STRATEGIES FOR INCREASING RHIZOMA PEANUT CONTRIBUTION TO PRODUCTIVITY AND ECOSYSTEM SERVICES OF LOW INPUT PASTURE SYSTEMS

By

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To my parents, Bill and Mary Cline

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

STRATEGIES FOR INCREASING RHIZOMA PEANUT CONTRIBUTION TO PRODUCTIVITY AND ECOSYSTEM SERVICES OF LOW INPUT PASTURE SYSTEMS

By

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Livestock production in the USA Gulf Coast is based on nitrogen-fertilized grass pastures, but increasing nitrogen cost threatens the future viability of this production system. Rhizoma peanut (RP; *Arachis glabrata* Benth.) is a regionally adapted perennial legume with documented long-term persistence and ability to spread in grass pastures. To date, RP has been used primarily for high value hay production because establishment costs are high. Expansion to grazed pasture is desired, but lower-cost establishment methods are needed. These projects were part of a larger research effort with the goal of providing technologies leading to sustainable grass-RP pastures with no requirement for nitrogen fertilizer. Specific project objectives were to: 1) determine if strip planting RP into grass pastures is a viable alternative to current practice; 2) quantify grazing tolerance of RP cultivars within the context of strip planting; and 3) measure soil quality benefits of conversion to RP-based vs. traditional grass systems. When strip-planted, Florigraze and Ecoturf RP had favorable sprout emergence, ground cover, frequency, and spread during the establishment year compared with Arblick and Peace RP. Rotational stocking of establishing pastures every 28 d decreased

establishment success compared with a hay production system. Strip planting resulted in an initial decrease in soil C and N across the 2-yr of the present study. When established RP cultivars were grazed using different management strategies, there were no differences in herbage accumulation among cultivars in the first year, but. favorable changes in sward characteristics with less frequent and intensive grazing suggest that these strategies may favor long-term stand production. Lastly, RP was used as the base forage in various production systems to determine its effect on soil quality compared with a grass-nitrogen system. Following 1 yr of imposing the year-round forage system treatments, soil C had increased in the macroaggregate (2000-250 µm) fraction, which best reflects short-term contributions of organic matter inputs from the systems. Finally, overseeding RP and bermudagrass with an early-maturing rye in this study did not negatively impact production of the warm-season perennials, indicating its utility as a winter forage option for producers in Florida.

CHAPTER 1
INTRODUCTION

Rhizoma peanut (RP; *Arachis glabrata* Benth.) is a warm-season perennial legume that is well-adapted to the lower Coastal Plain region of the USA. Contribution of RP to pasture-based livestock enterprises has been minimal due to the high cost of establishment, limiting the use of most planted areas to production of high value hay.

In recent years, greater input costs in beef cow-calf enterprises have increased interest in the use of legumes as an alternative N source in grass pastures. In the southeastern USA, pasture-based systems rely on N fertilizer and are increasingly vulnerable to high fertilizer costs (Rouquette and Smith, 2010). Incorporation of legumes into grass-based forage systems may provide a sustainable alternative for synthetic N fertilization, increase animal production by providing a source of high nutritive value forage (Sollenberger et al., 1989), and maintain pasture productivity (Lascano et al., 1989).

While productive and persistent grass-legume associations are well documented in temperate environments (Laidlaw et al., 2001; Frame and Laidlaw, 2011), the use of legumes in tropical ecosystems has been less successful (Shelton et al., 2005). Competition between aggressive C_4 grasses and the C_3 legume (Dunavin, 1992), difficulty in legume establishment and maintenance in grass swards (Sollenberger and Kalmbacher, 2005), and disease susceptibility (Shelton et al., 2005) have limited the contribution of forage legumes in tropical pastures. However, well-documented persistence of RP under a range of management strategies (i.e., haying or grazing; Ortega-S. et al., 1992a) and ability to spread and persist in grass mixtures (Dunavin, 1992; Castillo et al., 2013) make this legume an ideal candidate for use in livestock production systems based on grazed pasture.

Alternative establishment strategies are needed to reduce establishment costs if RP is to make significant contributions to pasture-based systems in the future. One approach is strip-planting the legume into grass swards (Castillo et al., 2013). Because RP is a long-lived perennial with ability to move laterally via an extensive rhizome system, it has potential to spread into the surrounding grass areas and form a mixed pasture over time. The amount of time needed for such a mixture to form is unknown and is likely dependent upon the RP genotype selected for use and the defoliation management imposed during the RP establishment phase.

In the past decade, several genotypes of RP have been developed and released from the University of Florida as dual-purpose hay and grazing crops (Prine et al., 2010; Quesenberry et al., 2010). These genotypes exhibit phenotypic variation in their growth habit from low-growing to upright types. Growth habit may affect the success of establishment using the strip-planting approach and also their response to a range of grazing management strategies. While studies have illustrated the yield and nutritive value potential of some of these entries under clipping (Mislevy et al., 2007; Quesenberry et al., 2010), no studies have evaluated plant responses of genotypes with varying growth habits to a range of grazing management strategies. Because long-term pasture productivity and persistence are of great importance in low-input systems, these data are needed to guide cultivar selection by producers.

Another potential benefit of incorporating legumes into livestock production systems is to sustain or enhance the ecosystem services provided by grasslands

(Boddey et al., 2004). Ecosystem services go beyond providing a feed source for livestock, and particularly include those which contribute to sustained, effective functioning of the agroecosystem. For example, managed grasslands can increase soil C and long-term sustainability of forage-based ecosystems through the improvement of soil quality, and RP has potential to contribute significantly in this regard in Florida (French et al., 2006). Tropical and temperate grasslands play a major role in the global C cycle and serve as an important C sink (Scurlock and Hall, 1998) with as much as 90% of the grassland C pool being belowground (Schuman et al., 2002; Liu et al., 2011a). Improved forage management strategies such as fertilization and proper grazing management increase aboveground biomass production for livestock, but can also contribute to belowground C pools (Liu et al., 2011b; Silveira et al., 2013).

The mild climate of Florida can provide favorable growing conditions for both warm- and cool-season forages, and selection of species and defoliation strategies for use throughout the winter and summer seasons has been shown to influence contribution to soil C (Franzluebbers et al., 2000; Franzluebbers et al., 2002). Currently, no work has been done in Florida to compare the potential C contribution of legume- and grass-based, year-round forage systems. Within this context, evaluation of the role of winter overseeding and utilization of forage by grazing or as hay is also important. Identifying year-round forage systems that promote soil C sequestration while maintaining aboveground production will enhance ecosystem function and sustainability of Florida livestock-grassland agroecosystems.

The overall objective of the dissertation research was to develop management strategies for increasing RP contribution to grazing systems in Florida and to determine ecosystem services associated with management of legume-based forage systems. Specific project objectives were to 1) determine the viability of strip-planting RP into grass pastures and quantify rate of establishment and spread of RP genotypes under defoliation during the establishment year (Chapter 3); 2) evaluate the productivity, persistence, and nutritive value of recently-released RP genotypes under differing levels of grazing intensity and frequency (Chapter 4), and 3) measure the effect on soil C sequestration of RP- vs. bermudagrass (*Cynodon* spp.)-based year-round forage production systems (Chapter 5).

CHAPTER 2
LITERATURE REVIEW

Background

History

Rhizoma peanut (RP; *Arachis glabrata* Benth.) is a warm-season, perennial legume that is well-adapted to Florida and the lower Coastal Plain region of the southern USA. In 1936, a collection of *A. glabrata* was first brought to the USDA National Plant Germplasm System from Matto Grosso, Brazil (Quesenberry et al., 2010) and became PI 118457. Later, this plant introduction was given the name 'Arb' by the Natural Resources Conservation Service. While major collections of *A. glabrata* continued through the 1960s and again in the 1980s, research efforts first began to evaluate potential forage use of the species in Florida in the 1960s (Prine et al., 2010).

Rhizoma peanut is self-pollinated and produces few viable seed (Prine et al., 1981). Unlike common peanut (*Arachis hypogea* L.), RP is primarily propagated vegetatively by rhizomes (French et al., 2006). The common name 'rhizoma peanut' was developed to distinguish this species from *Arachis pintoi* Krapov. & W.C. Greg., also a perennial species, but stoloniferous in nature (Quesenberry et al., 2010). Because RP is slow to establish (Rice et al., 1995; Williams et al., 1997), most of the research with RP in Florida over the past 20 yr has focused on improved establishment methods and evaluation of new germplasm under different management practices (Quesenberry et al., 2010). Multiple cultivars and germplasms of RP have been developed for use as forage crops and low-input ornamentals. Although RP exhibits decumbent growth in nature (Muir et al., 2010), selection of RP accessions over the past 60 yr has led to the development of several entries that vary in growth habit.

Depending on the type and level of management, growth habit may play a significant role in persistence and production potential of a RP stand. Evidence to support this hypothesis can be drawn from a comparison of erect-growing ‘Arbrook’ with intermediate growth habit ‘Florigraze’ under continuous stocking. Arbrook was less tolerant of continuous stocking than Florigraze (Hernández-Garay et al., 2004).

Genotypes of RP

Currently, there are five commercial cultivars (Florigraze, Arbrook, ‘UF Peace’, ‘UF Tito’, ‘Latitude 34’) and two germplasms (Arblick and Ecoturf) of RP released in the USA. With the exception of Latitude 34, all of these were developed and released by the University of Florida. The first commercial cultivar, Florigraze (PI 421707), was released in 1979 and is characterized by an intermediate growth habit (Prine et al., 1981). Florigraze was selected as an off-type, chance hybrid during early forage evaluation trials of RP lines in the 1960s (Quesenberry et al., 2010). In 1962, G. M. Prine observed the aggressively spreading RP between established plots of ‘Arb’ and PI 151982 (Prine et al., 1986). Upon the release of Florigraze, commercial acceptance of RP began to increase. This is the most widely grown cultivar in Florida, with roughly 10,500 ha statewide, and increasing acreage being planted annually (French et al., 2006). In recent years, peanut stunt virus (*Cucumovirus* sp.) has been reported in Georgia and Florida, which has been shown to negatively affect production of Florigraze RP (Blount, personal communication, 2013). Because such a large proportion of the RP acreage is planted to Florigraze, there is a need to diversify the genetic base by developing and evaluating new germplasm.

Arbrook (PI 262817) originated from RP germplasm collected in Paraguay in 1960 and was released in 1986 as a cultivar adapted to the deep, droughty sands of

Florida (Prine et al., 2010). The cultivar was selected from row evaluation plots of PI 212817 at the Arcadia and Brooksville, FL Plant Materials Centers and was thus given the name Arbrook (Prine et al., 1990). Arbrook is a larger plant type than Florigraze and exhibits an upright growth habit and shows favorable production in hay systems (Prine et al., 1986; Prine et al., 1990). Also, Arbrook has a more extensive, coarse root system than Florigraze, which gives it a greater drought tolerance compared to other commercially released cultivars. Although plant growth from rhizomes is slow, Arbrook provides more rapid upright growth than Florigraze. However, lateral spread from the plant is slower than Florigraze, which increases the time period to complete ground cover (Prine et al., 1990). Arbrook has been found to be less tolerant of continuous stocking than Florigraze (Hernández-Garay et al., 2004).

Arblick and Ecoturf were both selected from early accessions of RP from the 1950s. Arblick was introduced to the USA as PI 262839 after collection by W.C. Gregory in Paraguay near the Brazil-Paraguay border (Quesenberry et al., 2010). The entry was later given its name by the USDA Soil Conservation Service and was included in early evaluations of RP. Ecoturf (PI 262840) was also collected around the same time in Bela Vista, Brazil. Arblick and Ecoturf were included in the evaluation research leading to the selection and release of Florigraze; however, it was not until recently that Arblick and Ecoturf were released as germplasms (Prine et al., 2010). Earlier research with these germplasms focused mainly on selection for dry matter yield and persistence when managed for forage (Prine et al., 2010). These lines were noted to be low-growing types that may provide significant ground cover and were released in 2008 for their potential ornamental use (Prine et al., 2010).

Cultivars UF Tito (PI 262826) and UF Peace (PI 658214) originated from plant introductions from Paraguay in the late 1950s. Both cultivars exhibit a growth habit similar to that of Florigraze and were released in 2008 after a 20-yr program of evaluation based on the observation of consistently high dry matter yields, persistence, and competitive ability with weedy grasses (Quesenberry et al., 2010). UF Tito was selected as the top producing line from a 10-yr evaluation trial by Friere et al. (2000). They stated that UF Tito had the greatest percentage of pure peanut and less invasion by common bermudagrass (*Cynodon dactylon* L.) than other evaluated lines. Rate of spread was also greater for UF Tito when compared to other lines (Friere et al., 2000). At the end of the evaluation, UF Tito had greater than 90% ground cover, indicating the competitiveness of the line. UF Peace was also selected from this evaluation as having superior forage characteristics (Friere et al., 2000). UF Peace produced similar DM yields to UF Tito, although competitiveness with weeds and rate of spread were inferior to UF Tito.

Finally, ‘Latitude 34’ is the most recently released cultivar of RP in the USA (Muir et al., 2010). The cultivar was selected from PI 262819, part of the germplasm collection housed at Stephenville, TX, and released by Texas AgriLife Research in 2009. The PI was originally collected near Trinidad, Paraguay and then taken to Stephenville, TX by C. E. Simpson (Muir et al., 2010). Latitude 34 was observed to have good forage potential, high pH tolerance, and persisted and spread aggressively in field trials at Beeville, TX and Stephenville, TX. Compared with other commercially available cultivars, Latitude 34 is noted for its relative cold and drought tolerance. Butler et al. (2006) observed persistence of Latitude 34 during years with freezing temperatures lasting as long as 48 h consecutively and where subsoil temperatures reached 1˚C. Additionally, Latitude 34 persisted and spread in field trials with as little as 454 mm of annual rainfall (Butler et al., 2006).

Rhizoma peanut is often compared with alfalfa (*Medicago sativa* L.) because of its yield potential (Andrews et al., 1985), high nutritive value (Prine et al., 1981; Mislevy et al., 2007), and persistence under a variety of management conditions (Ortega-S. et al., 1992a; Butler et al., 2007). When compared with alfalfa, average DM yield of Florigraze RP was 7.6 vs. 11.8 Mg ha^{-1} for alfalfa over a 3-yr period in central Georgia (Terrill et al., 1996). Mislevy et al. (2007) evaluated the influence of harvest management and RP entry on DM yield, nutritive value, root mass, and persistence on a moderately drained soil. Over the 4-yr trial, average DM yield of all RP entries was 11.8 and 8.9 Mg ha^{-1} when clipped to 2.5- and 10-cm stubble heights, respectively. Average crude protein (CP) concentration was 172 g kg^{-1} and IVDOM was 690 g kg^{-1} DM for all entries. During a 4-yr trial in Citra, FL, DM yield of Ecoturf, UF Tito, UF Peace, Florigraze, and Arbrook ranged between 8.3 and 12 Mg ha^{-1}, illustrating the yield potential of RP (Prine et al., 2010).

Establishment

Methods of Establishment

Rhizoma peanut is vegetatively propagated from rhizomes because it produces very little viable seed (Quesenberry et al., 2010). Niles et al. (1989) suggested that producer reluctance to vegetatively establish RP had limited its production potential in Florida. Williams et al. (1997) stated that while small areas of land can be planted manually, larger areas must be planted with specialized equipment that is typically used for the establishment of vegetatively propagated tropical grasses. Rhizomes usually form a 5 to 8 cm deep mat just below the soil surface which can then be dug with a sprig harvester and planted as individual rhizome pieces or as sod-pieces lifted with a sod lifter or by other means (French et al., 2006). The recommended planting time for RP is between January and March (Prine at al., 1981), which is based on studies that have indicated highest sprout emergence during this period of time (Williams et al., 1993). Slow rate of cover is thought to be directly related to poor sprout emergence and survival of RP after planting (Williams et al., 1993). Because coverage rate appears to be dependent on the number of peanut sprouts per unit of land area that survive emergence and initial establishment, the suggested planting rate of RP has been increased to roughly 1000 kg rhizomes ha^{-1} (Williams et al., 1997). Additionally, planting should occur during a time of year with sufficient soil moisture and that maximizes the frost-free period after planting (Williams et al., 1997).

Factors Affecting Establishment

A slow-rate of establishment has been cited as the greatest factor limiting increased use of RP as forage (French, 1988; Saldivar et al., 1990). New germplasm evaluation of RP has focused on the development of RP genotypes with decreased time to establishment through increased sprout emergence, rate of spread, persistence, and competitiveness with weeds (Canudas et al., 1989; Quesenberry et al., 2010). While selection of genotypes is important, one of the most critical factors affecting establishment is adequate soil moisture at the time of planting. Williams et al. (1997) observed that reliable soil moisture, from rainfall or irrigation, is needed for 60 to 90 d post planting. In an establishment guide for RP, French and Prine (2002) suggest that irrigation be used when needed during the establishment phase if available and economical. Because the spring growing season in Florida can have limited rainfall

(Prine, 1981; Williams et al., 1993), adequate soil moisture may limit sprout emergence and rhizome survival in newly established stands.

Pre-plant land preparation and time of planting may also influence rate of establishment. Williams et al. (1993) evaluated the effect of planting date and preplant tillage method on emergence and survival of RP. Three tillage intensities were evaluated including plowed and well-prepared for minimal grass competition, disked with moderate grass competition, and no preplant tillage where RP was planted directly into sod. After RP establishment, time to first sprout emergence was shorter for the plowed than disked or sod-planted treatments. Based on these results, Williams et al. (1993) suggested that recommendations for establishing RP in well-prepared fields during the winter should be continued. French et al. (2006) stated that land preparation should begin in the late summer to allow for weed regrowth and subsequent elimination prior to a frost event. Preparing land early allows for adequate time for decomposition of plowed organic matter and provides time for accumulation of soil moisture and firming of the seedbed (French et al., 2006).

Planting depth may also affect establishment potential of RP stands. Williams et al. (1993) observed a faster rate of sprout emergence in plowed plots where RP was shallowly planted and covered uniformly at the time of planting compared with disked and sod-planted plots. In less well-prepared plots, grass clumps prevented uniform coverage of rhizomes which were then susceptible to drying and dessication (Williams et al., 1993). French et al. (2006) recommended a 3.5- to 5-cm planting depth for sandy soils and a 2.5-cm depth for clay, and they indicated that different cultivars may have more favorable emergence characteristics under deeper planting conditions than others depending on their rhizome characteristics.

Management of rhizomes during the season prior to harvest and handling following harvest affect rhizome characteristics that are important to ensure successful establishment of RP (Rice et al., 1995; Venuto et al., 1999). Storage carbohydrate levels in rhizomes have also been shown to influence establishment and are usually high during the late winter (Saldivar et al., 1992). Saldivar et al. (1992) noted that RP accumulates a high concentration (400 to 700 g kg^{-1}) of total non-structural carbohydrates (TNC) during the fall. If plants are to be used as a rhizome source for propagation, defoliation should be minimized during the preceding growing season in order to maximize TNC levels in the rhizomes (Saldivar et al., 1992). The effect of grazing management has been evaluated on rhizome chemical composition (Rice et al., 1995) and subsequent establishment success when these rhizomes were planted (Rice et al., 1996). Rhizomes with low TNC (62 g kg^{-1}) resulted in stand failure during a drought year; however, rhizomes with initial TNC levels of at least 228 g kg^{-1} resulted in accumulation of rhizome and shoot mass following planting (Rice et al., 1996).

Cost of establishment is an important consideration when choosing the amount of area to plant. It is estimated that establishment of RP can cost as much as $1,200 per ha (Blount, personal communication, 2013). When compared with seeded forages, it is evident that the cost of vegetative establishment is expensive and may limit RP usage to production systems with the highest net returns (Williams et al., 2004). Subsequently, this constraint has limited the use of RP for grazing by beef cattle. Although RP provides long-term productivity once established and an excellent source of high quality forage, the cost associated with establishment, removing land from defoliation until RP is established, and weed control should be considered.

Grazing Management

Although several studies have described management of various RP entries under haying, fewer studies have considered the influence of grazing management on RP. The response of plants to grazing is largely related to the type of grazing practice implemented. While many factors may influence plant responses to grazing, this review will focus mainly on plant growth habit, grazing intensity, grazing frequency, and their interaction.

Grazing intensity may be described in terms of stocking rate, grazing pressure, forage mass and allowance, or canopy height (Sollenberger et al., 2012). Plant response to various levels of grazing intensity is dependent on the species involved, frequency of grazing, and the environment (Sollenberger et al., 2012). Intensity of grazing has been suggested as a primary factor in determining plant productivity, persistence and sustainability in a given area (Sollenberger and Newman, 2007). Herbage accumulation (Ortega-S et al., 1992a), sward botanical composition, animal performance (Stewart et al., 2005), and soil and water quality (Franzluebbers et al., 2000; Liu et al., 2011c) can be influenced greatly by grazing intensity. Early clipping studies defined target stubble heights for Florigraze RP under defoliation. Prine et al. (1981) suggested an average height of at least 10 cm be maintained for Florigraze in order for adequate leaf tissue to be present to intercept light. In North Florida, Arbrook was found to be less tolerant of a 15- to 20-cm stubble height under continuous stocking than was Florigraze (Hernández Garay et al., 2004). Under these conditions, Florigraze RP percentage in total forage mass remained relatively constant from Year 1 (90%) to

Year 3 (87%), whereas Arbrook percentage decreased from 89 to 66% over the 3-yr study as perennial grass contribution increased. Hernández Garay et al. (2004) stated that the more upright growth habit of Arbrook makes it less tolerant of continuous stocking than Florigraze.

Frequency of grazing and grazing method also play a large role in management of pasture systems, although stocking rate has been cited as having a greater influence on pasture productivity than the grazing method used (Sollenberger and Newman, 2007). Sollenberger and Chambliss (1989) suggested that the most important tools for grazing management include the selection of the level of grazing intensity, as well as the frequency of grazing. The combination of these management factors affects the productivity of forage per land unit, efficient use of forage by grazing animals, and persistence and productivity of a pasture system (Sollenberger and Chambliss, 1989). A grazing period of a defined length is often used along with a given level of intensity (i.e., stubble height, residual dry matter, etc.) to describe management regimes. The effect of frequency of defoliation of RP was first described under clipping by Prine et al. (1981) for the cultivar Florigraze. Based on these results, Prine et al. (1981) suggested a grazing period of no longer than 10 d under rotational stocking, with a 3-wk or longer rest period. If continuous stocking is to be used, the stocking rate should be low enough to maintain an average stubble height of 10 cm throughout the grazing period (Prine et al. 1981). In an animal performance trial, Sollenberger et al. (1989) rotationally stocked Florigraze RP pastures with a grazing period of 1 wk and rest periods of 5 wk. Steer average daily gain (ADG) was 0.93 kg and nutritive value of RP was high (≥ 700 g kg^{-1}, IVDOM; 170 to 220 g kg^{-1} CP) under these management conditions, illustrating the forage quality of Florigraze RP under rotational management.

