.H., and W.R. Ocumpaugh. 1980. Crude protein, IVOMD and yield of stockpiled limpograss. Agron. J. 72:1021-1024.

Quesenberry, K.H., L.E. Sollenberger, and Y.C. Newman. 2004. Limpograss. p. 809-832. *In* L.E. Moser et al. (ed.) Warm-season (C4) Grass Monograph. Madison: ASA, CSSA, SSSA.

Quesenberry, K.H., L.S. Dunavin, Jr., E.M. Hodges, G.B. Killinger, A.E. Kretschmer, Jr., W.R. Ocumpaugh, R.D. Rousch, O.C. Ruelke, R.C. Smith, S.C. Schank, G.H. Snyder, and R.L. Stanley. 1978. Redalta, Greenalta, Bigalta limpograss, promising forages for Florida. Fla. Agric. Exp. Stn. Bull. 802, University of Florida, Gainesville.

Quesenberry, K.H., W.R. Ocumpaugh, and O.C. Ruelke 1983. Hemarthria altissima: a pasture grass for the tropics. p. 788-791. Westview Press, Boulder, CO.

Quesenberry, K.H., W.R. Ocumpaugh, O.C. Ruelke, L.S. Dunavin, and P. Mislevy. 1984. Floralta: a limpograss selected for yield and persistence in pastures. Florida Agric. Exp. Stn. Circ. S-312, IFAS, UF, Gainesville.

Ruelke, O.C., K.H. Quesenberry, and D.A. Sleper. 1976. Comparison of greenhouse vs. field plot techniques for evaluating new germplasm of limpograss (*Hemarthria altissima* (Poir) Stapf et C.E. Hubb) p. 112. In. 1976 Agronomy Abstracts. ASA, Madison, WI.

Rusland, G.A., L.E. Sollenberger, K.A. Albrecht, C.S. Jones, Jr., and L.V. Crowder. 1988. Animal performance on limpograss-aeschynomene and nitrogen-fertilized limpograss pastures. Agron. J. 80:957-962.

Santos, M.E.R., D.M. da Fonseca, V.P.B. Euclides, D. do Nascimento Jr, A.C. de Queiroz, and J.I. Ribeiro Jr. 2009. Características estruturais e índice de tombamento de Brachiaria decumbens cv. Basilisk em pastagens diferidas. Rev. Bras. Zootec. 38:626–634

Sbrissia, A.F., S.C. da Silva, and D. do Nascimento Jr. 2007. Ecofisiologia de plantas forrageiras e manejo do pastejo. p. 153-176. *In* C.G.S. Pedreira, J.C Moura, S.C. da Silva, V.P. Faria (ed.), Produção de Ruminantes em Pastagens. Piracicaba..

Schank, S.C., M.A. Klock, and J.E. Moore. 1973. Laboratory evaluation of quality in subtropical grasses: II. Genetic variation among *Hemarthrias* in in vitro organic matter digestibility and stem morphology. Agron. J. 65:256-258.

Sollenberger, L.E., and J.C. Burns. 2001. Canopy characteristics, ingestive behaviour, and herbage intake in cultivated tropical grasslands. p. 321-327. *In* J.A. Gomide et al. (ed.) Proc. Int. Grassl. Cong., 19th, Piracicaba, Brazil, 10-21 Feb. 2001. Brazilian Society of Animal Husbandry, Piracicaba, Brazil.

Sollenberger, L.E., G.F. Lima, W.E. Kunkle, J.E. Moore, J.F. Holderbaum, and A.C. Hammond. 1999. Cattle weight gain and sward-animal nitrogen relationships in grazed limpograss pastures. Agron. Abst. p. 150. ASA/CSSA/SSSA.

Sollenberger, L.E., W.R. Ocumpaugh, V.P.B. Euclides, J.E. Moore, K.H. Quesenberry, and C.S. Jones, Jr. 1988. Animal performance on continuously stocked 'Pensacola' bahiagrass and 'Floralta' limpograss pasture. J. Prod. Agric. 1:216-220.

Stobbs, T.H. 1973. The effect of plant structure on the intake of tropical pastures. I. variation in the bite size of grazing cattle. Aust. J. Agric. Res. 24:809-819.

Stobbs, T.H. 1975. The effect of plant structure on the intake of tropical pastures. III. Influence of fertilizer nitrogen on the size of bite harvested by Jersey cows grazing Setaria anceps cvcv. Kazungula swards. Aust. J. Agric. Res. 26:997-1007.

Tainton, N.M. 1974. Effects of different grazing rotations on pasture production. J. Br. Grassl. Soc. 29:191-201.

Valério, J.R. Cigarrinha-das-pastagens: bioecologia, importância e alternativas de controle. 2008. p.353-372. *In* O.G Pereira et al (eds.) IV Simpósio sobre manejo estratégico da pastagem, Viçosa: UFV.

Vendramini, J.M.B., and J.D. Arthington. 2010. Supplementation strategies effects on performance of beef heifers grazing stockpiled pastures. Agron. J. 102:112-117

Vendramini, J.M.B., J.D. Arthington, and W.F. Brown. 2008. Use of limpograss in grazing systems in Florida. Forage and Grazing, PMN International. Retrieved 13 Nov. 2011 http://www.plantmanagementnetwork.org/pub/fg/review/2008/limpograss/

Wallau, M.O., L.E. Sollenberger, K.H. Quesenberry, and J.M.B. Vendramini. 2012. A low-cost approach to evaluation of forage breeding lines under grazing and its application to limpograss cultivar development. *In* ASA/CSSA/SSSA Abstracts, Cincinnati, OH.

## BIOGRAPHICAL SKETCH

Marcelo Osorio Wallau was born in 1988 in Porto Alegre, Rio Grande do Sul, Brazil. Soon thereafter, he “moved” to Santana do Livramento, on the border with Uruguay, where he was raised on his family farm. The farm is located in the Pampas region, one of the most diverse grassland ecosystems in the world, and has been in the family for 5 generations. There they raise sheep, horses, beef and dairy cattle, all in pasture-based systems. Since he was a child he had close contact with livestock and nature, and developed a deep interest in pasture production. He moved back to Porto Alegre in 2004 for high school and started college in 2006 in the Agronomy Department at the Universidade Federal do Rio Grande do Sul. As scientific initiation, Marcelo worked for 3 years at the Soil Microbiology Laboratory, under the supervision of Dr. Enilson Sá. During his undergraduate career, he had internships in south and central Brazil and Argentina. In 2009, he went to Texas Tech University in Lubbock, TX as an exchange student for one year, where he studied and worked in Dr. Vivien Allen’s forage lab. Marcelo graduated as an agronomy engineer in August 2011 and shortly after joined the Agronomy Department at UF, where he has been working as a Graduate Research Assistant since. His professional goals are to better understand forage-livestock systems around the world, and help develop sustainable practices to improve livestock production in the Pampas while preserving biodiversity in the region.