Studies have also illustrated the interaction of grazing intensity with frequency. In Gainesville, FL, a 2-yr study evaluated the effects of three levels of postgraze residual dry matter (RDM, 500, 1500, and 2500 kg ha^{-1}) with four intervals between grazing events (7, 21, 42, and 63 d) on the productivity and persistence of Florigraze RP pastures. Ortega-S. et al. (1992a) reported that while RDM after grazing was the most important factor influencing RP herbage accumulation and botanical composition of accumulated herbage, frequency of grazing also had a pronounced effect. At low RDM, increasing the interval between grazing events increased herbage accumulation, but interval between grazing events had less effect as RDM increased. Herbage accumulation and peanut percentage were greatest when RDM was between 1500 and 2400 kg ha^{-1}, and the grazing interval was ≥ 42 d. In order to maintain 80% RP or greater in the stand, a postgraze RDM of 1500 kg ha^{-1} (a postgraze stubble height of 15 cm) or higher should be maintained if the grazing cycle is longer than 42 d, or ≥ 2000 kg ha^{-1} (20 cm stubble height) if the grazing cycle is less than 35 d (Ortega-S et al., 1992a).

Growth habit has been shown to play a role in the response of other forages to grazing and is an important consideration for RP use in pasture systems. Mathews et al. (1994) reported the effect of growth habit in a comparison of continuous and rotationally stocked ‘Callie’ bermudagrass [*Cynodon dactylon* (L.) Pers.] pastures that contained 10% of the decumbent-growing common bermudagrass at the beginning of the trial. During the 2-yr study, the proportion of common bermudagrass increased each year under continuous stocking, but little change occurred in botanical composition under rotational stocking. Mathews et al. (1994) suggested that rotational stocking allowed the more erect-growing Callie to shade common bermudagrass during the rest period. In contrast, continuous stocking may have allowed greater light penetration to the common bermudagrass, subsequently increasing its competitiveness with the hybrid bermudgrass. In 1995, Hernández et al. conducted a trial with mixed palisadegrass [*Brachiaria brizantha* (A. Rich.) Stapf] and pinto peanut under two continuous stocking rates (600 and 1200 kg liveweight ha^{-1}). Across the 3-yr grazing trial, pinto peanut contributed 34 and 6% of the dry matter production at the high and low stocking rates, respectively. The tolerance of pinto peanut to a high stocking rate was attributed to its prostrate, stoloniferous growth habit compared with the more upright-growing palisadegrass (Sollenberger et al., 2012). This suggests that growth habit of the plant may play a significant role in response to a variety of prescribed grazing practices, but the only grazing study to address these issues with RP was that comparing Florigraze and Arbrook response to continuous stocking (Hernández-Garay et al., 2004).

Several clipping studies have reported changes in RP growth habit under various clipping intensities and frequencies (Prine et al., 1981; Quesenberry et al., 2010), but no known studies have evaluated RP plant responses under grazing. As new entries continue to be released, recommendations are needed to provide producers with guidelines for use of RP in pasture systems. Plants within a given population have the ability to alter their morphology as a response to stress factors, also known as phenotypic plasticity (Nelson, 2000). Phenotypic plasticity is reversible and includes changes in size, structure, and spatial positioning of organs (Huber et al., 1999) in order to adapt to changes in environment. Rhizoma peanut has been observed to exhibit this response under various frequencies and intensities of defoliation. When Florigraze RP was mowed every 2 wk, the plant grew in a rosette formation with leaves oriented flat on the ground (Prine et al., 1981). This is a survival mechanism and differs from the typical intermediate to upright growth habit of the cultivar. Under this level of management intensity, overall productivity of Florigraze is decreased. However, if Florigraze is managed to the recommended stubble height, it will continue to maintain an intermediate growth habit that responds well to less intensive management (Prine et al., 1981).

Similar morphological and production responses were observed by Saldivar et al. (1990) when Florigraze RP was evaluated under clipping frequencies of 2, 6, and 8 wk. Plants in the 2-wk treatment had more prostrate growth habit with small leaves in mid-August, and little biomass was removed with each harvest thereafter (Saldivar et al., 1990). In the 6- and 8-wk treatments, plants had elongated to a great extent above the defined clipping level, were more upright in growth habit, and most of the leaf area was removed with clipping. Mislevy et al. (2007) suggested that differences in nutritive value for RP entries under two clipping management regimes were associated with leaf-to-stem ratio. Ecoturf and experimental line PI 262833, both low growing types, had higher CP concentration compared with the other entries, which was associated with a higher leaf-to-stem ratio. Observations during the trial indicated that other entries such as Arbrook were more erect in growth habit, contained fewer leaves and were more stemmy and these morphological traits were associated with a decrease in nutritive value (Mislevy et al., 2007). At the target stubble heights defined in this study (2.5 and

10 cm), defoliation regime may have favored an increased leaf-to-stem ratio in low-growing types compared with more upright cultivars (Mislevy et al., 2007).

Curl and Jones (1989) stated that frequent and intense defoliation of a grass-legume mixture may favor temperate, prostrate legumes, and tropical legumes that are generally susceptible to shading by the grass component. Arblick and Ecoturf were evaluated for ornamental use under a 4-cm cutting height with mowing every 4 wk and a 8-cm height mowed every 2 wk. Poorer color and appearance ratings were observed for plots mowed every 2 wk to a 8-cm stubble height compared with the 4-cm stubble, 4 wk frequency. Plants under the 4-cm mowing height assumed a low-growing canopy of leaves that remained intact between mowing events and reduced the appearance of stubble compared with the 8-wk treatment, illustrating a change in growth habit dependent upon management (French et al, 2001).

Mixed Legume/Grass Production Systems

Advantages and Challenges to Incorporating Legumes

Legumes offer several potential contributions to pasture systems. The primary advantage is that they have the ability to fix atmospheric N (N_2), which increases the total N contribution and sustainability of the soil-plant system. Transfer of fixed N from legumes to companion species does not occur directly, but through secondary processes. While excretion or leakage of N from living roots and nodules is minimal (Giller et al., 1991), root cell and nodule sloughing, death and decay may contribute N to the grass component of mixed swards (Trannin et al., 2000). Additionally, transfer of N can occur from the legume to the grass via mycorrhizal hyphae (Haystead et al., 1988). Aboveground stubble on the soil surface may be decomposed and nutrients leached over time which may be available for use by companion species (Trannin et al., 2000).

Nitrogen can also be cycled to plants through urine and dung of grazing animals (Dubeux et al., 2007). Russelle (1996) estimated that livestock only use 5 to 30% of ingested N in the diet for meat or milk production; therefore, contribution of urinary and fecal N can be a significant pool of nutrients for grazed swards. Total amount of N fixation can also be influenced by many factors including species, cultivar, soil nutrition, *Rhizobium* strain, season, environment and climate (Rouquette and Smith, 2010).

Legumes contribute to animal performance through increased nutritive value compared with most tropical C_4 grasses. Stobbs et al. (1975) stated that intake of legumes is usually greater than that of tropical grasses, and liveweight gain is increased. In a meta-analysis of studies involving grass-legume mixtures, Muir et al. (2011) reported that the greatest contribution of legumes from a ruminant nutrition standpoint is crude protein. With a few exceptions, CP concentration of legumes typically does not fall below 70 g kg^{-1}, at which point intake can become limited (Poppi and Mclellan, 1995; Muir et al., 2011). Additionally, the digestibility of legumes tends to be greater than for warm-season grasses throughout the growing season, which when combined with increased CP may increase intake and animal performance (Muir et al., 2011). Foster et al. (2009) evaluated the effect of supplementing bahiagrass (*Paspalum notatum* Flügge) hay with soybean (*Glycine max* L.) meal or warm-season legume hay on intake, digestibility, and N utilization by lambs. Lambs fed annual legume and RP hays were observed to have increased DM and N intake, digestibility, and improved microbial N synthesis, illustrating the potential of legumes to contribute to relatively low N diets (Foster et al., 2009). Legumes have been found to improve N retention by ruminants when grass diets do not meet energy and N requirements (Foster et al., 2009).

Although legumes are well-noted for their forage potential, the contribution of legumes in tropical pastures has been limited. Thomas et al. (1995) states that while legumes may have the capacity to help balance the N cycle in grazed pastures, several factors have limited their use in grass-based systems. Perhaps the most cited factor is a lack of persistence in mixed-species systems (Trannin et al., 2000; Shelton et al., 2005). Trannin et al. (2000) stated that legume persistence in mixed tropical grass-legume pastures is often poor because of the strong competitiveness of the grass associated with its extensive root system, high N and P utilization, and relative tolerance under grazing. Difficulty in establishing and maintaining legumes in grass-based systems is also a driver in the lack of persistence (Shelton et al., 2005). Sollenberger and Kalmbacher (2005) observed a lack of adoption by producers of aeschynomene (*Aeschynomene americana* L.) and desmodium (*Desmodium heterocarpon* L. DC.) due to difficulty of establishment and inability to be maintained in bahiagrass pastures. The majority of tropical forage legumes are annuals and must be reseeded every year. Adaptation of legumes to new environments has also been limited by their lack of disease and insect resistance, particularly in sub-tropical and tropical environments (Shelton et al., 2005).

Additionally, the nature of the grass-legume relationship may be cyclical in nature, which can make management a challenge. As the percentage of legume increases in the sward, N contribution from the legume to the grass increases. Competition from the grass component increases, which negatively affects the legume.

Decreased N supply from the legume then negatively impacts growth potential of the grass, and the legume may begin to proliferate again (Trannin et al., 2000). Identifying management strategies which minimize competition from the grass component, but do not reduce contribution of the legume can be a challenge. Management strategies must be developed and producers must be educated for the benefits of legume-grass pastures to be realized (Shelton et al., 2005).

Examples of Successful Warm-Season Grass-Legume Pastures

Shelton et al. (2005) estimated that the rate of adoption for the use of legumes in tropical systems has been greater in Asia, Australia, and Brazil than in Africa, the USA, or Latin America. Species that were able to provide multiple benefits had the greatest rate of success and acceptability by producers. Gross economic progress was greatest where large-scale adoption had occurred (Shelton et al., 2005). In Australia, early use of *Styloanthes guianensis* and *Styloanthes humilis* was widespread beginning in the mid-1900s, although disease susceptibility of the 'Townsville' cultivar (*S. humilis*) limited its use (Maass and Hawkins, 2004). Noble et al. (2000) stated that rapid adoption of pasture technology in Australia has resulted in oversowing of stylo on thousands of hectares of native pastures annually. *Styloanthes scabra* cv. Seca and tetraploid *S. hamata* cv. Verano account for 1 million ha (Noble et al., 2000). In Africa, 19,000 ha of stylo were cultivated in fodder banks by about 27,000 small land holders by the mid-1990s (Elbasha et al., 1999; Maass and Hawkins, 2004). Although success of this species has been prevalent in Australia and West Africa, Kalmbacher et al. (2002) stated that adoption in the USA has been limited.

In Brazil, Valentim and Andrade (2005) stated that death of large areas of palisadegrass has led farmers in the Acre state to look for alternatives to maintain productivity and profitability in their production systems. Tropical kudzu (*Pueraria phaseoloides* Roxb.) was an important forage legume used to restore pastures in that region during the 1990s, with an estimated 480000 ha present in 2005 (Valentim and Andrade, 2005). However, lack of compatibility of kuzdu with other introduced grasses such as African stargrass (*Cynodon nlemfuensis* Vanderyst) promoted further investigation into use of other species for mixed pasture systems. In 2000, *Arachis pintoi* cv. Belmonte was established vegetatively with stolons in African stargrass. Successful establishment and production from this system was realized by local producers, and planted acreage has increased annually to 65000 ha (Valentim and Andrade, 2005). Lascano et al. (2005) observed successful use of *Arachis pintoi* in a variety of brachiaria-based pastures for dairy systems in Colombia, illustrating the potential success of forage peanut for tropical regions.

While the use of cool-season annual legumes has been prevalent throughout the USA (Ball et al., 2007; Rouquette and Smith, 2010, Muir et al., 2011), the number of success stories for warm-season grass-legume pastures has been limited. Although the track record of legumes in warm climates is not stellar, RP use in the southeastern USA has been cited as one of several “success stories” for the use of legumes by producers (Shelton et al., 2005). Because of RP’s persistence and ability to spread when growing in association with grasses, it is unique among legumes adapted to the region. Shelton et al. (2005) stated that one success has been the use of RP for high quality hay for horse and dairy markets. The introduction of new genotypes has increased the planted acreage of RP throughout the Gulf Coast region of the USA and provided a more stable, profitable enterprise when compared with other land uses (Williams et al., 2004; Shelton et al., 2005).

Also, while grasses are rarely planted with RP, mixtures may occur because of a lack of control of grasses during RP establishment (Valencia et al., 1991). Valentim et al. (1986) observed that RP is competitive with perennial grasses such as bahiagrass, bermudagrass, and digitgrass (*Digitaria* × *umfolozi* Hall), even at high levels of N application (Valentim et al., 1986). In general, Florigraze RP contributed over 50% of the total CP yield in these mixtures, illustrating the contribution of the legume to pasture system (Valentim et al., 1986). Prine et al. (1981) reported that during 6 yr of close grazing, RP percentage in a mixed Florigraze-bahiagrass pasture was relatively constant and RP was observed to have competitive ability with the grass component. Dunavin (1992) evaluated the potential of growing Florigraze RP with ‘Tifton 44’ bermudagrass, ‘Floralta’ limpograss [*Hemarthria altissima* (Poir.) Stapf and C. E. Hubb], and ‘Pensacola’ bahiagrass in an 8-yr trial at Jay, FL. During the first 4 yr, Florigraze competed well with each perennial grass, although the percentage of RP declined in all mixtures during the last 4-yr of the trial. Results at this northern location indicate that RP may compete well with perennial sods for several years, but may eventually be crowded out by thick-sodded grasses over time (Dunavin, 1992).

In cases where tropical legumes have been the most successful, the target goal of the legume was well-defined and producers were made aware of the potential benefits of the legume to their production system through education. Miles (2001) suggested that adoption of new practices is often low due to a lack of established relationships between farmers and public institutions. Decreased awareness about legumes and their benefit appears to be a key factor in their rate of adoption (Shelton et al., 2005). In order for the introduction of new systems to be accepted by producers, understanding the socioeconomic needs, skills, and willingness of producers is an important consideration for the education efforts of land-grant institutions (Angle, 2011).

Rationale for the Use of Rhizoma Peanut-Grass Pastures in the Southeast USA

Pasture systems in the southeastern USA are based largely on warm-season perennial grasses, but forage nutritive value of these species rapidly declines from mid-summer to late fall (Sollenberger et al., 1989). Incorporation of a warm-season legume into these grass pastures may increase forage nutritive value, as well as provide a source of N to otherwise low-input systems. Lack of maintenance fertilization, especially N, and inadequate grazing management are primary factors resulting in the degradation of pastureland in low-input systems in warm-climate environments (Boddey et al., 1997). Degraded pastureland has limited potential to serve as a source of forage for livestock or to provide ecosystem services.

Association of N-fixing legumes with grasses offers an economic opportunity for improving pasture quality, productivity, and animal production in warm-climate regions characterized by low soil fertility (Lascano et al., 1989). The presence of even relatively small amounts of legume has increased forage nutritive value and productivity of the system, increased N cycling through cattle excreta, and reduced or eliminated the need for N fertilization (Boddey et al., 2004).

Moreover, a combination of fluctuating feeder calf prices and costs of feed, fertilizer, and energy are challenging beef producers to place increased emphasis on grazed forages with significantly reduced inputs and improved management (Prevatt, 2008). Because the cost of N fertilizer can be prohibitive in the maintenance of perennial grass sods, the incorporation of legumes into these existing systems may reduce the need for N fertilization, as well as increase the nutritive value of the pasture. This technology is needed because current production systems are based on N-fertilized grasses and are increasingly vulnerable to high fertilizer cost (Rouquette and Smith, 2010).

Currently, the majority of RP planted in the Southeast USA is used for commercial hay production, although grazing trials have demonstrated excellent levels of animal performance (Sollenberger et al., 1989; Hernández Garay et al., 2004). Because RP is relatively expensive to establish (Williams et al., 2004), it is often not profitable for use solely as pasture by beef cow-calf operations. In addition, the high nutritive value of pure stands of RP may exceed the nutrient requirements of most beef cattle (NRC, 1996). A more cost-effective option for use of pure RP stands in beef production systems may be to limit grazing to classes of animals that would benefit the most from high-quality forage, such as calves and replacement heifers (Williams et al., 2004).

Considering the high cost of establishment and the need to take establishing pastures out of the grazing rotation for 1 to 2 yr (Williams et al., 1993), alternative approaches are needed if RP is to become an important component of beef cattle production systems in the Southeast. One option for increased use of RP pastures for classes of livestock other than dairy animals (e.g., beef cow-calf operations) may be to incorporate RP into perennial grass sods through strip-planting. Strip-planting entails preparation of a small area of land through tillage followed by planting with RP at the recommended planting rate. Because of RP’s ability to spread (Quesenberry et al., 2010), strip-planting of RP with perennial grasses may eventually result in the formation of a sustainable grass-legume mixture. Compared with establishing RP in prepared seedbeds, this approach may also allow grazing to continue on these pastures during a significant portion of the establishment phase.

Ecosystem Services and C Sequestration in Grasslands

Grasslands have the capacity to provide a wide array of goods and services to society that are of economic, environmental, and social importance (Follet and Reed, 2010). It is generally accepted that the primary role of grasslands is to provide feed for beef, dairy, and sheep industries in the USA (Follet and Reed, 2010). Ecosystem services are considered secondary services provided by grasslands and include the capacity of grasslands to act as a carbon sink (Conant et al., 2001), provide bioenergy (Casler et al., 2009), decrease erosion (Karlen et al., 2007), promote retention of nutrients and moisture in the soil (Woodard et al., 2002), act as vegetative buffer strips (Blanco-Canqui et al., 2004), and provide aesthetic value for society. Although the list of ancillary benefits is quite extensive, the focus of this review will primarily be on the potential role of grasslands as a global C sink.

Grassland Management and Factors Affecting Soil Quality

Overview

Increasing interest in reducing the impact of increasing atmospheric CO_2 has stimulated research evaluating the C sequestration potential of grasslands (Follett, 2001). Agricultural C sequestration is defined as the process through which agricultural practices remove CO_2 from the atmosphere, enhancing C storage in trees and soils, and preserving existing tree and soil organic carbon. Agricultural management practices can affect the quantity, quality, and placement of C in the soil via crop selection, crop rotation, fertilization, organic amendments, and tillage type and frequency (Paustian et al., 1997; Magdoff and Weil, 2004). In cropping systems, soil cultivation has disrupted the balance of the soil organic pool, causing organic matter to be exposed to oxidative processes (Rees et al., 2005). Ingram and Fernandes (2001) estimated that the oxidation of SOM in cultivated soils has contributed approximately 50 Pg C to the atmosphere. Depletion of the soil organic carbon (SOC) pool leads to degradation in soil quality and declining biomass productivity (Follett, 2001) which has implications for the ecosystems involved.

Other factors affecting the amount and rate of change in SOC include historical land use (Conant et al., 2001), soil texture (Hassink, 1997), plant species (Paustian et al., 1997), total soil nitrogen (TSN), and environmental factors such as temperature and rainfall (Conant et al., 2001). The role of forage management in C sequestration will be discussed in a later section. The importance of protection of SOM by silt and clay particles is well-established (Hassink, 1997; Six et al, 2002). Hassink (1997) showed a relationship between SOM fractions and silt- and clay-associated C and soil texture. These findings formed the basis for the conclusion that the ability of soil to protect C is based on its association with these particles (Six et al., 2002). In Florida, many of the soils are characterized by low clay plus silt concentrations, reducing their capacity to protect the SOM (Hassink, 1997), and likely limiting the amount of C that can be sequestered. However, through changes in land management, the potential exists to increase C in Florida soils.

Species effects may also play a role in the C sequestration potential of grasslands. Warm- season perennial grasses (C_4 photosynthetic pathway) have been proposed for use in the improvement of SOC in grasslands because they produce extensive root systems and provide permanent vegetative cover (Conant et al., 2001).The role of cool-season grasses (C_3 photosynthetic pathway), such as small grains, for improvement and maintenance of SOC as cover crops has long been established in crop rotation systems. In an integrated crop-livestock system with summer cropping of sorghum (*Sorghum bicolor* L.) and winter grazing of rye (*Secale cereal* L.), total particulate organic matter remained relatively constant (2.3 Mg ha^{-1} yr^{-1}) across a 3-yr experiment in Georgia (Franzluebbers and Stuedemann, 2008). Lal et al. (1999) reviewed literature on crop rotations and concluded that potential exists to utilize cover crops on about 51 million ha in the USA, which could sequester an estimated 100 to 300 kg C ha^{-1} yr^{-1}. Results illustrate the potential of various grass species to contribute to the maintenance of the soil C pool.

Legumes also offer potential to promote the sustainability of agricultural systems not only through biological N fixation, but through the improvement of soil C as well. Continuous cropping systems with legumes can provide constant land cover and stimulate the retention of SOM (Boddey et al., 1997). Also, pasture degradation is commonly related to decreasing N availability caused by an accumulation of low quality plant litter and net immobilization of N due to the activity and number of soil microbes (Vendramini et al., 2007). Thus, one reason for the recommendation of establishing legumes in grass pastures is based on the assumption that legumes increase soil fertility through deposition of high quality litter (Dubeux et al., 2007).

Grazing Management and Soil Quality

Grazing management, which includes grazing intensity, frequency, and method, plays an important role in C and N sequestration potential of pasture systems.

Franzluebbers and Stuedemann (2002) stated that pasture management systems in the southeastern USA stimulate greater stratification of SOC than conservation tillage practices, illustrating the potential inputs provided by these systems. Literature describing the influence of stocking rate, a measure of grazing intensity, indicates that is is the most prominent management factor in pasture studies in the southeastern USA where soil C and N were evaluated. However, evaluation has been less extensive in this region compared to more temperate environments of the USA (Ganjegunte et al., 2005).

Franzluebbers et al. (2009) conducted a 12 yr study to evaluate management effects on the rate of change in SOC and TSN throughout various depths in the soil profile in a Coastal bermudagrass (BG) pasture system. Management regimes included unharvested BG, hayed monthly, and grazing at low (5.8 steers ha^{-1}) and high (8.7 steers ha^{-1}) stocking rate. Grazing of pasture led to significantly greater levels of SOC in the surface 15 cm of soil than in ungrazed pastures. Additionally, the difference between low and high stocking rate became significant at the end of the 12-yr evaluation (21.6 vs. 19.9 g kg^{-1} SOC). Total and particulate organic N were greater under the high stocking rate than under the low stocking rate at the end of 4 yr in the 0- to 6-cm depth (Franzluebbers and Stuedemann, 2002), but were not different throughout the soil profile between stocking rates at the end of 12 yr throughout the soil profile (Franzluebbers and Stuedemann, 2009).

Schuman et al. (1999) stated that generally less than 10% of grassland organic C is located in aboveground biomass, while the remainder is in root biomass or soil organic matter. Greater SOC in the grazed pastures was attributed to root biomass turnover, return of aboveground residues, and cycling of manures (Franzluebbers et al., 2009). Also, grazing intensity and frequency affect aboveground production of forages and promote nutrient cycling (Schuman et al., 2002), and they affect plant allocation of C by altering tillering and rhizome production and stimulating root exudation (Wright et al., 2004). Wright et al. (2004) stated that these above- and below-ground plant factors interact with grazing intensity and influence soil C and N mineralization rates. Over the 12-yr study, they found that the annual rate of change in SOC to a depth of 90 cm was greatest (1.17 Mg C ha^{-1} yr^{-1}) for the low stocking rate treatment. These results suggest that a moderate stocking rate will optimize soil organic C and N fractions compared with unharvested or hay management.

Wright et al. (2004) evaluated grazing management impacts on soil C and N in BG pastures in Overton, TX. Management included low (2.5 cow-calf pairs ha^{-1} for cv. Coastal, 2 cow-calf pairs ha^{-1} for common) and high-grazing intensity (7.4 cow-calf pairs ha^{-1} for cv. Coastal, 5 cow-calf pairs ha^{-1} for common), fertilization, and winter overseeding with annual ryegrass (*Lolium multiflorum* L.; RG) and clover (*Trifolium* sp.; C). Grazing intensity played an important role in soil C and N sequestration, with the high grazing intensity resulting in a smaller increase in C and N over time compared with the low grazing intensity. Soil organic C increased 67 and 39% from 7 to 26 yr at low-grazing intensity for BG + RG and BG + C overseeded pastures, respectively. Differences in the two intensities was attributed to enhanced turnover of plant material, excreta, and physical disruption of the soil at high grazing pressure (Wright et al., 2004).

A study by Liu et al. (2011b) evaluated the effect of a range of grazing intensities on the distribution of soil and plant nutrient pools in Tifton 85 bermudagrass. Pastures were stocked rotationally every 28 d and grazed to a post grazing stubble height of 8, 16, or 24 cm. Although the nutrient concentration of plant pools was not as affected by grazing intensity, there was a 17% increase in soil C content with increasing postgraze stubble height. Soil N concentration increased from 0.56 to 0.75 g kg^{-1} as stubble height increased from 8 to 24 cm, respectively. The authors suggested that changes in soil C and N were a function of the change in above- and belowground biomass allocation and retention of C in the plant-soil system. These results illustrate that selecting an appropriate level of grazing intensity is an important management strategy to maximize plant and soil quality and can increase soil C content in Florida grassland ecosystems.

The effect of grazing frequency and method is less well-documented for systems in the southeastern USA. Because intensity and frequency often interact, frequency effects are usually reported in the literature along with a given level of management intensity. Impacts of the intensity × frequency interaction may include changes in soil bulk density, soil penetration, and water filtration, and nutrient cycling in grazed systems.

Grazing method may affect soil OM through the influence on above- and below-ground C pools. It has been suggested that plant-related advantages attributed to rotational vs. continuous stocking include increased pasture carrying capacity, higher gain ha^{-1}, improved persistence (Matches and Burns, 1995), and more uniform use of an extensive pasture area (Hart et al., 1993). These pasture responses will influence nutrient cycling in grasslands through the amount and spatial distribution of plant litter and excreta, which ultimately impacts the soil OM pool (Dubeux et al., 2007).

Hay Management and Soil Quality

There are an estimated 55 million acres of land harvested for hay production in the USA annually, representing $6.7 billion in cash receipts (USDA NASS, 2013). Thus, quantifying the role of ecosystem services of forage systems under various harvest managementd is of interest. Franzluebbers and Stuedemann (2002) compared two grazed 15-year-old and one 19-year-old stands of Tifton 44 bermudagrass to two hayed 15-year-old stands of 'Coastal' and one 19-year-old stand of 'Tifton 44' bermudagrass. Grazed pastures were continuously stocked for 5 mo yr^{-1}, and hayed pastures were clipped three to four times annually. Total organic C was greater under grazed than hayed bermudagrasses (13 vs. 10.6 g kg^{-1}) within the surface 20 cm. Differences among treatments was attributed to the return of feces and urine in the grazed treaments compared with those that were hayed. Additionally, surface litter C:N ratio was lower for the grazed pastures than hayed, illustrating the importance of quantity and quality of litter returned to these systems in C accumulation potential (Franzluebbers and Stuedemann, 2002).

Franzluebbers and Stuedemann (2009) stated that haying removed forage from the field which was ultimately fed to cattle elsewhere, resulting in a removal of C from the system. Although the hay would have the potential to sequester C through excreta of the animals consuming the feed elsewhere, this is a relatively inefficient system when compared with animals grazing directly on pasture (Franzluebbers and Stuedemann, 2009).

Forage Management and Effects on SOM Dynamics

Grazing intensity, frequency, and stocking method may influence the soil organic matter pool through the return of nutrients to the soil via plant litter or excreta (Dubeux et al., 2007). Nutrient retention in cattle body tissue and nutrient export through animal products represents less than 30% of the total nutrients ingested by cattle (Haynes and Williams, 1993). Thus, a large portion of the nutrients consumed by cattle is returned to the soil via excreta (Vendramini et al., 2007). Nutrient return by excreta is non-uniform in distribution, and tends to be concentrated in areas of shade and water (Mathews et al., 1996). Plant litter is distributed more evenly (Dubeux et al., 2007); however, litter from tropical C_4 grasses is often harder to degrade due to a high C:N ratio, which causes immobilization by soil microbes (Vendramini et al., 2007). Stocking rate plays an important role in determining the proportion of litter or excreta returned to the system (Dubeux et al., 2007). Nutrients from animal excreta are more readily plant-available upon deposition compared with low quality warm-season C_4 plant residues often found in tropical systems (Dubeux et al., 2007). Although nutrient recovery is realized more quickly from excreta than plant litter, nutrient loss from the system can be significant depending on the management. Thus, strategies are needed to increase the uniformity of excreta distribution and minimize nutrient losses from this nutrient pool to increase plant recovery efficiency (Mathews et al., 2004; Dubeux et al., 2007). Removal of plant material through clipping influences the nutrient cycling dynamic as well. When herbage is removed for hay, less litter is available for degradation and return to the system. Although clipping frequency may increase nutritive value of potential litter, the act of removing clippings from the system negates the contribution of aboveground material to the system.

Soil C and N pools are a function of the C and N concentration in the soil organic matter (SOM) and the amount of SOM present (Dubeux et al., 2006). The quantity and chemical composition of SOM is important to C and N cycling, as N is often the productivity limiting factor in grassland ecosytems (Ganjegunte et al., 2005). Soil OM includes plant, animal and microbial residues in all stages of decomposition (Post and

Kwon, 2000). Many of these organic compounds are closely associated with inorganic soil particles, and their turnover time is highly dependent upon biological, chemical, and physical processes in the soil. Traditionally, SOM has been characterized through chemical fractionation (i.e., fulvic acid, humic acid, etc.); however, the use of these fractions to explain dynamics of agroecosystems has been limited (Dubeux et al., 2006). Physical fractionation of SOM by size or density has become a well-accepted method for characterizing SOM quality (Meijboom et al., 1995). Physically fractionated SOM relates to specific carbon pools, which are important for understanding soil carbon processes that occur in grasslands (Post and Kwon, 2000). Light fraction organic carbon (LFOC) is free, particulate plant and animal residues undergoing decomposition (Christensen, 1996). In systems with significant returns of plant litter, LFOC can accumulate readily, despite higher decomposition rates. Rate of turnover for this pool is on the order of months to a few years. The intermediate fraction is made of partially humified material. Soil OM can also be transformed by bacterial action and stabilized in clay- or silt-sized organomineral complexes, also known as heavy fraction organic carbon (HFOC), where the majority of SOC is found (Post and Kwon, 2000). For C sequestration strategies to be effective in the long term, it is likely that they must increase the slow and passive pools of SOM, such as that of the HFOC (Franzluebbers and Studemann, 2002).

Evaluation of changes in these fractions may be useful in describing the contribution and dynamics of forage management to SOM, but few studies have evaluated changes in these fractions in pasture management systems. Dubeux et al. (2006) evaluated changes in SOM of a bahiagrass pasture under various N fertilization levels, stocking rates, and stocking methods. Over the 3-yr study, bulk soil C and N was not affected by management intensity; however, effects were observed in the light density fraction of SOM that readily responds to changes in management (Dubeux et al., 2006). As management intensity increased (fertilization level and SR), both C and N concentration were increased in the light density fraction, illustrating short-term changes in this pool. Carbon and N concentrations were greater for rotationally stocked treatments than the low stocking rate, continuously stocked treatments. Thus, increasing management intensity can contribute positively to soil fertility and C sequestration (Dubeux et al., 2006). Silveira et al. (2013) investigated the short-term impacts of differing levels of grazing intensity (postgraze stubble height of 8, 16, and 24 cm) and N fertilization (50, 150, and 250 kg N ha^{-1} yr^{-1}) on soil C dynamics of rotationally-stocked ‘Tifton 85’ bermudagrass pastures. Across the 2-yr study, particulate organic C and total C and N increased linearly with increasing stubble height in the < 53 µm fraction. The authors suggested that C associated with this size fraction represents relatively short-term changes in soil C for sandy soils, although similar evaluations in other soil types typically show the influence of management occurs more readily in macro and microaggregates (≥ 250 µm and 53 to 250 µm, respectively). Therefore, understanding how grassland C is allocated to different soil size classes further help determine short- and long-term impacts of pasture management on soil C.

Summary

Rhizoma peanut is a perennial, forage legume well-adapted to the lower Coastal Plain region of the southeastern USA and with potential for incorporation into beef cattle production systems. Mixed species swards with RP may increase pasture productivity over non-fertilized grasses and provide a source of high nutritive value forage in otherwise low-input production systems. Time to establishment and establishment cost have been cited as the primary factors limiting the adoption of RP in the Southeast, and alternative strategies are needed if RP is to make a significant contribution to the beef cattle industry in Florida. Strip-planting of RP may be a viable method of establishment; however, further research is needed to determine the effect of different RP growth habits on rate of establishment, response to RP defoliation management practices, and the effect of a range of grazing frequencies and intensities on persistence, productivity, ad nutritive value of established RP pastures. Additionally, there is a need to define potential of RP and grass-based systems to contribute to changes in soil quality and to assess the role of defoliation management on this response.

CHAPTER 3
GROWTH HABIT OF RHIZOMA PEANUT CULTIVARS AFFECTS ESTABLISHMENT AND SPREAD WHEN STRIP-PLANTED IN BAHIAGRASS SOD

Overview of Research

Warm-season perennial grasses such as bahiagrass (*Paspalum notatum* Flügge) and bermudagrass [*Cynodon dactylon* (L.) Pers.] form the basis of many grazing systems in the USA Gulf Coast Region (Ball et al., 2007). These grasses require N inputs for production and persistence, but rising cost of fertilizer (USDA NASS, 2013) makes N less affordable for many producers and prohibitively expensive for others. Failure to maintain adequate N nutrition reduces forage accumulation, resulting in overgrazing and subsequent degradation of grasslands (Boddey et al., 2004), threatening the sustainability of grass-based pasture-livestock systems in the region.

Association of N-fixing legumes with grasses offers an opportunity for improving pasture quality, productivity, and animal production in regions characterized by low soil fertility (Lascano et al., 1989). The incorporation of legumes into these existing systems may provide required N to livestock through consumption of high crude protein forage (Sollenberger et al., 1989), needed N to associated grasses through nutrient cycling from livestock waste and legume nodule sloughing (Dubeux et al., 2007), and critical economic relief to producers.

The contribution of legumes to pasture systems has been less pronounced in warm compared with temperate climates due to a general lack of persistence of tropical and subtropical legumes under grazing, few disease-resistant cultivars, and limited adoption of technologies leading to successful use (Ortega et al., 1992a; Shelton et al., 2005). However, in the southeastern USA rhizoma peanut (RP; *Arachis glabrata* Benth.) has been cited as one of the “success stories” for the use of legumes by producers

(Shelton et al., 2005). Rhizoma peanut is a warm-season perennial legume that is well-adapted to the southern Gulf Coast region and has potential for incorporation into pasture-based livestock systems. It is often compared with alfalfa (*Medicago sativa* L.) because of its yield potential (Andrews et al., 1985), high nutritive value (Prine et al., 1981; Mislevy et al., 2007), and persistence under a variety of management conditions (Ortega-S. et al., 1992a; Butler et al., 2007). Because of RP's persistence and ability to spread when growing in association with grasses (Dunavin, 1992), it is unique among legumes adapted to the region.

In spite of its many desirable attributes, high cost of establishment of pure stands of RP (~ \$1250 ha^{-1}; Blount, personal communication, 2012) has made it uneconomical for use in livestock enterprises characterized by relatively low economic return per hectare such as beef cow (*Bos* sp.)-calf and other pasture-based systems. Consequently, use of RP has primarily been limited to a high value hay crop for horses (*Equus caballus*) or dairy cows. Lower-cost, alternative establishment strategies are needed if RP is to make significant contributions to grazing systems for livestock. One approach for lower-cost incorporation of RP into grass pastures is strip-planting (Castillo et al., 2013). Because RP is a long-lived perennial with ability to move laterally via an extensive rhizome system, it has potential to spread into the surrounding grass areas over time and form a mixed pasture.

To date, only 'Florigraze' RP has been evaluated using the strip-planting approach (Castillo et al., 2013). There are other recently released genotypes of RP that may have potential for incorporation into existing grass pastures, but they have not been tested. In 2010, the University of Florida released 'UF Tito' and 'UF Peace' as cultivars with an intermediate to upright growth habit that may exhibit high dry matter yields, persistence, and disease tolerance (Quesenberry et al., 2010). Prine et al. (2010) also released the germplasms ‘Ecoturf’ and ‘Arblick’ as low-growing ecotypes for grazing or ornamental use. The range in growth habits represented by these genotypes may well affect their ability to spread and persist in grass pastures using a strip-planting establishment approach.

Furthermore, Florida grasslands have the potential to contribute to soil C sequestration (Silveira et al., 2013). Conversion of agricultural land from cultivation or native vegetation to improved grasslands has been shown to increase soil C sequestration (Conant et al., 2001). However, there is a need to understand how conversion among improved forage systems, such as shifting from C_4 to C_3-based systems, and forage management practices influence soil C and N in this environment. Therefore, the objectives of this study were to 1) evaluate differences among RP genotypes in their establishment ability and spread potential when strip-planted in bahiagrass sods; 2) to determine the effect of defoliation management during the establishment year on these responses; and 3) to quantify the effects of converting from a C_4 to C_3-based pasture system on soil C and N dynamics.

Materials and Methods

Experimental Site

An establishment study was conducted during 2011 and 2012, with a new area planted each year, at the University of Florida Beef Research Unit in Gainesville, FL (29.72°N, 82.35°W). The site was chosen because of the presence of well-established ‘Pensacola’ bahiagrass on a moderately well-drained soil. Soils at the site include Pomona fine sand (sandy, siliceous, hyperthermic Ultic Alaquods) and Plummer fine sand (loamy, siliceous, subactive, thermic Grossarenic Palequults). Soil samples were taken to a depth of 15 cm and analyzed by the University of Florida Extension Soil Testing Laboratory. Initial characterization of the surface soil (top 15 cm) indicated a soil pH of 6.5 and Mehlich-1 extractable P, K, Mg, and Ca of 11, 37, 107, and 659 mg kg^{-1}, respectively.

Treatments and Experimental Design

Four RP genotypes and two defoliation management regimes were replicated three times in a split-plot arrangement, with main plots allocated in a randomized, complete block design. Defoliation management regime served as the main plot, and RP entry as the sub-plot for a total of 24 experimental units. Each experimental unit was 6-m wide × 5-m long and consisted of a 4-m wide strip through the entire length of the plot into which RP was planted, bordered by a 1-m strip of bahiagrass on each side.

Entries included Arblick, Ecoturf, Florigraze, and UF Peace. The entries were selected to represent a range in plant growth habit among existing RP cultivars and germplasms. Germplasms Arblick and Ecoturf are decumbent (Prine et al., 2010), whereas cultivars Florigraze and UF Peace have a more intermediate to upright growth habit (Quesenberry et al., 2010). The two defoliation treatments were selected based on preliminary results from a strip-planting study with Florigraze RP that has since been published (Castillo et al., 2013). Defoliation treatments were hay production or rotational stocking. Hay production plots (bahiagrass and planted strip) were mechanically harvested every 28 d to a 10-cm bahiagrass stubble height using a sickle bar mower. The 10-cm stubble was chosen to approximate the height used in bahiagrass hay production systems. The rotational stocking treatment was grazed every 28 d to a 15-cm bahiagrass stubble height. The 15-cm stubble was chosen because it was not certain to what degree the grazing animals would select herbage from the planted strip versus the bahiagrass bordering the planted strip. The intent was that a taller bahiagrass stubble for grazing than for hay production would minimize the likelihood that RP would be overgrazed in the planted strip. The defoliation treatments were imposed both in the year of establishment and the year after establishment.

For grazed treatments, mob stocking (Allen et al., 2011) was used to attain the target stubble height using 12, 350-kg yearling cross-bred beef heifers. Animals were assigned to an experimental unit for a short period of time (~1 hour), and grazing was monitored until a 15-cm bahiagrass stubble height was reached. Animals were given access to both the bahiagrass bounding the planted strip and the RP within the strip. Defoliation management treatments were imposed starting 10 wk after first sprout emergence (13 wk after planting) on 15 June 2011 and 14 June 2012, respectively.

Plot Establishment and Management

A new set of plots was established in both 2011 and 2012. To prepare for planting, the 4-m wide strip in each plot was sprayed with glyphosate in October 2010 and 2011 at a rate of 3.4 kg a.i. ha^{-1}. The application was done using a CO_2-pressurized backpack sprayer calibrated to deliver 187 L ha^{-1} at 310 kPa using a 3.04-m wide boom. In spring each year, the sprayed strips were prepared with a moldboard plow and heavily disked to ensure a clean-tilled planting area. Prior to planting, 10-cm deep furrows were made at 50-cm intervals in each plot (eight furrows per plot). Rhizomes of RP entries were harvested from existing planting stock nursery areas and were planted by hand, covered, and packed in the furrows at a rate of 1000 kg ha^{-1} on 17 and 18 March 2011 and 15 March 2012. Sprout emergence and successful establishment occurred in all plots in 2011; however, in 2012, all plots planted with Ecoturf failed to establish. The reason for stand failure is unknown; however, the Ecoturf planting material had a total non-structural carbohydrate (TNC) concentration of 135 and 57 g kg^{-1} DM in 2011 and 2012, respectively. In general, it is not recommended to use rhizomes with a pre-plant TNC concentration less than 130 g kg^{-1}, and stand failure has been associated with a concentration of less than 62 g kg^{-1} (Rice et al., 1995). Pre-plant TNC concentration was 120 and 73 g kg^{-1} DM for Florigraze, 122 and 139 g kg^{-1} DM for Arblick, and 138 and 107 g kg^{-1} DM for UF Peace in 2011 and 2012, respectively. Because stand establishment was successful across a range of TNC values for Florigraze, there may be other contributing factors which led to stand failure of Ecoturf in 2012.

Several methods were used to control weeds in the planted strip. Herbicides used were ammonium salt of imazapic (Impose®; +/- -2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-methyl-3-pyridinecarboxylicacid) and 2,4-D (dimethylamine salt of 2,4-D-dichlorophenoxyacetic acid) at rates of 0.07 kg a.i. ha^{-1} and 0.26 kg a.i. ha^{-1}, respectively. Impose® was applied on 11 May and 5 June 2011 and 6 July 2012 to control a broad spectrum of weeds when they were approximately 5- to 10-cm tall (Ferrell and Sellers, 2012). The herbicide 2,4-D was applied on 30 Aug. 2011 and 6 July 2012 for broadleaf weed control. At the end of the 2011 growing season, all plots were hand-weeded to remove competition from Old World diamondflower [*Hedyotis corymbosa* (L.) Lam]. It did not recur in the 2012 plots.

Fertilization was based on soil test results, and P and K were applied over the entire experimental area in the forms of triple superphosphate and muriate of potash, respectively, at a rate of 30 kg P and 80 kg K ha^{-1} on 11 Apr. 2011 and 12 Apr. 2012 (25 days after planting). Irrigation was used during the establishment phase prior to initiation of the defoliation treatments. Amount of irrigation applied weekly was equal to the 30-yr average rainfall for that week less any rainfall that occurred during that week. Total irrigation applied in March, April, May, and June 2011 was 12.5, 60, 80, and 12.5 mm, respectively. In 2012, 65, 52, and 40 mm of irrigation were supplied in March, April, and May, respectively. The final irrigation event occurred on 13 June 2011 and 21 May 2012 prior to initiation of the defoliation treatments. Monthly rainfall during the 2011 and 2012 calendar years and the 30-yr average for this location are shown (Figure 3-1).

Response Variables

Shoot Emergence

After first-shoot emergence was observed for each genotype (3 wk after planting in 2011 and 2012), emergence data were collected weekly. Prior research has shown that sprout emergence of RP is complete by 7 wk after it begins (Williams, 1993, Williams et al., 1997), however, that work was conducted with Florigraze RP and no studies have evaluated shoot-emergence patterns of other, newly released RP genotypes. To accommodate potential differences among entries in duration of the sprout-emergence period, measurements were taken for 10 wk. Counts were made in four 20- x 50-cm quadrats per plot, and counting locations were the same at each count date. Paired quadrats were placed at each of two fixed distances along a transect that ran parallel with the length of the plot and bisected the planted strip. A. The quadrat was placed such that the 50-cm side was parallel to the orientation of the RP rows, and the 20-cm side was centered on top of a row. Both defoliation treatment plots of each entry within a block were counted and because defoliation treatments had not yet been imposed there were a total of six observations per entry (three blocks times 2 defoliation treatments). Shoot emergence was calculated as the average of the four locations in each plot. In 2011, first shoot emergence was observed on 5 April and data were collected weekly until 8 June. Sprout emergence was observed for the 2012 establishment plots beginning on 4 April and continued weekly until 6 June.

Rhizoma Peanut Ground Cover

Percent RP ground cover was estimated visually every 28 d prior to each defoliation event during the establishment year. During the year after establishment, ground cover was measured prior to the first and last defoliation event of the year. A 1-m^2 (2 × 0.5 m) quadrat was placed in the center of the RP strip at two marked locations along the length of the strip so that ground cover was estimated from the same areas at each date. The 0.5-m side of the quadrat was oriented parallel to planted RP rows, and the quadrat encompassed four rows of RP. The quadrat was divided into 100, 10- by 10-cm squares to facilitate estimations. Percentage ground cover was visually estimated by the same observer in twenty of the 10- by 10-cm squares and averaged across estimates within a quadrat and across the two quadrats per plot to obtain an overall average for each experimental unit.

Rhizoma Peanut Frequency

Frequency of RP occurrence was evaluated at the same time and in the same twenty 10- by 10-cm squares per quadrat placement as percent cover. Two quadrats were sampled per plot and frequency was calculated as [# of squares per plot containing RP/40] × 100.

Rhizoma Peanut Spread

Rhizoma peanut spread was measured each year prior to the last defoliation event of the season. Spread of RP was estimated as the distance from the center of the planted strip to the farthest location at the edge of the planted strip where distinguishable aboveground RP plant parts were found. A marked transect was positioned at the center of the planted strip parallel to the planted rows. At two locations along the transect, 1.5 and 3.5 m from one end of the plot, a line perpendicular to the original transect was extended on each side. Along the perpendicular line, distance from the middle of the planted strip to the last visible peanut plant material at the edge of the planted strip was measured, resulting in four measurements of spread per plot. Spread per experimental unit was expressed as the average of the four measurements per plot.

Bahiagrass Herbage Harvested

Herbage harvested was measured every 28 d prior to each grazing or haying event to determine the quantity of bahiagrass herbage that could be utilized for livestock feed during the establishment year of RP. Herbage harvested was measured in the bahiagrass portion of each plot by hand clipping two representative 0.25-m^2 quadrats to a stubble height of 15 cm for grazed and 10 cm for hayed plots. The harvested herbage was dried at 60°C until constant weight to determine dry matter harvested.

Root-rhizome-to-Shoot Ratio and Root-rhizome Mass

At the end of the 2012 growing season, root-rhizome and shoot mass were measured at two random locations in each plot planted in 2011. The goal was to assess above- vs. below-ground partitioning of the different treatments and relate that to measures of establishment success. Above-ground biomass within a 20- x 20-cm quadrat was harvested and dried at 60°C until constant weight to determine dry matter harvested. Roots and rhizomes under that quadrat were removed to a 20-cm depth, washed, and dried at 60°C to constant weight. Root-rhizome-to-shoot ratio was calculated as the total dry weight of roots and rhizomes divided by the mass of above-ground herbage harvested.

Soil Bulk Density and Total C, N, and C:N Ratio

Soil measurements were taken at the time of establishment and after 2-yr of imposing treatments to quantify the effect of converting a well-established C_4 grassland to a C_3-based system on soil C and N in the planted strip. Soil samples were collected by strata to a 70-cm sampling depth from each experimental unit at five random locations within the tilled strip. Sampling occurred prior to planting and imposition of treatments in March 2011 and again at the end of the 2-yr experiment (only the experimental area planted in 2011 was sampled) in March 2013. Before the establishment of this experiment, the pasture area consisted of a 20-yr-old stand of Pensacola bahiagrass. Two undisturbed soil cores were taken per plot for bulk density determination using a JMC Soil Sampler (Clements Associates, Inc., Newton, IA). Bulk density was calculated as the total dry weight of the soil divided by the volume of the coring device. Two additional soil cores were extracted from each experimental unit from the following strata using a soil auger: 0 to 10, 10 to 20, 20 to 40, and 40 to 70 cm. Sample collection below a 70-cm depth was limited by the presence of an argillic layerin the Spodosol, which created variability in the amount of sample that could be collected past this depth. As the stratum above 70 cm was variable in depth from plot to plot, these data are not reported. Total C and total N were determined by dry combustion using a Flash EA 1112 C/N analyzer on samples ground in a ball mill for 5 min. The C:N ratio was calculated as the percentage of C within a sample divided by the percentage of N.

C Isotope Ratio Determination of C_3 and C_4-derived C and SOC Retained

Natural abundance stable isotope ratios ($\delta^{13}C$) were measured for a subset of soil samples to determine the origin of soil organic matter (SOM) inputs that occurred during the experiment. A subset from the samples taken in 2011 and 2013 were analyzed in order to determine change in C isotope following 2 yr of legume growth in the planted strips . The soil samples analyzed were those from Florigraze plots, from the upper two soil layers (0 to 10 and 10 to 20 cm), from the two defoliation regimes (grazed or hayed), and from all three replications of these treatments (total 24 samples). Samples were analyzed using a Thermo-Finnigan MAT DeltaPlus XL Isotope Ratio Mass Spectrometer (IRMS) interfaced via a Conflo-III device to a Costech ECS 4010 elemental analyzer (Costech, Valencia, CA). Results are reported in relation to $\delta\,^{13}C_{PDB}$ standard as described by Boutton (1991). The ratio of $^{13}C/^{12}C$ is expressed as:

$$\delta^{13}C\ ‰ = [(^{13}C/^{12}C \text{ ratio of sample})/(^{13}C/^{12}C \text{ ratio of standard}) - 1] \times 1000.$$

A negative value indicates a smaller proportion of ^{13}C in the sample compared with the standard. The more negative value for C_3 plants is related to discrimination in favor of ^{12}C by the primary carboxylation steps in the photosynthetic pathway catalyzed by ribulose bisphosphate carboxylase. Because the primary carboxylation step differs for C_4 plants, there is typically greater discrimination for ^{13}C in C_3 plants (Lefroy et al., 1993).

The ratio of carbon isotopes $^{13}C/^{12}C$ in a soil sample was compared to a plant standard (RP for C_3 or BG for C_4, respectively) to detect the photosynthetic pathway (C_3 vs. C_4) of the source plant. The contribution of soil C from C_3 or C_4 plants was determined according to the following equations by Follett et al. (2009):

$$C_3\text{-derived } C(\%) = (\delta^{13}C_{sample} - \delta^{13}C_{C4})/(\ \delta^{13}C_{C3} - \delta^{13}C_{C4})*100$$

C_4-derived C(%) = $(\delta^{13}C_{C3} - \delta^{13}C_{sample}) / (\delta^{13}C_{C3} - \delta^{13}C_{C4})*100$

Carbon contribution from C_3 or C_4 plants was calculated as the percentage of C_3- or C_4-derived C multiplied by the total soil organic C (g kg^{-1} soil).

The amount of SOC retained was determined to quantify how much C remained in the system following 2 yr of imposing treatments. The following equations were used to calculate the change in C across the experiment and expected residence time of C as described by Clay et al. (2007) and Silveira et al. (2013):

$SOC_{retained} = [SOC_{final}*(\delta^{13}C_{soil\ final} - \delta^{13}C_{plant})]/(\delta^{13}C_{SOCinitial} - \delta^{13}C_{plant})$

The δ^{13} values represent ^{13}C associated with soil measurements from 2011 and 2013, respectively, and current RP plant material.

Statistical Analysis

Data were analyzed using PROC MIXED of SAS (SAS Institute, 2010). In the year of establishment, entries, defoliation treatment, and their interactions were considered fixed effects, and years, blocks, and their interactions were considered random effects. In 2012, observations for Ecoturf plots that failed to establish were treated as missing data for the purpose of analysis of the two establishment years. Mean separation of entries was done using the PDIFF option of LSMEANS in SAS. Defoliation treatment means were separated using the F test. Date was considered a repeated measure for sprout emergence, ground cover, and frequency with an autoregressive covariance structure. For soil responses, data were analyzed within a given soil layer. Year, RP entry, and defoliation management regimes were considered fixed effects and block was considered random. Treatments were considered different for plant responses when $P \leq 0.05$ and when $P \leq 0.10$ for soil responses.

Results and Discussion

Shoot Emergence

Total shoot emergence was greater for Florigraze (79 sprouts m^{-2}) than all other genotypes. Ecoturf and Arblick were similar (66 and 57 sprouts m^{-2}, respectively), but had greater total emergence compared with UF Peace (30 sprouts m^{-2}). Shoot emergence increased for up to 10 wk after planting, after which it was difficult to distinguish between individual shoots. Previous work with Florigraze suggested that emergence was complete at 7 wk after first emergence (Williams et al., 1993). However, differences in shoot emergence patterns have been previously reported in Florigraze and Arbrook (Williams et al., 1997), which suggests that the time to reach peak emergence may differ among genotypes. The results of the present study show that shoot emergence may continue for up to 10 wk, but there was no date x genotype interaction for emergence pattern ($P > 0.05$).

Rhizoma Peanut Ground Cover

There were date x entry ($P = 0.0003$) and date x defoliation ($P = 0.0012$) interactions for RP cover. Interaction occurred because Arblick and Florigraze had greater ground cover during June and July (Figure 3-2), while Florigraze and Ecoturf had the greatest ground cover from September through the remainder of the season. All entries reached their peak percentage cover in August with the exception of Ecoturf which continued to increase through October. UF-Peace had the least ground cover compared to the other lines and cover remained below 15% throughout the entire establishment year. Cover of Florigraze and Ecoturf exceeded 30% by the end of the growing season. Interrante et al. (2011) observed similar cover for a monoculture of Florigraze during the year of establishment. Williams et al. (2008) reported 30 to 40%

ground cover for Arblick and Ecoturf during the year of establishment when the area planted was harvested every 9 wk. Prine et al. (2010) reported that Arblick generally is slower to establish than other forage-type genotypes of RP, an observation which is supported by the results of the current study.

There was also a date x defoliation management interaction (Figure 3-3) that occurred because the hayed treatment resulted in greater percentage cover in July and August of the establishment year, but there were only trends favoring the hayed treatment thereafter. The apparent advantage of the hayed treatment likely occurred because grazed plots were defoliated more severely than clipped plots. This occurred even though the stubble height for the hayed treatment was 10 cm vs. a target stubble height (bahiagrass component) of 15 cm for grazing. When cattle entered the rotationally stocked plots, they first went to the planted peanut strip and grazed it close to soil level before initiating grazing on the bahiagrass. Thus, by the time the bahiagrass was grazed to 15 cm the strip planted to RP had been grazed considerably lower than that. There was a much larger and highly significant advantage of hayed vs. grazed defoliation management in previous work with Florigraze in the same environment where the current work was done (Castillo et al., 2013). In that experiment, the greatest percentage of ground cover reported for the 28-d rotational stocking treatment was 4% vs. 29% for harvested treatments (Castillo et al., 2013). Lower RP cover in that experiment could be explained in part because measurements were taken following defoliation instead of before defoliation as in the current study, and in the present study, bahiagrass strips were sprayed and killed with glyphosate in the fall prior to planting. In the study by Castillo et al. (2013), no glyphosate was applied and bahiagrass likely regenerated more rapidly following tillage of the strip than in the current study, likely resulting in greater competition to establishing RP.

Ground cover differences were observed during the year after establishment among defoliation regimes. Hay production treatments had a greater percentage ground cover compared with rotational stocking (66 vs. 46%, respectively). This implies that defoliation management during the year after planting continues to affect RP establishment success. There was no effect of entry or entry x defoliation interaction during the second year of management, and all genotypes had cover of ≥ 45%. Measurement of ground cover on these plots at the beginning of the 2013 growing season further illustrated an additional carryover effect of management on cover. In spring 2013, rotationally stocked treatments had 47% ground cover compared with 70% (P = 0.0037) for clipped. Percentage of ground cover tended (P = 0.0789) to be different among entries, with the low-growing ecotypes Arblick and Ecoturf having increased ground cover (68%) compared with Florigraze and UF Peace (46%).

Rhizoma Peanut Frequency

There were date x entry (P = 0.0002) and date x defoliation (P = 0.0356) effects on RP frequency during the establishment year. Entry differences in RP frequency followed a similar pattern to ground cover. Arblick and Florigraze had greater frequency in June compared with the other lines (Figure 3-2), but beginning in July, frequency of Ecoturf began to increase and was similar to Arblick and Florigraze. Florigraze and Ecoturf continued to increase throughout the remainder of the season, and had a greater frequency of occurrence than Arblick and UF Peace. Frequency of UF Peace was lower than all other genotypes from June to October, and did not exceed 30%. Increased late-season cover and frequency associated with Florigraze and Ecoturf illustrate apparent greater potential for establishment success compared with other genotypes. Castillo et al. (2013) reported slightly lower values for strip-planted Florigraze under the same management strategies (44%).

At the beginning of the establishment year, RP frequency did not differ between defoliation management strategies, but it was lower for grazed treatments compared with those under hay production in July and August (Figure 3-3). This was likely due to the same reasons that RP cover was sometimes greater for hayed than grazed plots. No differences were observed between grazed and hayed treatments during September and October. These data illustrate that hay production treatments achieved a greater frequency early in the season, whereas those under rotational stocking took longer to achieve a similar level of occurrence.

During the year after establishment, no differences ($P \geq 0.05$) were observed among treatments for percentage of RP frequency. Frequency of RP occurrence ranged from 77 to 95% for all entries. The average establishment period for RP to reach a full stand is 2 to 3 yr (Williams et al., 1993). Distribution of RP reached its peak during this time frame as planted areas begin to fill in, which may explain the lack of differences among entries in the year after planting.

Rhizoma Peanut Spread

Differences in RP spread were observed among entries ($P = 0.0086$) and defoliation strategies ($P = 0.0023$) (Tables 3-1 and 3-2, respectively). Ecoturf, Florigraze, and Arblick had greater total spread (25, 13, and 12 cm, respectively) into bahiagrass compared with UF Peace (-3 cm). In an evaluation of RP genotypes, UF Peace and Florigraze were noted for superior spread potential and competitiveness with bermudagrass compared with other entries (Friere et al., 2000). However, these plots were allowed to reach full establishment and then managed as pure stands under clipping and encroachment into surrounding grass borders occurred over a 10-yr period. In the present study, the competition between well-established grasses and the establishing legume may have reduced spread potential of UF Peace. The low-growth habit of Ecoturf and Arblick may have protected RP from complete leaf removal during a defoliation event, resulting in greater spread potential for those entries. Haynes (1980) suggested that the sustainability of legumes in grazing systems is largely determined by growth habit and the ability to protect growing points. Legumes with creeping stems tend to escape serious damage by grazing animals, whereas those with an upright habit are more susceptible. Rotational stocking decreased RP spread (0 m) compared with treatments under hay production (0.24 m). Spread may have been reduced in the rotationally stocked treatments because of animal selection as described in the previous section. Preference for legumes in mixed swards has been shown to affect their persistence in temperate and tropical forage systems (Lascano and Thomas, 1988; Schwinning and Parsons, 1996), and this may negatively impact establishing RP-grass associations.

When spread was measured at the end of the year after establishment, there were differences due to defoliation management regime ($P = 0.0127$). Mean spread for hayed plots (Table 3-1) was 0.89 m compared with 0.55 m for those under rotational stocking. Although spread increased in the second year, these observations illustrate that the management strategy utilized during the first 2 yr after planting can significantly impact the establishment success of RP. No differences were observed among entries for spread during the second year of management, and all genotypes had spread ≥ 0.51 m into adjacent bahiagrass strips.

Herbage Harvested

Total herbage harvested did not differ among defoliation regimes and was 4.0 and 4.4 Mg DM ha^{-1} for grazed and hayed treatments, respectively. One management consideration for strip-planting is to determine whether the area can be utilized during the establishment phase for grazing or hay production without negatively impacting RP establishment. If the area is removed from production during this time, these values represent the amount of bahiagrass that would be sacrificed. Average production from bahiagrass in Florida ranges from 3,000 to 11,000 kg ha^{-1} depending upon N fertilization rate and environmental conditions (Stewart et al., 2005; Newman et al., 2011). Thus, the values reported in this study fall within the range of production for pastures in Florida, and their presence in the lower portion of this range reflects the absence of N fertilizer application.

Root-rhizome-to-Shoot Ratio and Root-rhizome Mass

There were no main effects of entry for root-rhizome-to-shoot ratio (P = 0.255) or root-rhizome mass (P = 0.499) due to large standard errors (0.29 for root-rhizome-to-shoot ratio and 1010 kg ha^{-1} for root-rhizome mass). Root-rhizome-to-shoot ratios were 0.95, 1.4, 1.5, and 0.84 for Arblick, Ecoturf, Florigraze, and UF Peace, respectively. Root-rhizome-to-shoot ratio comparisons of Florigraze and UF Peace (P = 0.101)approached significance. Root-rhizome mass of Arblick, Ecoturf, and Florigraze was ≥ 5,020 kg ha^{-1} compared with 3,830 kg ha^{-1} for UF Peace. The comparison of root-rhizome mass of Ecoturf (5,750 kg ha^{-1}) and UF Peace approached significance (P = 0.178). Entires with root-rhizome mass ≥ 5,020 kg ha^{-1} correspond to those with the greatest above-ground spread. Interrante et al. (2011) suggested that measuring above-ground RP spread can provide an indication of how far rhizomes have spread during the growing season. Florigraze, Ecoturf, and Arblick had the most favorable cover, frequency, and spread characteristics throughout the study. These data illustrate a range in allocation of resources to root-rhizome vs. shoot growth that may impact long-term persistence of RP stands, and despite large variation in the response appear to favor Ecoturf and Florigraze. A correlation analysis detected a positive relationship (r = 0.41, *P* = 0.048) between ground cover and root-rhizome mass. Thus, selecting genotypes for use in the strip-planting system with a combination of desirable above- and below-ground plant characteristics may lead to increased potential for contribution of RP to a mixed species sward.

Soil Bulk Density, Total C, N, and C:N Ratio

Soil characteristics were measured in the planted strip before and 2 yr after imposing treatments to assess the effect of planting RP on soil traits. Soil bulk density was affected by soil depth and was 1.21, 1.61 and 1.69 g cm^{-3} for the 0- to 10-, 20- to 40- and 40- to 70-cm strata, respectively. In the 10- to 20-cm stratum, there was a decrease in bulk density (P = 0.0613) from 1.37 to 1.29 from 2011 to 2013, although the reason for the decrease at this depth is uncertain.

Differences were observed in total C at varying soil depths after 2 yr of imposing treatments. A year effect (*P* = 0.0917; Table 3-3) was observed for SOC within the surface 10-cm of soil. Total C before planting in 2011 was greater (12.5 g C kg^{-1} soil) than in 2013 (11.7 g C kg^{-1} soil). In the 10 to 20 cm layer, soil C decreased across years (*P* = 0.0002) from 9.1 g C kg^{-1} in 2011 to 6.6 g C kg^{-1} in 2013. Defoliation management affected soil C within this layer, and hayed treatments had 32% greater total C (9.3 g C

kg^{-1} soil) than grazed plots (6.4 g C kg^{-1} soil). Total C did not differ among treatments within the 20- to 40-cm and 40- to 70-cm layers. Average soil C concentration in the 20- to 40-cm layer was 5.2, and it was 4.7 g C kg^{-1} soil for the 40- to 70-cm depth.

A decrease in soil C for the 0- to 10- and 10- to 20-cm layers likely occurred due to tillage of the strip prior to planting with RP. Soil disturbance associated with this practice may have disrupted aggregates, and caused an initial decrease in soil C until RP plants began to establish. After planting, RP under hay production generally had greater establishment success during Year 1 (i.e. ground cover, frequency, spread), which may explain the greater total C associated with this management practice compared with rotational stocking.

Total N differed within layers (Table 3-3), and the greater N contribution occurred in the top 20 cm of soil. The 0- to 10-cm layer had the greatest total N (0.38 g N kg^{-1} soil), but no differences were observed among treatments. Soil N decreased from 0.42 to 0.25 g N kg^{-1} soil across the 2-yr study (year effect, $P = 0.0032$) at the 10- to 20-cm depth, which may be due to tillage prior to establishment of the experiment in 2011 Contribution of soil N was low and variable at depths of greater than 20 cm. Mean soil N was 0.13 and 0.07 g N kg^{-1} soil for the 20- to 40- and 40- to 70-cm depths, respectively.

Soil C:N ratio was not different among treatments (Table 3-3) for the surface 10 cm (20.2) and the 10- to 20-cm depth (26.7). This ratio for the 0- to 10-cm layer approaches the threshold C:N level of 20:1 that is typically when N immobilization begins to occur (Tisdale et al., 1985). A year x defoliation regime interaction was observed for the 20- to 40-cm depth. Interaction occurred because the C:N ratio was not different among defoliation strategies in 2011 (32.2. vs. 45.5 for grazing vs. hay management, respectively), but C:N ratio was greater for grazed (50.3) than hayed (37.4) treatments in 2013. Mean C:N ratio for the 40- to 70-cm layer was 43.8 and did not differ among treatments. The increased C:N ratio below the 10-cm depth is consistent with the low concentration and decreasing contribution of N moving deeper into the soil profile.

C Isotope Ratio Determination of C_3 and C_4-derived C and SOC Retained

Stable isotope ratios increased from before initiation of treatments to 2 yr after initiation for the 0- to 10- ($P = 0.0029$) and 10- to 20-cm ($P = 0.0049$) soil layers. Isotope discrimination increased (value became more negative) from 2011 to 2013 for the surface 10-cm of soil (-20.4 to -21.3 ‰). A similar pattern was observed for the 10- to 20-cm depth where $\Delta^{13}C$ values changed from -21.2‰ in 2011 to -22.6‰ in 2013. Despite the relative short duration of the study, these data illustrate the shift in the C source from a C_4- to a C_3-based plant population affected soil C pools. A more negative isotope value reflects the influence of RP on soil C following strip-planting in previously established bahiagrass swards (-13.79 ‰ and -28.29 ‰ for bahiagrass and RP plant material, respectively, in the present study). The changes in the present study are within the range reported in other experiments in which vegetation type shifted from C_4 to C_3-based plant communities and vice-versa (Lefroy et al., 1993; Hobie and Werner, 2004).

$\Delta^{13}C$ signatures did not differ between grazed and hayed Florigraze plots at the 0- to 10- or 10- to 20-cm depths. Mean C contribution from plants associated with the C_3 photosynthetic pathway was 5.8 g C kg^{-1} for the 0- to 10-cm layer, and 4.7 g C kg^{-1} for the 10- to 20-cm layer. Soil C contribution of C_4 plants differed from before treatments were imposed to 2 yr later ($P = 0.0098$) in the surface 10 cm of soil (Table 3-4). Prior to imposing treatments, C_4-derived C accounted for 54.4% of soil C, whereas the contribution decreased to 49.1% by 2013. Differences across the 2 yr were also prevalent for the 10- to 20-cm layer (*P* = 0.0108), and C_4-derived C decreased from 48.1 to 39.1% of the soil C from 2011 to 2013. These results agree with the stable isotope discrimination data, which illustrated a shift toward C contribution from a C_4 to C_3 population. The change in isotope discrimination is likely associated with maintenance of C_3-C contribution, while C_4-derived soil C decreased. Finally, the amount of relic SOC retained across the 2-yr observation period did not differ between defoliation regimes and was 13.0 and 8.7 g C kg^{-1} soil for the 0- to 10- and 10- to 20-cm depths, respectively.

Implications of the Research

When planted in strips, Florigraze and Ecoturf generally had the greatest mean cover and frequency of occurrence throughout the study. Ground cover differences due to defoliation regime were more apparent during the year after establishment and early in the third year, with grazed plots having less RP cover compared with those under hay production. Spread of RP entries was reduced under grazing every 28 d compared with the hay production treatment during the establishment year, but differences were less pronounced in the year after establishment. Greater rhizome-root mass was associated with entries with greater above-ground cover and may play a role in rate of RP establishment. A decrease in total soil C from 2011 to 2013 illustrates the initial impact of strip-planting RP and converting from a well-established perennial grass pasture to an establishing mixed species pasture system. Surface soil C decreased for RP under rotational stocking, and contribution of C_4-derived C decreased across the 2-yr observation period.

These results indicate that differences exist among commercially available RP entries in their ability to establish in strip-planted swards, with these results favoring Ecoturf and Florigraze. Selection of defoliation management strategy is an important consideration that can impact the success of RP establishment during the year of planting and in subsequent growing seasons. Rotational stocking of establishing strip-planted RP following conversion from an established grass pasture may also cause an initial decrease in soil C. Hay production following strip-planting is a more favorable option for utilizing the grass component during the establishment phase while reducing removal of RP in the planted strip. Identification of alternative grazing management strategies are needed if RP entries are to be grazed during the establishment phase without negatively impacting stand establishment. Finally, evaluation of strip-planting into warm-season perennial grass pastures other than bahiagrass would provide needed information to beef cattle producers considering the adoption of this technology. Identifying complementary growth habits of both the grass and legume component in these systems will likely be needed to achieve successful stand establishment.

Table 3-1. Spread of RP entries during the year of (P = 0.0086) and year after establishment (P = 0.2424).

Entry	Establishment year	Year after establishment
	------------------------------m------------------------------	
Ecoturf	0.25[‡] a	0.82
Florigraze	0.13 a	0.83
Arblick	0.12 a	0.72
UF Peace	-0.04 b	0.51
SE[†]	0.08	0.12

[†] Standard error
[‡] Within a column, means without common letters differ ($P < 0.05$).

Table 3-2. Defoliation management effects on RP spread during the year of (P = 0.0023) and year after establishment (P = 0.0127).

Defoliation strategy	Establishment year	Year-after-establishment
	------------------------------m------------------------------	
Hay production	0.25[‡] a	0.89 a
Rotational stocking	0 b	0.55 b
SE[†]	0.10	0.08

[†] Standard error
[‡] Within a column, means without common letters differ ($P < 0.05$).

Table 3-3. Soil organic C, N, and C:N ratio in the surface 20 cm of strip-planted rhizoma peanut from 2011 to 2013.

	Layer	
Year	0 to 10 cm	10 to 20 cm
	SOC, g C kg^{-1} soil	
2011[‡]	12.5 a	9.1 a
2013	11.7 b	6.6 b
SE[†]	0.66	0.79
	SON, g N kg^{-1} soil	
2011	0.39	0.42 a
2013	0.37	0.25 b
SE	0.03	0.04
	C:N Ratio	
2011	23.2	25.0
2013	17.3	28.4
SE	3.3	3.4

[†] Standard error
[‡] Within a column, means without common letters differ ($P < 0.05$).

Table 3-4. Percentage of C_4 and C_3-derived C in the surface 20 cm of strip-planted rhizoma peanut from 2011 to 2013.

	Layer	
Year	0 to 10 cm	10 to 20 cm
	C_4-derived C, % of total C	
2011[‡]	54.4 a	48.1 a
2013	49.1 b	39.1 b
SE[†]	3.5	3.5
	C_3-derived C, % of total C	
2011	45.5 b	50.8 b
2013	51.8 a	61.0 a
SE	3.7	3.2

[†] Standard error
[‡] Within a column, means without common letters differ ($P < 0.05$).

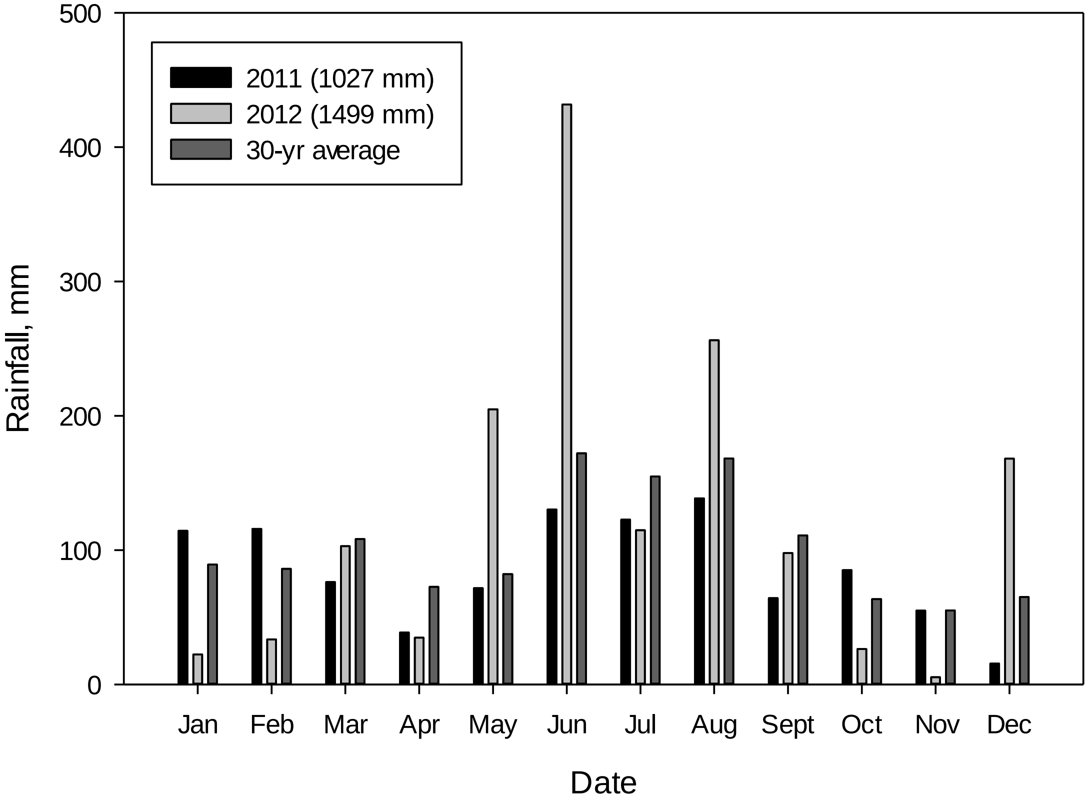

Figure 3-1. Total monthly rainfall for 2011 and 2012 and 30-year average rainfall for the experimental location.

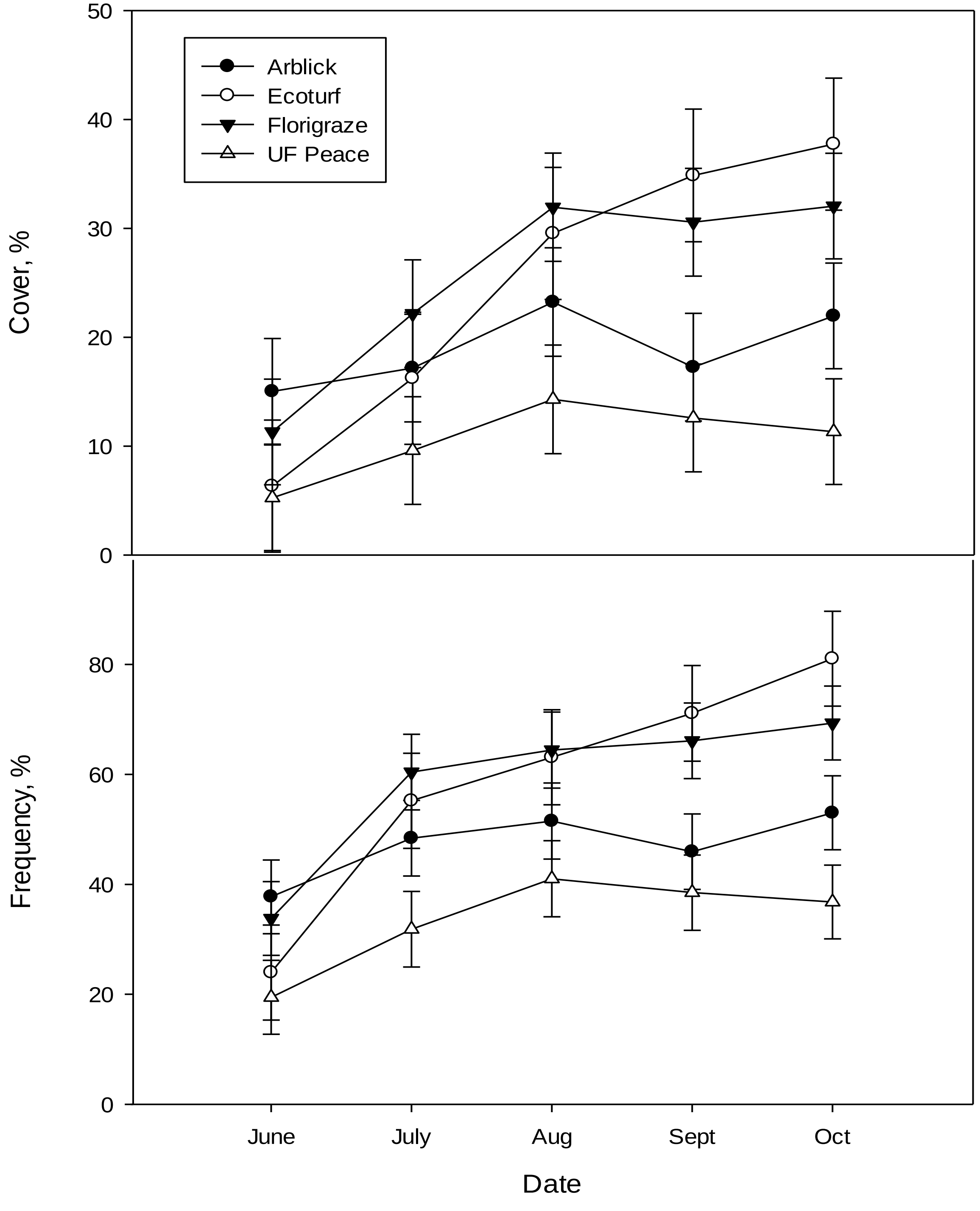

Figure 3-2. Date x entry interaction for rhizoma peanut ground cover (%; *P* = 0.0003) and frequency (%; *P* = 0.0002) during the year of establishment.

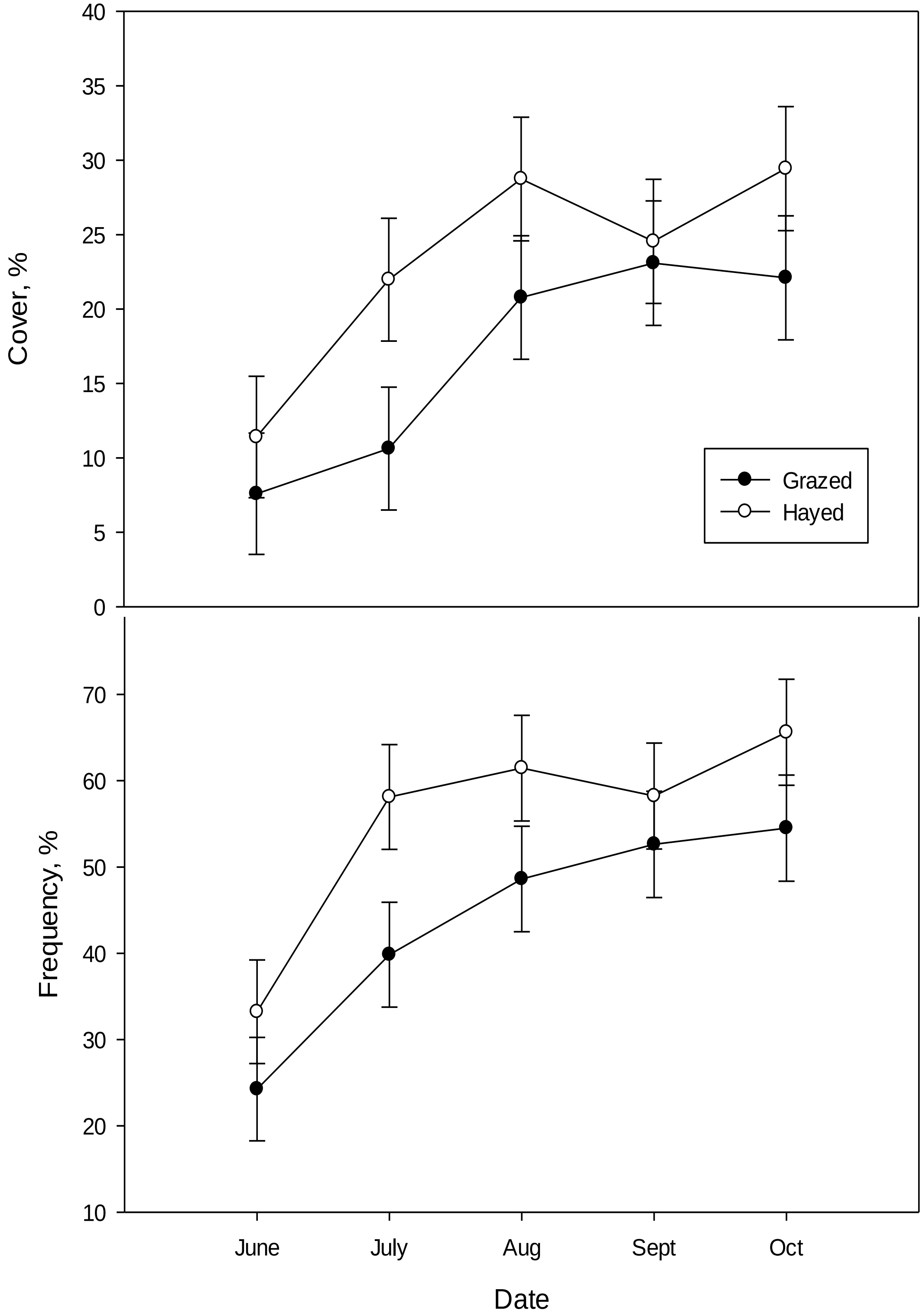

Figure 3-3. Date x defoliation treatment interaction for rhizoma peanut ground cover (%; *P* = 0.0012) and frequency (%; *P* = 0.0356) during the year of establishment.

CHAPTER 4
SWARD CHARACTERISTICS OF RHIZOMA PEANUT GENOTYPES UNDER A RANGE OF GRAZING MANAGEMENT STRATEGIES

Overview of Research

Recent research has explored options for increasing the contribution of rhizoma peanut (RP; *Arachis glabrata* Benth.) to pasture-based livestock systems in the Southeast USA (Castillo et al., 2013; Chapter 3). As new RP cultivars are released for use in pastures, it is necessary to evaluate their grazing tolerance to provide recommendations for management (Quesenberry et al., 2010). Although several studies have described management of various RP entries under clipping, few experiments have determined the influence of grazing management on RP, particularly with more recently-released cultivars and germplasms.

The evaluation of RP under grazing has been conducted primarily with ‘Florigraze’ and ‘Arbrook’ (Ortega-S. et al., 1992a; Williams et al., 2004; Hernández Garay et al., 2004). Florigraze is the most widely planted cultivar in Florida (French et al., 2006), but it has become susceptible to peanut stunt virus (*Cucumovirus* sp.) (Prine et al., 2010). The use of new cultivars may provide genetic diversity and resistance against potential disease spread from infected RP stands. Since 2010, the University of Florida has released two RP germplasms, Ecoturf and Arblick, and two cultivars, ‘UF Peace’ and ‘UF Tito’, for potential forage and ornamental use. These ecotypes represent a range in growth habit from decumbent to upright, which may affect their response to different grazing management strategies.

Growth habit has been shown to play a role in the response of other forages to grazing (Mathews et al., 1994; Hernández et al., 2004). Plants under defoliation can exhibit phenotypic plasticity, or environment-induced effects on plant morphology and architecture that include changes in size, positioning, and structure of above-ground plant growth (Nelson, 2000). However, the effect of growth habit and the degree to which plasticity occurs in these cultivars and germplasms have not been evaluated under differing levels of grazing management.

The response of plants under grazing is largely related to the type of grazing practice implemented. Intensity and frequency of grazing have been cited as key factors which influence plant responses (Sollenberger and Chambliss, 1989; Sollenberger and Newman, 2007). The evaluation of how grazing management practices interact with plant growth habit will provide an understanding of how to manage RP cultivars to maintain stand productivity, persistence, and quality for long-term stand production.

Thus, the objectives of this experiment are to determine the impact of grazing frequency and intensity on the productivity, persistence, and nutritive value of RP entries that vary in growth habit and to define the effect of growth habit on RP response to grazing management regimes.

Materials and Methods

Experimental Site

A 2-yr grazing experiment was conducted at the University of Florida Beef Research Unit in Gainesville, FL (29.72 N°, 82.35°W). The site had previously been planted to bermudagrass [*Cynodon dactylon* (L.) Pers.] from 1993 to 2003 and summer annual legumes in 2004 and 2005. In the last 5 yr, the area was unmanaged and occupied by a mixture of bahiagrass (*Paspalum notatum* Flügge) and common bermudagrass. Soils at the site are Pomona sand (sandy, silceous, hyperthermic Ultic Alaquods) and Myakka fine sand (sandy, siliceous, hyperthermic Aeric Alaquods). Prior to planting, soil samples were collected to a 20-cm depth and analyzed by the

University of Florida Extension Soil Testing Laboratory. Initial characterization of the site indicated soil pH of 6.7 and Mehlich-1 extractable P, K, Mg, and Ca of 5, 18, 75, and 458 mg kg^{-1}, respectively. These levels are considered to be very low for P and K and very high for Mg.

Treatments and Experimental Design

Thirty-six, 9-m^2 plots were established in two replicates of a randomized complete block design. The experiment included 16 treatments, consisting of the factorial combinations of four RP entries and four rotational stocking treatments (32 plots total). One extra plot was established for each of the four entries to use for calibration of measuring equipment and double-sampling for herbage mass.

Entries included Florigraze, UF Peace, UF Tito, and Ecoturf RP. They were chosen to represent a range in plant growth habit. Florigraze and UF Peace are intermediate in growth type, whereas UF Tito and Ecoturf are upright and decumbent in growth habit, respectively. Each entry was evaluated under two levels of grazing intensity and frequency. Intensities were 50 or 75% removal of the pre-grazing canopy height, and frequencies were 3 or 6 wk. Proportion of herbage removed based on height was chosen as the measure of grazing intensity because widely varying growth habits among RP entries precluded the use of a standard post-grazing stubble height. The grazing frequencies were chosen to be within a range typically recommended for RP (6 wk; Ortega-S. et al., 1992a) and which would apply significant stress (3 wk), particularly when used in combination with the 75% removal treatment. In 2012, grazing was initiated on 11 and 21 June for the 6- and 3-wk frequency treatments, respectively. The final grazing event of the season occurred on 3 Oct. 2012 for the 3-wk frequency (six grazing events in 2012) and 15 Oct. 2012 for the 6-wk frequency (four grazing events in

2012). The second year of the study began on 5 June 2013 for the 6-wk frequency and 14 June 2013 for the 3-wk frequency treatments, but only first year data are reported in this chapter.

Plot Establishment and Management

The experimental site was initially sprayed with glyphosate on 28 July 2010 at a rate of 4.5 kg a.i. ha^{-1}, then plowed and heavily disked. Plots were planted between 11 and 16 Aug. 2010 using 10-cm diameter plugs that were inserted into the soil on 30-cm centers for a total of 100 cores per plot. Cores were harvested from existing stands of the four entries and planted within 4 h of removal from the soil. This method was chosen to expedite the establishment process compared with the use of rhizomes alone. Florigraze, UF Peace, and UF Tito plugs were dug from established stands located at the Agronomy Forage Research Unit in Hague, FL. The Florigraze stand had been established for ≥ 15 yr, and there was some common bermudagrass present. Rhizome cores were taken from areas with less common bermudagrass to minimize transfer of grass rhizomes to the experimental site. The UF Peace and UF Tito stands were 2-yr-old stands that had been established as increase plots for distribution of planting material to growers. Ecoturf plugs were dug from a 20-yr-old mixed stand of RP, bahiagrass, and common bermudagrass, but the area sampled was essentially free of grass.

Four weeks after planting, plots were sprayed with imazapic (Impose^{TM}, MANA, Raleigh, NC) at a rate of 0.26 kg a.i. ha^{-1} to control emerging broadleaf weeds and sedge. Additional plant cores were added to plots during late September and early October in areas where establishment of RP was slow or not successful. All plots were sprayed with clethodim (Select Max®, Valent, Walnut Creek, CA) at a rate of 0.10 kg a.i.

ha^{-1} on 14 Oct. 2010 to control common bermudagrass that had begun to grow. Additional herbicide applications occurred in 2011 and 2012 prior to beginning of the experiment to control annual broadleaf weed and grass encroachment and promote RP stand establishment. In 2011, imazapic was applied on 11 April at a rate of 0.26 kg a.i. ha^{-1} for control of winter annual weeds, and clethodim was applied on 5 July and 28 September at a rate of 0.10 kg a.i. ha^{-1} for bermudagrass control. Imazapic and 2,4-D were applied on 17 May 2012 (0.26 and 0.60 kg a.i. ha^{-1}, respectively) prior to the start of the experiment in June 2012. Following the start of the experiment, no additional herbicide applications were made.

During the growing seasons of the establishment period, irrigation was applied weekly to supplement rainfall when it was below long-term averages in order to ensure adequate soil moisture for establishment. Total annual and 30-yr average rainfall is presented in Table 1. During the establishment year, total irrigation applied was 70 mm in August and 50 mm in September. No irrigation was applied in October 2010. In 2011, 70 mm was applied in both April and May, 13 mm in June, 25 mm in August, and 50 mm in September. No irrigation was applied during the experimental years of 2012 and 2013.

Soil samples were collected annually to a depth of 15 cm, and fertilization was guided by recommendations of the University of Florida Extension Soil Testing Laboratory. Plots were fertilized annually with 60 kg ha^{-1} of K_2O and 30 kg ha^{-1} of P_2O_5 in the forms of muriate of potash and triple superphosphate, respectively, on 16 Sept. 2010, 11 Apr. 2011, and 12 Apr. 2012.

Response Variables

Herbage Mass and Accumulation

Herbage mass was determined before and after each grazing event using a double sampling technique (Frame, 1981). The indirect measure was a 0.25-m^2 aluminum disk meter, and the direct measure was hand clipping herbage from the same quadrat areas to a 2-cm stubble. The extra (non-treatment) plot of each RP entry was used to calibrate the disk so as to minimize destructive sampling and any possible carryover effects in the treatment plots. Three double samples were collected in the extra plot and served as calibration samples for the prediction equation. Calibration samples were taken in June, August, and October at a time when the regrowth in the extra plots was 3 wk and again when it was 6 wk.

Indirect sampling occurred in the treatment plots before and after each grazing event. Disk heights were taken at 10 locations per plot both pre-grazing and post-grazing, and the average of these observations was entered into a calibration equation to predict herbage mass. Herbage accumulation (HA) was calculated as the difference between post-grazing herbage mass and pre-grazing herbage mass of the next grazing event. For the first grazing event of the year, pre-grazing herbage mass was considered to be HA.

Nutritive Value

Hand-plucked samples were taken at 10 locations per experimental unit prior to each grazing event for nutritive value determination. Locations were selected in a grid pattern to represent the entire plot, and individual samples were harvested using hand shears to the target stubble as defined by pre-grazing height measurements. The 10 samples per plot were composited for analysis. In addition, the samples from consecutive 3-wk grazing events (i.e., Grazing Events 1 + 2, 3 + 4, and 5 + 6) were composited after drying for laboratory analyses. Samples from each grazing event of the 6-wk frequency were analyzed separately, providing one nutritive value sample every 6 wk for each experimental unit.

Nutritive value analyses included crude protein (CP) and in vitro digestible organic matter (IVDOM) concentrations. Crude protein was estimated using a micro-Kjeldahl technique for N (Gallaher et al., 1975) and the two-stage technique for IVDOM (Moore and Mott, 1974). A weighted total-season herbage CP concentration was calculated as the CP concentration multiplied by herbage accumulation for each grazing event, summing these numbers across grazing events, and dividing that sum by total herbage accumulation for the season. A weighted value for IVDOM was estimated using the same calculation.

Early, mid-, and late season CP and IVDOM were also compared. For the 3-wk treatment, Grazing Events 1 and 2 were termed early, 3 and 4 were mid-, and 5 and 6 were late season. These time periods of the production season will be referred to as seasons throughout the remainder of the chapter. For the 6-wk treatment, Grazing Event 1 was early, 2 was mid-, and 3 and 4 were late season. For the seasonal comparisons, consecutive grazing events of the 3-wk treatment were composited as described earlier, and weighted CP and IVDOM were calculated for the third and fourth grazing events (late season) of the 6-wk treatment.

Pre-grazing Sward Height

Sward height was measured before each grazing event at 15 locations per plot. Because of the definition of the grazing intensity treatment, pre-grazing heights were used to determine target post-grazing height for each entry at each grazing event.

Height determinations were also used to compare entries in terms of relative growth potential and canopy structure under differing defoliation regimes. Data are reported by season and grazing events were averaged within early- (June/early July), mid- (late July/August), and late season (September/October), and compared across grazing frequencies.

Pre-grazing Leaf-to-Stem Ratio

Leaf-to-stem (L:S) ratio of the RP canopy was measured pre-grazing twice during each grazing season in July and again in August/September. A set of 10 hand-plucked samples were harvested to the target post-grazing stubble height for each entry. After collection, samples were separated into leaf, including petiole, and stem, dried, and weighed to determine L:S ratio of the grazed portion of the canopy.

Pre-grazing Canopy Light Interception

Light measurements were taken at the same time as the leaf-to-stem ratio measurements using a SunScan SS1 (Dynamax Inc., Houston, TX) to provide information on the relative extent of canopy regeneration following grazing events. The unit consisted of a 1-m long quantum sensor that was used to measure photosynthetically active radiation (PAR) at the bottom of the RP canopy. A beam fraction sensor was placed outside of the plots in full sunlight to measure incident PAR. Canopy light interception was calculated as the transmitted PAR divided by the incident PAR multiplied by 100 to obtain a percentage. Measures were taken the day prior to grazing between 1000 and 1200 h at four locations per plot.

Post-grazing Residual Leaf Area Index

Short post-grazing stubble heights and the decumbent growth habit of Ecoturf RP limited the accuracy of light interception measurements as a means of characterizing treatment effects on post-grazing photosynthetic capacity. Quantifying residual leaf area was chosen as an alternative approach. Leaf area was measured following a grazing event in July and again in August/September. Live, photosynthetically active leaves (including petiole) were removed from four, 20- by 20-cm quadrats per plot. Sites were selected to be representative of the average condition for that plot. Leaves were put in plastic bags and placed immediately on ice in a cooler for transport to the lab for area analysis. Samples were analyzed using a LI-COR™ (LI-COR Biosciences, Lincoln, NE) rolling leaf area meter. Individual leaves were placed directly onto the meter with no overlap to estimate total leaf area. Total leaf area was divided by the area of the quadrat to determine leaf area index remaining following a defoliation event.

Sward Botanical Composition

Botanical composition was quantified for each treatment prior to the first and last grazing each year. Percentages of RP, grass, and weeds were determined as the mass of each component present divided by total pre-grazing herbage mass. Measurements were made by hand clipping two representative 0.25-m^2 quadrats per plot to the target post-grazing height and separating the fresh herbage into respective components. Component samples were dried at 60°C until constant weight and weighed.

Rhizoma Peanut Ground Cover

Percent RP cover was estimated prior to the first and last grazing event of each year. A 2-m by 0.5-m quadrat was used that was divided into 100, 10- by 10-cm squares. The quadrat was placed at two locations per plot, and for each location 20 squares were evaluated. Within each square, the percentage of ground cover by RP was estimated visually by a trained evaluator.

Weed Frequency

To assist in characterizing changes in botanical composition, frequency of occurrence was measured for weeds (collectively, not by species). These measurements were done in conjunction with the cover estimates. At each placement of the 2- by 0.5-m frame within the plot, 20 individual 10- by 10-cm quadrats were evaluated for weed frequency. If any weed plant matter was present in the quadrat it was assigned a “1”, if none was present, it was assigned a “0”. The percentage (n/40) of plots in which weeds were present was the measure of weed frequency (WF).

Rhizome Mass

Rhizome-root samples were taken immediately after the first and last grazing event in 2012. Samples were taken using a 10-cm soil coring device to a depth of 20 cm. Previous studies have shown this depth encompasses the entire rhizome mat plus ~10 cm of soil below (Saldivar et al., 1992; Rice et al., 1995). Four samples were taken per plot at each date. Above-ground biomass was removed and the samples composited prior to washing over a 2-mm mesh, window-type screen to remove soil. Samples were exposed to temperatures of 100°C for 1 h to quickly stop respiration, and dried at 60°C to constant weight. After drying, samples were weighed to determine belowground biomass.

Rhizome TNC and N

Rhizome samples were ground to pass a 1-mm screen in a Wiley mill and analyzed to determine total non-structural carbohydrate (TNC) and N concentration. The TNC concentration was determined by a modification of the procedure of Christiansen et al. (1988) that was described in detail by Chaparro et al. (1996). This procedure uses invertase and amyloglucosidase to convert starch and oligosaccharides into monosaccharides and measures reducing sugars with a photometric copper reduction method (Nelson, 1944). The N analysis was conducted using a micro-Kjeldahl technique with a colorimetric analysis of N.

Statistical Analysis

Data were analyzed using PROC MIXED of SAS (SAS Institute, Cary, NC, 1996). The experiment was conducted in 2012 and 2013, but only 1 yr of data are included in the dissertation. Entry, defoliation frequency, defoliation intensity, and their interactions were considered fixed effects and block and interactions with block were random. When a responses was measured at multiple dates, date was considered a repeated measures with an autoregressive covariance structure. Differences were declared when $P \leq 0.05$, and trends were evaluated when $P \geq 0.05$ and ≤ 0.10. Interactions were described when $P \leq 0.10$. Mean separation for entry effects was based on the PDIFF option of LSMEANS in SAS. Defoliation frequency and intensity means were separated using the F test.

Results and Discussion

Herbage Accumulation

No differences were observed among genotypes for total-season HA, and the seasonal average was ≥ 7,950 kg ha^{-1} for all entries. Average seasonal production of RP was 7 to 11 Mg DM ha^{-1} throughout the southeastern USA (Terrill et al., 1996; Venuto et al., 1998). During a 4-yr trial in Citra, FL, DM yield of Ecoturf, UF Tito, UF Peace, Florigraze, and Arbrook ranged between 8.3 and 12 Mg ha^{-1}, illustrating the yield potential of RP (Prine et al., 2010). Thus, this value is within the range reported by other studies conducted in this region. There was no effect of grazing intensity or frequency during the first year of the study on seasonal herbage accumulation.

When evaluating treatment effects on seasonal distribution of HA, interactions were observed for season x entry (*P* = 0.0124) and season x frequency (*P* = 0.0183). Differences among entries were apparent for early season (Figure 4-1). Florigraze had greater HA than all other entries during this time period. During the middle of the season, Florigraze (1750 kg ha^{-1}) and Ecoturf HA decreased (1500 kg ha^{-1}), and Ecoturf HA was less than that of the upright genotypes UF Tito (2440 kg ha^{-1}) and UF Peace (2300 kg ha^{-1}). Florigraze HA was intermediate to both low- and upright-growing entries. No differences were observed among entries for late season HA. Ecoturf maintained a similar level of production from mid- to late season, but there was a pronounced decrease in HA from mid- to late season for more erect growing lines. Williams et al. (2008) noted that RP DM production decreases with decreasing daylength, and that the magnitude of response is greater in entries selected as forage types with greater DM production. In greenhouse and field evaluations of RP lines under natural daylength or extended photoperiod, Ecoturf was less daylength sensitive in aboveground production than other forage ecotypes (Williams et al., 2008). The authors suggested that because Ecoturf has been selected as a low-maintenance ornamental genotype, production potential is less sensitive to changes in daylength. In an evaluation of shoot and root growth of RP during the establishment year, Saldivar et al. (1992) observed shoot DM production began to plateau or decline in September, while rhizome growth continued. Shoot-to-rhizome ratios increased from 0 at planting to 2 by late summer, but decreased to 0.5 in the fall. The authors attributed this to photosynthate partitioning from shoots to rhizomes, which further supports that herbage production of RP is responsive to photoperiod.

A date x frequency interaction (Figure 4-2) showed greater HA for the 6-wk (2750 kg ha^{-1}) than 3-wk frequency (2230 kg ha^{-1}) from June through early July. From late July through August, HA decreased for the 3-wk frequency compared with the previous cycle (1290 kg ha^{-1}), but HA was maintained (2,720 kg ha^{-1}) for the 6-wk frequency. Herbage accumulation was lowest during September and October for both frequencies, but HA remained greater for swards grazed every 6 wk vs. those defoliated every 3 wk. These results illustrate that the average HA per defoliation event was greater for the 6-wk frequency during Year 1 of the study, but total-season HA did not differ because of greater number of grazing events for the 3-wk frequency. Further investigation of the effects of grazing management strategies is being conducted in 2013 to determine their impact on a longer time scale. This is important because the impact of grazing management on HA of Florigraze RP was much greater in the second year of imposing treatments than in the first (Ortega-S. et al., 1992a).

Nutritive Value

Total-season weighted CP concentration was ≥ 170 g kg^{-1} DM for all entries. There were differences among entries ($P < 0.0001$), with Florigraze having a lower CP concentration (170 g kg^{-1}) than UF Peace, Ecoturf, and UF Tito (~195 g kg^{-1}). Grazing frequency affected CP ($P = 0.0369$), and concentration was reduced for the 6-wk frequency (190 g kg^{-1}) compared with the 3-wk treatment (200 g kg^{-1}). There was an entry x frequency interaction ($P = 0.0898$) for CP. UF Peace and UF Tito had greater CP ($P = 0.0244$ and $P = 0.0400$, respectively) when grazed every 3 wk (mean 210 g kg^{-1}) than under a longer regrowth interval of 6 wk (mean 190 g kg^{-1}). Florigraze had lower CP (170 g kg^{-1} for 3-wk and 6-wk frequency; $P = 0.04096$) compared with all other entries, and Ecoturf was not different (*P* = 0.3248) between the 3-wk (200 g kg^{-1}) and 6-wk frequency (195 g kg^{-1}).

A longer regrowth interval likely caused increased stem growth relative to leaf in more upright-growing entries, which may have decreased CP concentrations. Although differences were observed among genotypes, these values exceed the protein requirements of all classes of beef cattle (NRC, 1996), and illustrate the high quality of RP forage. Romero et al. (1987) reported 190, 186, and 180 g CP kg^{-1} for Florigraze RP harvested every 6, 9, and 12 wk, respectively, during the summer growing season. Across a range of harvest methods, frequencies, and stubble heights, Butler et al. (2007) observed 186 to 204 g CP kg^{-1} for 'Latitude 34' RP grown in Texas, which illustrates the ability of RP to maintain nutritive value across a wide range of defoliation management practices.

There was a season x entry effect (*P* < 0.0001). Interaction occurred because CP was greater for UF Peace (240 g kg^{-1}) than all other genotypes from June to mid-July. UF Tito and Ecoturf had lower CP (210 g kg^{-1} each) than UF Peace, but were greater than Florigraze (187 g kg^{-1}) during this period. From mid-July through August, UF Peace maintained a similar CP concentration to that in early season (230 g kg^{-1}), but Ecoturf CP increased (220 g kg^{-1}) compared with UF Tito and Florigraze (200 g kg^{-1} for both). During September and October, CP concentration decreased for all lines, and Ecoturf maintained a greater CP (175 g kg^{-1}) compared with the more upright genotypes (mean 155 g kg^{-1}).

A frequency effect approached significance (*P* = 0.0535) for total-season IVDOM, and IVDOM tended to be greater for the 6- than the 3-wk frequency (720 vs. 700 g kg^{-1}).

These values are both in the upper range of digestibility that can be achieved in most forage-livestock production systems in the southern region (Ball et al., 2007). In a 2-yr evaluation of RP across a range of harvest frequencies, IVDOM decreased from 750 early to 500 g kg^{-1} in the late season (Saldivar et al., 1990). Decreasing IVDOM was associated with a decline in leaf percentage across the season (Saldivar et al., 1990). Romero et al. (1987) observed a digestibility range of 570 to 610 g kg^{-1} for Florigraze RP hay harvested every 6 to 12 wk.

When comparing seasonal patterns of response, there was a season x frequency interaction ($P = 0.0115$) for IVDOM. From June to October 2012, digestibility decreased more for the 3-wk (730 to 650 g kg^{-1}) compared with the 6-wk frequency (730 to 700 g kg^{-1}). While there were no differences between the 50 and 75% grazing intensity treatments from June through August, late-season percentage IVDOM was greater (season x intensity interaction; $P = 0.0955$) for the 75 than the 50% treatment (690 vs. 670 g kg^{-1}, respectively; $P = 0.0227$). Overall, the impact of grazing management on nutritive value was limited and RP nutritive value was high regardless of grazing treatment.

Pre-grazing Sward Height

There were season x entry ($P = 0.0004$) and season x frequency ($P < 0.0001$) effects for RP pre-grazing sward height (Figures 4-3 and 4-4, respectively). At the beginning of the growing season (June/early July), sward height differences were apparent, with UF Tito being taller (15 cm) than all other entries. Florigraze and UF Peace were similar in height (13 cm), but both were taller than Ecoturf (10 cm). Height differences among entries followed a similar pattern throughout the remainder of the growing season. Pre-grazing sward height was tallest for all entries during late July through August and decreased from September to October. Quesenberry et al. (2010) described UF Tito as an upright ecotype, whereas UF Peace is more intermediate in growth habit like Florigraze. Anderson et al. (2012) evaluated the response of 16 RP selections to sun and shade tolerance, and observed that sward height was more affected by inherent growth characteristics of RP selections than by various shade treatments. The height observations in the present study further support differences in growth habit among released genotypes.

The effect of grazing frequency on sward height differed across the season (Figure 4-2), but this interaction was primarily due to timing of the first grazing event. Height was greater for the 3- than the 6-wk frequency at the beginning of the season because grazing was initiated 1 wk later for the 3-wk treatment than the 6-wk treatment. From mid-July through August, entries grazed every 6 wk were tallest (22 vs. 16 cm), and both treatments achieved their greatest heights during this season. At the end of the growing season, sward height decreased for both frequencies (16 and 12 cm for 6 and 3 wk, respectively), and treatments grazed less frequently achieved a taller height. Maroso et al. (2007) observed similar results for birdsfoot trefoil (*Lotus corniculatus* L.) clipped every 2 or 4 wk to a 4- and 8-cm stubble heights.

Grazing intensity also affected sward height, with the 50% canopy removal treatment having a greater (*P* = 0.0082) pre-grazing sward height (15 cm) compared with the 75% treatment (13 cm). Although these height differences were small, this illustrates that grazing intensity can impact subsequent sward regrowth potential. Regardless of plant growth habit, the longer regrowth interval and greater residual stubble height favored taller sward heights compared to the more intensive management strategies.

Pre-grazing Leaf-to-Stem Ratio

For two sampling dates in 2012, there were date x frequency (*P* = 0.0230), date x entry (*P* = 0.0315), and entry x frequency (*P* = 0.0235) interactions for L:S ratio. In July, a greater L:S ratio was observed for the 6- than the 3-wk frequency (1.7 vs. 1.3, respectively) while in August/early September there was no difference (1.31 vs. 1.27, respectively). This response is unexpected based on typical response for other forages, but it likely reflects the relatively slow regrowth of RP immediately following a defoliation event that results in maintaining a high L:S even through 6 wk. Romero et al. (1987) observed that for fall-harvested RP, L:S ratio was less with a regrowth interval of 6 wk, than for 9 to 12 wk. The authors suggest that this was likely a function of defoliation stress, where a longer regrowth interval was needed to regenerate leaf area. The L:S response is consistent with the trend toward greater IVDOM at 6- than 3-wk defoliation frequency.

Ranking of entries in L:S differed across dates (Table 4-1). Ecoturf had a greater L:S ratio (2.04) during July compared with the more erect-growing ecotypes. UF Tito and Florigraze had a similar L:S ratio (1.75 and 1.67, respectively), and both of them were greater than UF Peace (1.41). In August/early September, although L:S ratio decreased for all entries, Ecoturf and UF Peace had the least change in L:S ratio (1.46 and 1.27, respectively) compared with Florigraze (1.21) and UF Tito (1.17). The decrease in L:S ratio later in the season is likely associated with a decrease in regrowth as herbage accumulation decreased from the beginning to the end of the season, and the presence of residual stem following a defoliation event.

The entry x frequency interaction (Table 4-2) occurred because for the 6-wk defoliation frequency Ecoturf had the greatest L:S ratio (1.87) while for the 3-wk frequency Ecoturf (1.53) and UF Tito had similar L:S ratio (1.50), but both were greater than UF Peace (1.29) and Florigraze (1.33). Ecoturf was the only entry for which L:S was greater at a 6- than a 3-wk grazing frequency. The short canopy height of Ecoturf reduced the contribution from stem, and the amount of leaves associated with the dense-growing canopy resulted in a greater L:S ratio. In more upright growing ecotypes, L:S was decreased because of increased stem growth. In clipping studies with RP harvested every 2-, 6-, or 8-wk, leaves were 60 to 80% of the shoot component of Florigraze RP (Saldivar et al., 1990). Beltranena et al. (1981) reported that leaf fractions of established Florigraze RP declined seasonally when harvested under clipping every 56 d. Thus, increased stem contribution and less leaf regeneration later in the season may decrease L:S ratio. Saldivar et al. (1990) noted that Florigraze RP harvested every 2 wk assumed a prostrate growth habit by mid-season, and was characterized by small leaves that were not readily removed during a defoliation event. When clipped every 6 or 8 wk, RP had elongated stems, and much of the leaf area was removed during harvest. This illustrates that plasticity of RP under defoliation may impact L:S ratio. Weijschedé et al. (2007) observed morphological plasticity among white clover (*Trifolium repens* L.) selections when grown in competition with perennial ryegrass (*Lolium perenne* L.) and managed under clipping every 48 d. Total shoot mass, internode length, petiole length, and total ramet number of clover decreased when clipped compared with the undefoliated control. The authors attribute this to a change in canopy structure from vertical to more horizontal, which illustrates the role of growth habit and degree of plant plasticity in response to differing levels of defoliation management.

Pre-grazing Canopy Light Interception

Light interception was affected by sampling date ($P < 0.0001$), and pre-grazing LI decreased from July (92%) to August/early September (84%). The greater LI occurred during the period of maximum herbage accumulation of RP. Percentage LI was greater ($P = 0.0219$) for Ecoturf, UF Peace, and UF Tito (89, 90, 89%, respectively) than Florigraze (85%). Although differences occurred among entries, these values were relatively high throughout Year 1, and may explain the lack of difference in seasonal herbage accumulation among entries during 2012. Grazing frequency affected LI ($P < 0.0001$), with the 3-wk frequency having reduced LI (85%) compared to 6 wk (91%). Although total HA was not different among grazing frequency treatments, a shorter regrowth interval and lower percentage of LI for the 3-wk frequency decreased herbage accumulation within a grazing cycle compared with RP defoliated every 6 wk.

Post-grazing Residual Leaf Area Index

A date x entry interaction ($P = 0.0384$) occurred for post-grazing RLAI (Table 4-1). UF Peace, UF Tito, and Ecoturf had greater RLAI (mean 1.34) than Florigraze (0.87) during July. However, in August, Ecoturf and UF Peace had greater RLAI (1.07 and 0.98, respectively) following a grazing event than UF Tito and Florigraze (0.75 for both entries). Florigraze had lower pre-grazing canopy LI compared with the other entries from July to September, which may have contributed to a lower post-grazing RLAI. Increasing the intensity of defoliation decreased ($P < 0.0001$) the post-grazing RLAI (0.89 for 75% removal vs. 1.22 for 50%). More photosynthetically active leaf area remaining following a grazing event likely enhances regrowth potential. With fewer leaves for regrowth, defoliated plants rely upon reserves to produce new aboveground growth (Richards, 1993).

Ortega-S. et al. (1992a) observed that canopy regrowth following a defoliation event was greater when RP post-grazing residual dry matter was 1700 kg DM ha^{-1} or more, and that residual leaf area was a primary factor contributing to regrowth under less intense grazing strategies. In the present study, early- and mid-season post-grazing herbage mass ranged from 750 to 1900 kg DM ha^{-1} for the 6-wk frequency, but was ≤ 770 kg DM ha^{-1} for the 3-wk treatment across the 50 and 75% removal intensity treatments. By September and October, postgraze herbage mass decreased to ≤ 700 kg DM ha^{-1} for each frequency x intensity treatment. These values are lower than those recommended by Ortega-S. et al. (1992a), indicating that all treatments were putting significant stress on RP. It is useful to note that greater mid-season height and HA for the 6-wk frequency were associated with greater residual DM as a function of the structure of the grazing management treatments.

Sward Botanical Composition

Composition was measured in June and October 2012 and June 2013. Percentage of sward components was affected by date for RP (P = 0.0001), grass (P = 0.0003), and weeds (P = 0.0001). Percentage RP decreased from 91 to 83%, weeds increased from 5 to 11%, and grass increased from 4 to 7% from June to October 2012. In June 2013, stands consisted of 70% RP, while grass and weed presence increased to 10 and 19%, respectively, from the previous fall. Increased weed percentage from October 2012 to June 2013 may be partially associated with the increased presence of winter annual weeds. In addition, there was no herbicide applied during the experimental period starting from June 2012, so weed encroachment was not controlled during this period.

Hernández-Garay et al. (2004) observed a decrease of 89 to 66% for continuously-stocked Arbrook RP after 3 yr of grazing management, whereas RP percentage was maintained for Florigraze (90 to 87%) during this same time period. The authors suggest that the upright growth of Arbrook made it less tolerant of continuous stocking compared with Florigraze. This illustrates that choice of grazing management may have more long-term impacts on RP stand percentage than observed in Year 1 of the present study.

An entry x frequency interaction (Table 4-3) occurred for percentage of RP and grass ($P = 0.0200$ and $P = 0.0355$, respectively). There were no differences in RP percentage due to defoliation frequency for UF Peace, UF Tito, and Ecoturf, but Florigraze plots had greater RP associated with the 6-wk (84%) compared with the 3-wk frequency (67%). More grass encroachment occurred in Florigraze plots grazed every 3-wk (17%) than those under the longer rest period (6%), but frequency did not impact grass percentage for UF Peace, UF Tito, and Ecoturf. Although bermudagrass rhizomes associated with Florigraze planting material may account for some of the observed response, these data illustrate that a shorter rest period between grazing events increased competition between grass and RP. Ortega-S. et al. (1992a) observed that grass contribution in RP pastures increased with decreasing intervals between grazing cycles and decreasing residual herbage mass. In that study, grass accumulation in Florigraze RP pastures was lowest with a regrowth interval of 21 d or greater, and residual herbage mass of 1500 kg DM ha^{-1}.

Rhizoma Peanut Ground Cover

There were sampling date x frequency ($P < 0.0001$) and entry x frequency interactions ($P = 0.0005$) for RP ground cover. In June 2012 before grazing treatments were imposed, ground cover was greater for plots assigned to the 6-wk (90%) than the 3-wk (79%) grazing interval (Figure 4-5). However, by the end of the grazing season, ground cover increased to 93% for the 3-wk treatment and was greater than that for the 6-wk treatment (87%). At the beginning of the 2013 grazing season, cover did not differ among defoliation frequencies (mean of 92% for both frequencies). For the entry x frequency effect (Figure 4-6), Ecoturf ground cover was greater when defoliated on a 6-wk interval than every 3 wk and achieved a higher cover than all other lines. UF Peace grazed every 6 wk had greater cover than when grazed every 3 wk (96 vs. 86%, respectively). However, the upright growing UF Tito had less ground cover when grazed every 42 d compared with the 21-d frequency (84 vs. 91%, respectively). Percent cover of Florigraze did not differ between frequencies, and was ≥ 80%.

There was entry x frequency interaction ($P = 0.0785$) for change in ground cover from June 2012 to June 2013. Florigraze and UF Peace grazed every 3-wk had a net positive increase in cover (+ 22 and 13%, respectively), while there was less change in cover for the 6-wk frequency (0% for both lines). An increase in ground cover was observed for both the 3-wk (+ 14%) and 6-wk (+ 7%) frequencies for UF Tito, whereas Ecoturf had the least change of all entries across frequencies (+ 4% for 3-wk and 0% for 6-wk frequencies, respectively). These results suggest that intermediate to upright-growing ecotypes may be responding to more frequent grazing by altering their growth habit, resulting in a greater change in cover ratings. Grazing tolerant grasses have been characterized as shifting growth from more upright to decumbent to avoid defoliation

(Chapman and Lemaire, 1993). When managed to maintain a low-level of herbage allowance, Roth et al. (1990) observed plasticity for ‘Coastal' bermudagrass under continuous stocking and four levels of herbage allowance (9, 35, 81, and 148 kg DM [100 kg]$^{-1}$ BW). Under increased grazing pressure, there was increased ground cover and a decrease in the amount of prehensible forage for animals. Thus, increasing forage ground cover can be associated with more intensive or frequent grazing, but the long-term effects of frequent defoliation are not yet clear in the current study.

Weed Frequency

A date x entry interaction (*P* = 0.0110; Figure 4-7) occurred for WF. In June 2012, Florigraze had greater weed occurrence (63%) than all other lines (≤ 38%). Weed frequency decreased for all lines at the end of the 2012 season; however, Florigraze continued to have greater WF (49%) than UF Peace, UF Tito, and Ecoturf (≤ 36%). At the start of Year 2 of the study (June 2013), Florigraze had greater weed occurrence than UF Tito (60 vs. 45%), but did not differ from UF Peace and Ecoturf (55% for each line, respectively). Increased weed encroachment in June 2013 compared with fall of 2012 was likely due to the presence of winter annual weeds in all entries, but the presence of bermudagrass in Florigraze plots contributed toward the higher WF observed for that cultivar.

A date x frequency interaction (*P* < 0.0001; Figure 4-8) occurred for WF. Before treatments were imposed, the 3-wk frequency had greater WF (53%; *P* < 0.0001) than the 6-wk treatment (31%), but WF decreased for both frequencies by October 2012 (34 and 37% for the 3- and 6-wk treatment, respectively). Weed encroachment increased from October 2012 to June 2013, but no differences were observed among frequencies (mean 55%). Grazing intensity affected WF ($P = 0.0184$), with less weed presence for the 50 than 75% canopy removal treatment (41 and 47%, respectively).

There also was entry x intensity interaction for WF ($P = 0.0835$). Weed frequency in Florigraze and Ecoturf was greater ($P = 0.0236$ and $P = 0.0391$, respectively) when 75% of canopy height was removed (62 and 43%, respectively) than when 50% of height was defoliated (52 and 32%, respectively). Weed frequency of UF Tito and UF Peace was less than Florigraze for both the 50% ($P = 0.0002$ and $P < 0.0001$, respectively) and 75% removal treatment ($P = 0.0008$ and $P = 0.0007$, respectively), but they were similar to Ecoturf. Hernández-Garay et al. (2012) observed that for an alfalfa (*Medicago sativa* L.) and orchardgrass (*Dactylis glomerata* L.) mixed pasture under a high grazing frequency (rotational stocking every 25 to 35 d) and intensity (target stubble 3 to 6 cm), forage mass could be increased, but there was greater risk for weed presence when managed more aggressively. Hoveland et al. (1996) conducted a 3-yr evaluation on the effect of harvest frequency on weed encroachment in grazing-tolerant alfalfa cultivars in north Georgia. During Year 3, the authors reported that genotypes harvested every 2 wk had decreased persistence, production potential, and increased bermudagrass and crabgrass (*Digitaria sanguinalis* L.) presence compared to a 4- or 6-wk harvest frequency (Hoveland et al., 1996). Although the observed effects for grazing frequency and intensity were more temporal in the present study (i.e., effects changed with season, etc.), these studies illustrate the potential for more long-term effects of these management strategies on weed encroachment.

When change in WF was evaluated from June 2012 to the beginning of Year 2, it increased (frequency effect; $P < 0.0001$) to a greater degree for the 6- (+ 19%) than for the 3-wk frequency (+ 5%). This occurred because WF was initially greater for the 3-wk treatment, but decreased across the season in 2012, whereas WF increased during this time frame when defoliated every 42 d. Increase in WF among entries (entry effect; *P* = 0.0062) was greater for Ecoturf (+ 24%) and UF Peace (+ 23%) than UF Tito (+ 7%) and Florigraze (+ 5%). These data agree with the botanical composition data from June 2013 that illustrates a decrease in the percentage of RP since the beginning of the experiment in 2012.

Rhizome Mass

Rhizome mass decreased (date effect; *P* = 0.0104) from 4,270 to 3,710 kg DM ha^{-1} from the beginning to the end of the 2012 grazing season. More frequent grazing decreased rhizome mass (*P* = 0.0274), with means for the 3-wk frequency of 3,750 kg ha^{-1} compared with 4,230 kg ha^{-1} for the 6-wk frequency. Ortega-S. et al. (1992b) observed no differences in Florigraze RP rhizome mass following 1 yr of grazing, but during the spring of Year 2, there was a trend for decreasing mass for RP defoliated every 7-d with residual DM of 500 kg ha^{-1}. By the end of Year 2, rhizome mass ranged from 400 to 4100 kg ha^{-1} among treatments. Specifically, the lowest levels of rhizome mass were associated with short regrowth cycles (7 d) and low levels of residual herbage mass (500 kg DM ha^{-1}). Increasing the length of the regrowth cycle (> 7 d) increased rhizome mass when residual herbage mass was 1000 kg ha^{-1} or less. However, for treatments exceeding 1700 kg ha^{-1} residual herbage mass, the effect of less frequent grazing was diminished. Under more frequent and intense defoliation, RP reserve resources decreased in order to sustain forage DM accumulation. Liu et al. (2011a) noted decreased root-rhizome mass for ‘Tifton 85’ bermudagrass from 9090 to 7080 kg ha^{-1} as postgraze stubble height decreased from 24 to 8 cm. Mousel et al.

(2005) quantified root growth and reserve characteristics of big bluestem (*Andropogon gerardii* Vitman) under different levels of grazing intensity and frequency. Root mass, surface area, and volume decreased more when grazed more frequently (< 40 d between rest periods) than under longer recovery periods. Thus, the effect of grazing management strategy can influence root reserves, and similar responses were observed in the present study.

Differences were also observed among entries for rhizome mass ($P < 0.0001$). Ecoturf and UF Tito had greater rhizome mass (4,750 and 4,350 kg ha^{-1}, respectively) than UF Peace and Florigraze (3,200 and 3,660 kg ha^{-1}). Although rhizome mass decreased across the season, there were no differences among entries between dates (date x entry interaction, $P > 0.10$), which suggests that Ecoturf and UF Tito may partition more resources to below-ground growth than UF Peace and Florigraze. These data are also within the range reported for RP entries under clipping or rotational stocking every 28 d in Chapter 3.

Rhizome TNC and N

Rhizome TNC concentration was affected by date x entry interaction ($P = 0.0424$). Grazing treatments did not affect TNC concentration during the first year of the study. In June 2012 before grazing treatments were imposed, no differences were observed among entries and TNC concentration ranged from 104 to 126 g TNC kg^{-1} DM. An interaction was observed because TNC concentration decreased from June to October (126 vs. 99 g TNC kg^{-1}) for UF Tito, but TNC concentration was similar among all other lines across the season (mean 110 g TNC kg^{-1} DM in October). Although rhizome mass of UF Tito did not decrease across the season, decreased TNC concentration in the fall may be attributed to reallocation of resources for canopy regeneration.

Saldivar et al. (1992) reported that TNC concentration was low and variable in Florigraze under clipping every 2, 6, or 8 wk, but ranged from 100 to 200 g kg^{-1} during the summer growing season. Beginning in November, RP TNC concentration began to increase to levels > 400 g kg^{-1}. Ortega-S. et al. (1992b) observed 68 to 154 g kg^{-1} TNC for Florigraze RP rhizomes across a range of grazing frequencies (7 to 63 d regrowth) and intensities (residual DM 500 to 2500 kg ha^{-1}) following 1 yr of management. After 2 yr of grazing, TNC concentration ranged from 58 to 210 g kg^{-1}, and was influenced by grazing cycle length and post-grazing residual DM. Rhizome TNC concentration increased with increasing grazing cycle length when residual DM was ≤ 1,000 kg ha^{-1}, but the effect of grazing frequency was neglible when post-grazing herbage mass remaining was ≥ 1,700 kg ha^{-1}. During both years of the study, the lowest TNC concentration was associated with low residual herbage mass (500 kg ha^{-1}). Thus, the TNC values reported in the present study are relatively low, but fall within this observed range following 1 yr of management.

A date x entry interaction (*P* = 0.0178) occurred for rhizome N concentration. Mean N concentration was ≥ 18 g kg^{-1} for all lines in June 2012, and did not differ among entries. Florigraze maintained a similar N concentration across the season (18 g kg^{-1}) , whereas N decreased to ≤ 5 g kg^{-1} DM for UF Tito, Ecoturf, and UF Peace from June to October. These values are similar to Ortega-S. et al. (1992b) who reported 13 to 16 g kg^{-1} for RP rhizomes with post-grazing residual herbage mass from 500 to 2500 kg ha^{-1}. Although N concentration changed across dates, there was no effect of grazing frequency or intensity on rhizome N. While changes in the amount of rhizome storage carbohydrates occur more readily under different levels of defoliation (Saldivar et al., 1992; Rice et al., 1995), N concentration has been observed to be a more transient compound used in respiration that is not stored in a large concentration (Richards, 1993), which may make treatment differences less prevalent.

Implications of the Research

Grazing management strategies were observed to impact sward characteristics of RP genotypes during Year 1 of the study. Although there were no differences among grazing treatments for total HA, similar or greater leaf-to-stem ratio and pre-grazing light interception, and maintenance of a high percentage of ground cover with the 6-wk frequency suggest an advantage for longer regrowth intervals. Greater RLAI, less WF, and trends for greater pre-grazing sward height associated with the 50 vs. 75% removal level may favor RP persistence. Increased cover for the 3-wk frequency at the end of Year 1 may be associated with canopy structural adaptation of RP genotypes under short regrowth cycles. A second year of evaluation is being conducted through summer 2013 to quantify continuing changes in sward canopy characteristics of entries under these strategies.

The results indicate that while total HA was not affected by grazing management strategy in Year 1, changes in other above and below-ground sward characteristics suggest that RP genotypes may favor a 6- vs. a 3-wk regrowth interval and that these differences may become more pronounced over time. Selection of RP genotypes that exhibit grazing tolerance through increased production, persistence, and nutritive value will likely increase the use of these entries in pastures by producers.

Table 4-1. Date x entry interaction for rhizoma peanut leaf-to-stem ratio ($P = 0.0315$) and post-grazing residual leaf area index ($P = 0.0384$; RLAI). Data are means across two grazing intensities, two frequencies, and three replicates (n = 8).

	Leaf-to-stem ratio			Post-grazing RLAI		
Entry	July	Aug./Sept.	*P* value	July	Aug./Sept.	*P* value
Ecoturf	2.04^{a}[†]	1.46^{a}	<0.0001	1.33^{a}	1.07^{a}	0.0249
Florigraze	1.67^{b}	1.22^{b}	0.0003	0.87^{b}	0.73^{b}	0.2232
UF Peace	1.41^{c}	1.27^{ab}	0.2291	1.38^{a}	0.99^{a}	0.0011
UF Tito	1.75^{b}	1.18^{b}	<0.0001	1.34^{a}	0.75^{b}	<0.0001
SE	0.09	0.10		0.11	0.12	

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

Table 4-2. Entry x frequency interaction ($P = 0.0235$) for rhizoma peanut leaf-to-stem ratio. Data are means across two dates, two grazing intensities, and two replicates (n = 8).

	Frequency (wk)		
Entry	3	6	*P* value
Ecoturf	1.53^{a}[†]	1.87^{a}	< 0.01
Florigraze	1.33^{b}	1.56^{b}	0.06
UF Peace	1.29^{b}	1.40^{b}	0.39
UF Tito	1.50^{a}	1.43^{b}	0.59
SE	0.07	0.07	

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

Table 4-3. Entry x frequency interaction for percentage of rhizoma peanut ($P = 0.0200$) and grass ($P = 0.0355$) in total herbage mass above the target stubble height. Data are means across two grazing intensities and two replicates (n = 4).

	Rhizoma peanut			Grass		
	Frequency (wk)			Frequency (wk)		
	3	6		3	6	
Entry	--------------%--------------		*P* value	--------------%--------------		*P* value
Ecoturf	84^{a}[†]	85	0.5461	8^{b}	3	0.7670
Florigraze	67^{b}	84	<0.0001	17^{a}	6	<0.0001
UF Peace	82^{a}	84	0.2970	5^{b}	3	0.8849
UF Tito	80^{a}	84	0.5607	7^{b}	6	0.9785
SE	4	4		2	2	

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

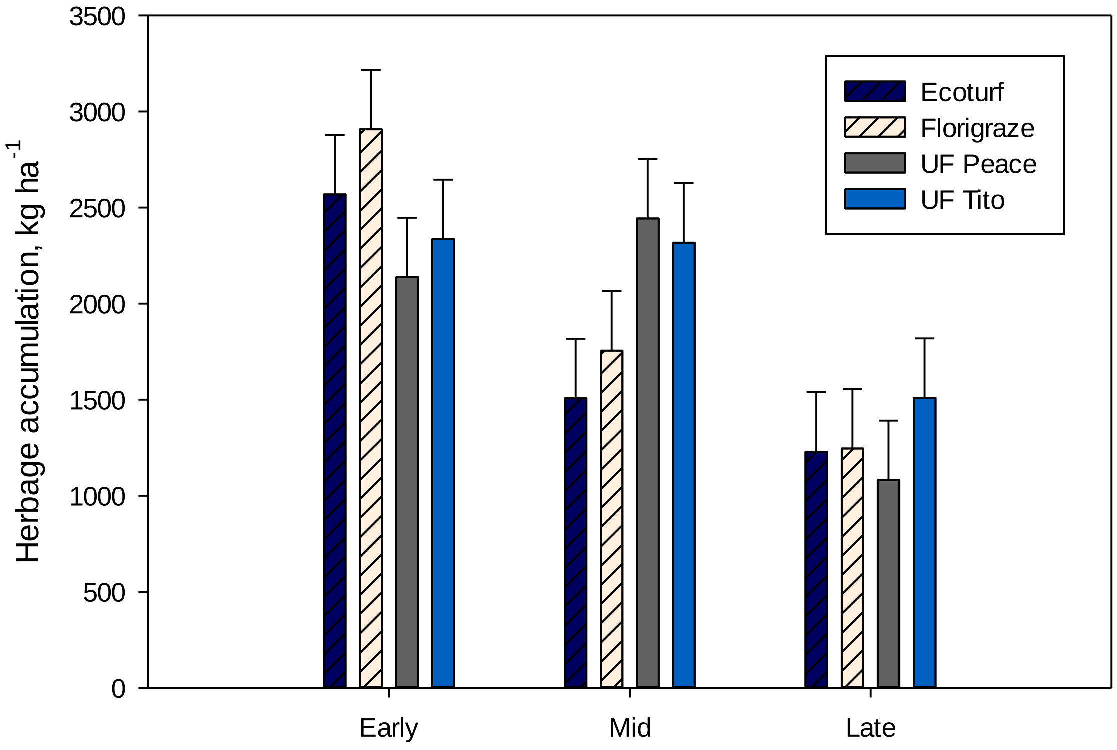

Figure 4-1. Season x entry interaction (*P* = 0.0124) for herbage accumulation (kg DM ha^{-1}) of RP genotypes. Early, mid-, and late-season dates correspond to June/early July, late July/August, and September/October, respectively, in 2012. Data are means across two grazing intensities, two grazing frequencies, and two replicates (n = 8).

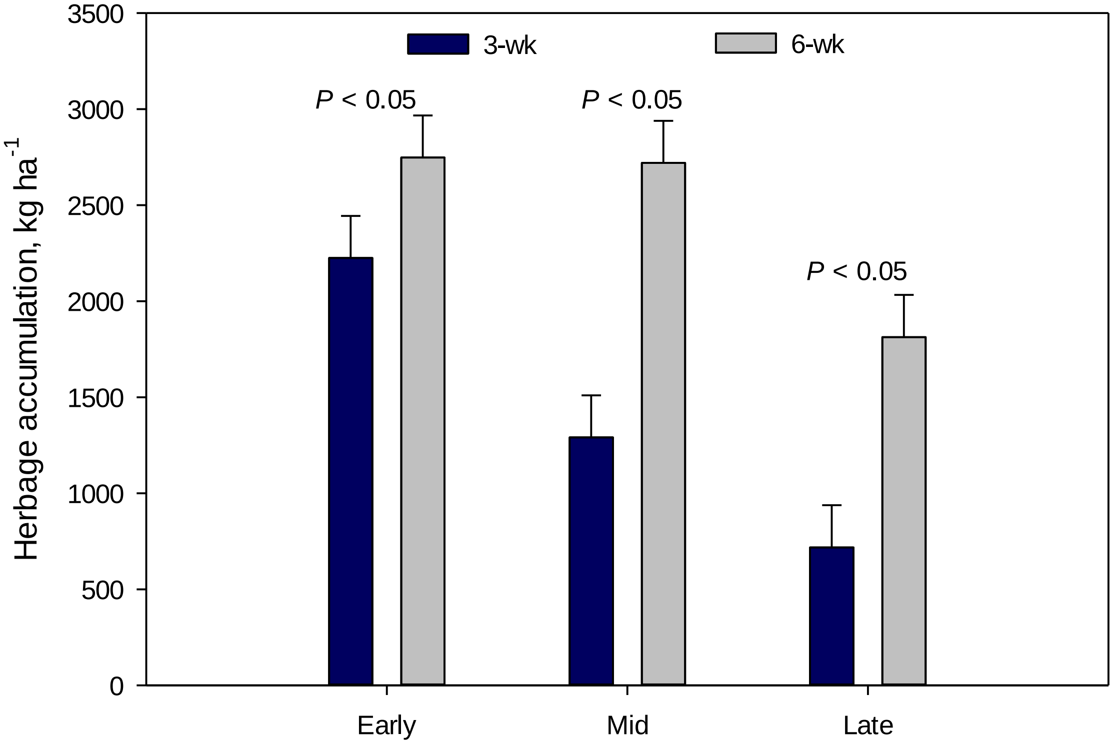

Figure 4-2. Season x grazing frequency ($P = 0.0183$) interaction for rhizoma peanut herbage accumulation. Early, mid- and late-season dates correspond to June/early July, late July/August, and September/October, respectively, in 2012. Data are means across four rhizoma peanut entries, two grazing intensities, and two replicates (n = 16).

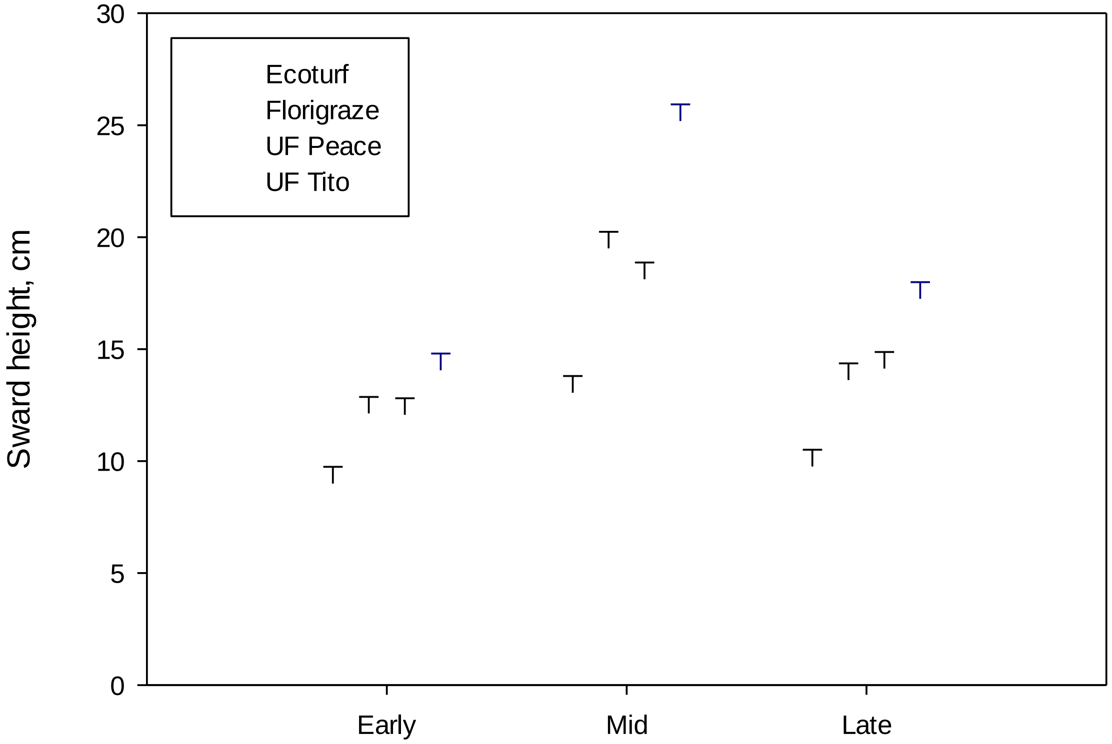

Figure 4-3. Season x entry interaction (*P* = 0.0004) for pre-grazing sward height of RP genotypes under different levels of grazing management. Early, mid-, and late-season dates correspond to June/early July, late July/August, and September/October, respectively, in 2012. Data are means across two grazing frequencies, two grazing intensities, and two replicates (n = 8).

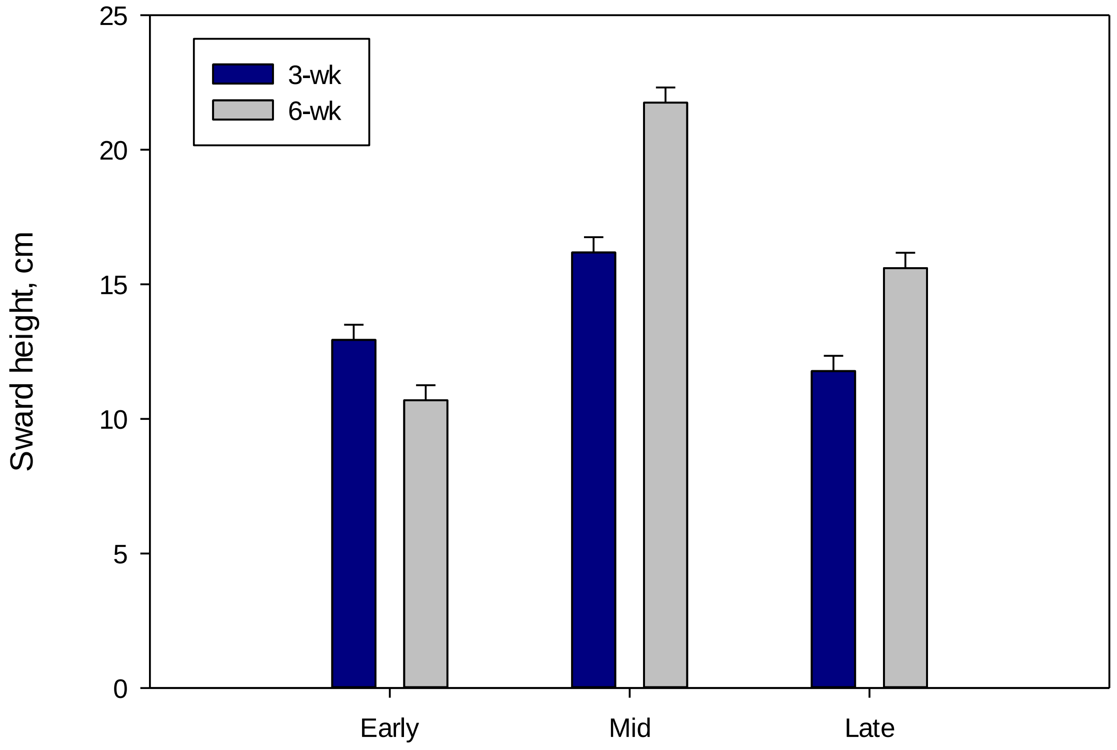

Figure 4-4. Season x grazing frequency interaction (*P* < 0.0001) for pre-grazing rhizoma peanut sward height. Early, mid-, and late-season dates correspond to June/early July, late July/August, and September/October, respectively, in 2012. Data are means across four rhizoma peanut entries, two grazing intensities, and two replicates (n = 16).

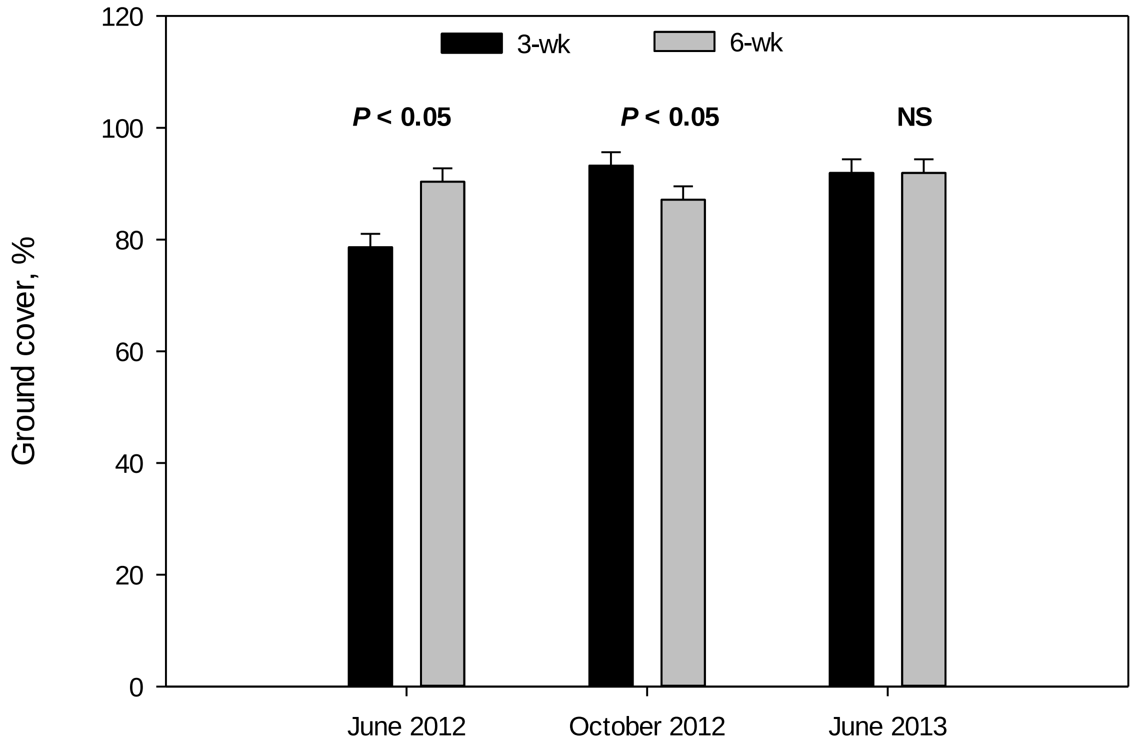

Figure 4-5. Date x grazing frequency interaction ($P < 0.0001$) for ground cover of rhizoma peanut entries. Data are means across four rhizoma peanut entries, two grazing intensities, and two replicates (n = 16).

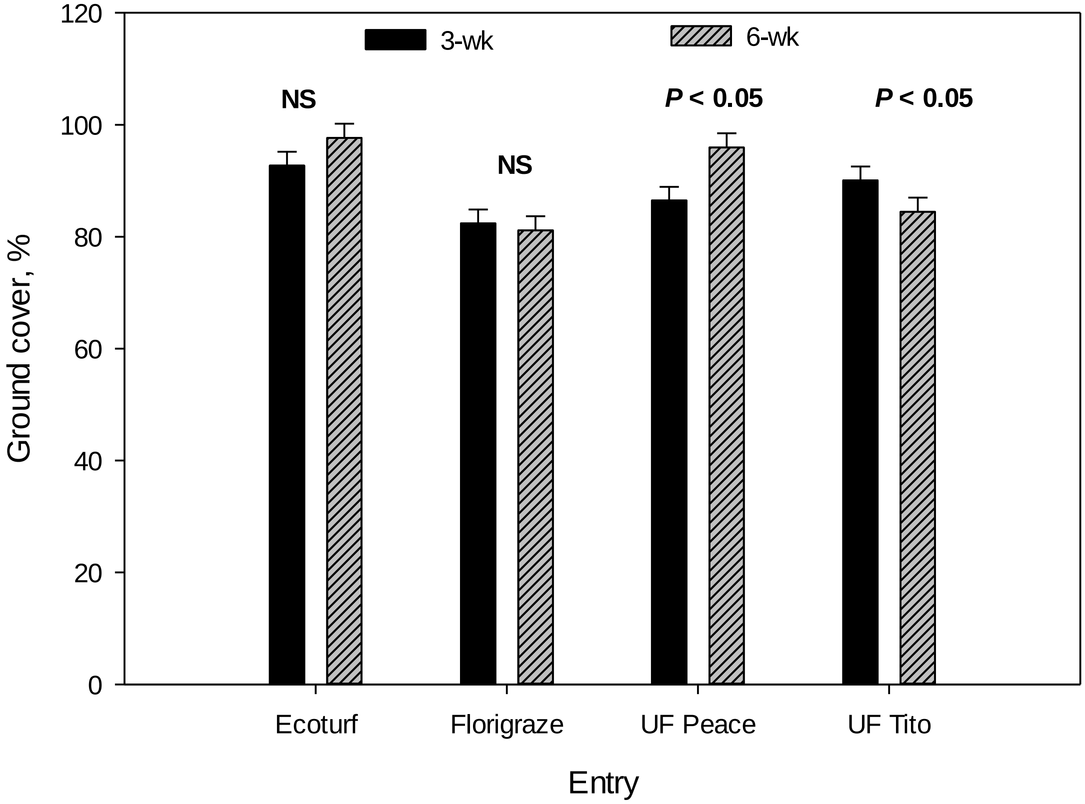

Figure 4-6. Entry x grazing frequency interaction (*P* = 0.0005) for ground cover of rhizoma peanut entries. Data are means across two grazing intensities, three dates, and two replicates (n = 12).

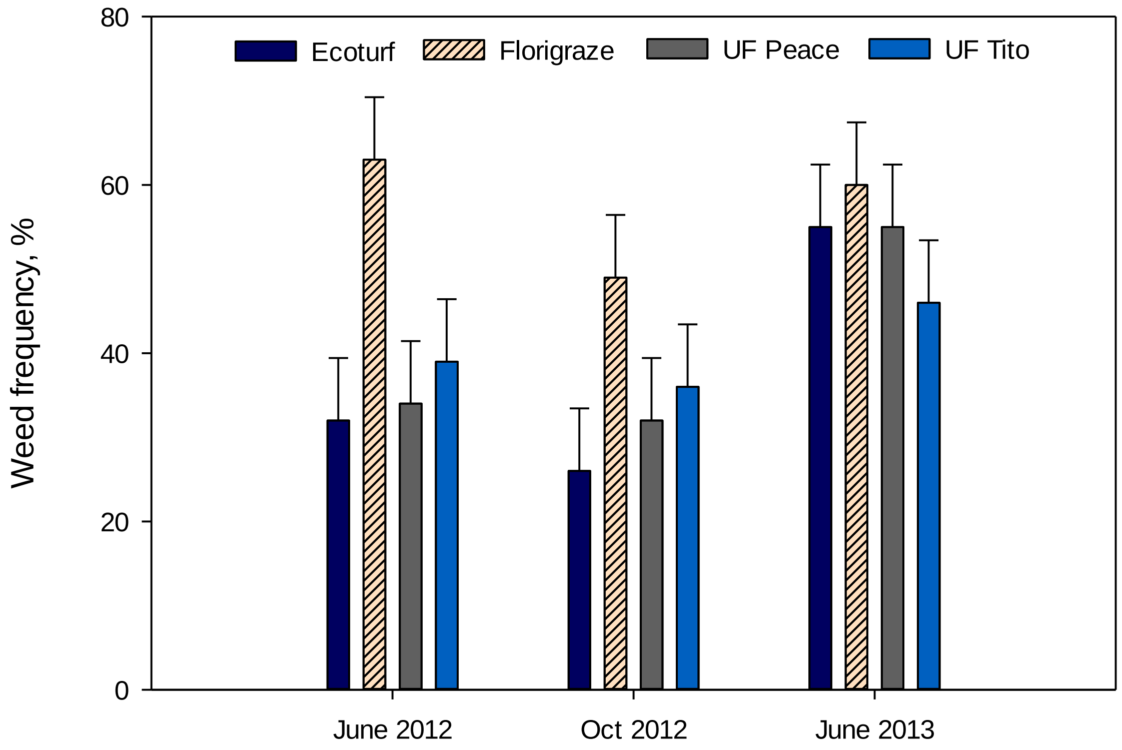

Figure 4-7. Date x entry interaction (*P* = 0.0110) for frequency of weed occurrence in rhizoma peanut under different grazing regimes. Data are means across three dates, two grazing intensities, and two replicates (n = 12).

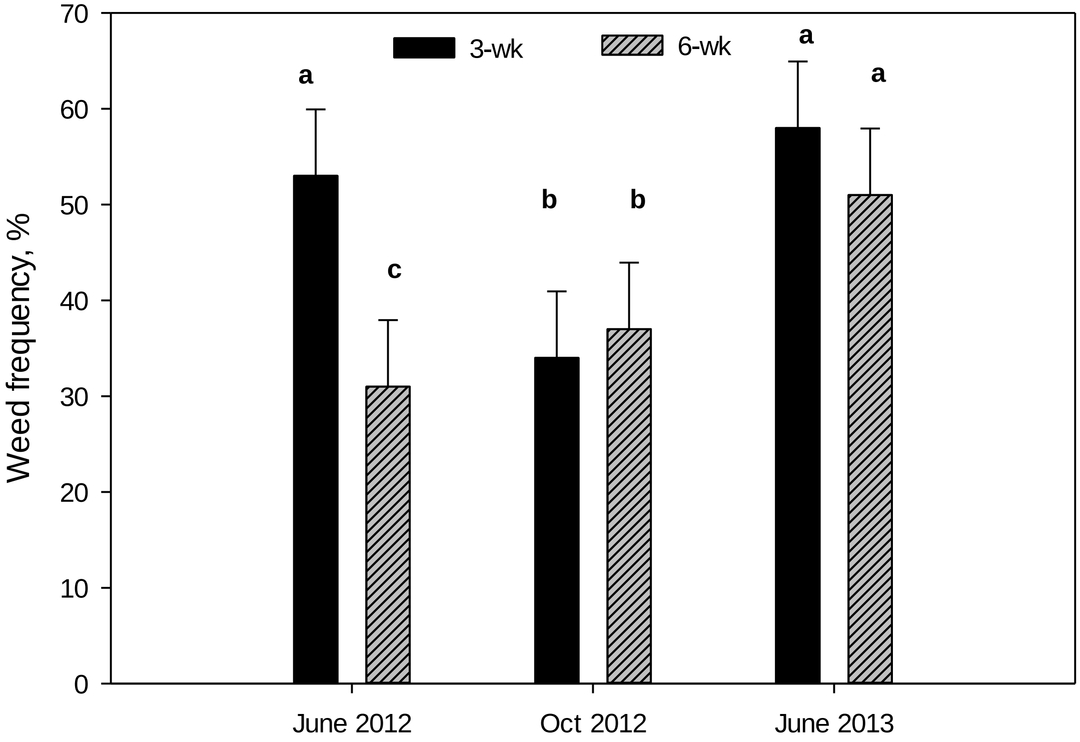

Figure 4-8. Date x grazing frequency interaction ($P < 0.0001$) for frequency of weed occurrence in rhizoma peanut swards. Data are means across four entries, two grazing intensities, and two replicates (n = 16).

CHAPTER 5
DEFOLIATION MANAGEMENT AND SOIL CARBON DYNAMICS OF VARIOUS PRODUCTION SYSTEMS BASED ON WARM-SEASON PERENNIAL FORAGES

Overview of Research

In addition to their role as a source of feed for livestock, grasslands are increasingly being evaluated in terms of the ecosystem services they provide. An example of a particularly critical ecosystem function is the major role grasslands play in the global C cycle. They serve as an important C sink, with approximately 22% of global soil C stores existing under grassland (Soussana et al., 2004), and it is estimated that as much as 90% of C stored in grassland ecosystems is below ground (Schuman et al., 2001).

Soil C can accumulate when agricultural land is removed from annual row-crop cultivation and planted with perennial grasses (Post and Kwon, 2000; Conant et al., 2001), but it has been suggested that there is also an important role of management in affecting the ability of a grassland to increase soil C sequestration (Silveira et al., 2013). In a meta-analysis of grazing effects on soil C sequestration, McSherry and Ritchie (2013) reported that both vegetation type and grazing intensity strongly influence soil organic C storage potential of grasslands. In support of the conclusions of McSherry and Ritchie (2013), Franzluebbers and Stuedemann (2009) found that management of grass-based forage systems, e.g., N fertilization, haying vs. grazing, and grazing at a range of stocking rates, affects their potential to store soil C. Thus, a key consideration for future research is whether forage systems and their management practices can be designed to maintain forage production while also increasing contribution to soil C and ecosystem sustainability.

There are significant gaps in the literature relative to the effect of grassland production systems on soil C. Specifically, little attention has been given to perennial legume-based pasture systems. In addition, the effects of defoliation management, vegetation type, and their interaction on soil C have been less explored in sandy soil conditions like those of Florida relative to fine-textured soils. This information is needed to understand the potential for C sequestration in large areas of the USA Gulf Coast region.

Thus, the objectives of this study were to quantify the effects of defoliation management and winter overseeding of forage systems based on rhizoma peanut (*Arachis glabrata* Benth.; RP) or N-fertilized ‘Tifton 85’ bermudagrass (*Cynodon* spp.) on herbage production and short-term soil organic C and N responses after land conversion from row cropping. This experiment is expected to identify management techniques which promote sustainable grassland production systems and begin to quantify the capacity of USA Gulf Coast grassland systems as a C sink. Also, the research project will provide producer recommendations for winter overseeding in, and grazing management practices for, RP and bermudagrass systems.

Materials and Methods

Experimental Site

The experiment was planted in 2011 and treatments were imposed starting in fall 2011 and continuing through fall 2013 at the University of Florida Plant Science Research and Education Unit in Citra, FL (29.24°N, 82.10°W). For the purposes of this chapter, only data from the cool and warm seasons of 2011-2012 and the cool season of 2012-2013 will be reported.

The site was chosen because it was previously under long-term (> 5 yr) crop production until the planting of ‘Pensacola’ bahiagrass (*Paspalum notatum* Flügge) in March 2010. The area was managed extensively during the 2010 growing season, and because rainfall was limited during the summer at this location, the bahiagrass stand did not establish well and much of the area was occupied by weeds or bare ground by the end of the 2010 growing season. On 1 Feb. 2011, a 0.6-ha portion of this area was plowed and heavily disked to ensure a well-prepared seedbed for establishing the perennial forages upon which the systems were based.

Soils at the site consist of a Placid fine sand (sandy, siliceous, hyperthermic Typic Humaquepts) and Tavares sand (hyperthermic, uncoated Typic Quartzipsamments). Prior to planting, soil samples were taken to a depth of 15 cm within each plot and analyzed by the University of Florida Extension Soil Testing Laboratory. Initial soil organic Cto 15 cm for the experimental area at large was 9.4 g kg^{-1}. Soil pH was 5.7 and Mehlich-1 extractable P, K, Mg, and Ca were 26, 17, 18, and 295 mg kg^{-1}, respectively. Just prior to land preparation on 1 Feb. 2011, 910 kg ha^{-1} of dolomitic lime was applied.

Treatments and Experimental Design

Treatments were replicated three times in a split-plot arrangement, with main plots allocated in a randomized complete block design. Perennial species was the main plot and the two species used were Tifton 85 bermudagrass (BG) or ‘Florigraze’ RP. Within each main plot there were five production systems for a total of 10 treatments. The five production systems (Table 5-1) consisted of i) summer hay production of the warm-season forage and no overseeded cool-season forage (SH-No); ii) hay production of the warm-season forage during summer and of overseeded ‘Florida 401’ rye (*Secale* *cereal*e L.) during winter (SH-WH); iii) grazing of the warm-season forage during summer and no overseeded cool-season forage (SG-No); iv) grazing of the warm-season forage during summer and of overseeded rye during winter (SG-WG); and v) hay production of the warm-season forage during summer followed by grazing of overseeded rye during winter (SH-WG). The SH-WG treatment was included because there are many RP and Tifton 85 hay producers in the region, and overseeding hay fields for winter grazing is a feasible practice. It is important to determine if soil organic C (SOC) accumulation will be increased by overseeding rye and grazing during winter compared with allowing the hay field to remain dormant during winter.

Overseeded plots were defoliated during winter according to practices associated with each production system. Winter grazing occurred when rye reached a 30-cm height and every 4 to 5 wk thereafter through the early spring. Grazing treatments were imposed beginning on 17 Jan. 2012 and 23 Jan. 2013. Postgrazing target stubble height was 10 cm. In the hay treatment, rye was harvested when it reached 30 cm of height and every 4 wk until the boot stage was reached in the spring. The final harvest was made at this time. Clipping was initiated on 24 Jan. 2012 and 23 Jan. 2013. For both grazed and clipped treatments, there were three defoliation events in 2012 and two in 2013.

During the summer of 2012, hayed RP and BG areas were harvested every 4 wk to a cutting height of 10 cm. Experimental units under hay production were cut using a disk mower and raked to remove harvested material from the plot area. Grazed areas were also defoliated on a 4-wk frequency, but the target postgraze stubble height was 15 cm for both species. Animals grazed individual experimental units separately, and grazing activity was monitored until the target stubble height was reached or when animals ceased grazing. Because animals were not fasted prior to grazing and were not accustomed to grazing small pastures, multiple grazing events over several days were sometimes needed to approach the target postgraze height, but it was not always achieved. Animals typically were left on the plots for ≥ 2 hr per grazing event. Grazing was initiated on 23 May 2012 for BG plots and occurred monthly until October. Clipping of BG hay treatments began on 25 May 2012 and occurred monthly until the end of the season in October. Rhizoma peanut plots were defoliated beginning in August 2012 when they first achieved a 20-cm stubble height. Grazing and clipping treatments were imposed beginning on 7 Aug. and 14 Aug. 2012, and monthly thereafter until October.

Plot Establishment and Management

Warm-season perennial species main plots were planted individually and each occupied an area of 35 x 13 m. Areas planted to RP were established using Florigraze rhizomes at a planting rate of 1000 kg ha^{-1} and a commercial planter (4-row planter with 50 cm between rows) on 5 Apr. 2011. On 2 June 2011, RP plots were fertilized to supply 15 kg P and 55 kg K ha^{-1} according to soil test recommendations. Tifton 85 BG was planted on 9 June 2011 using above-ground stems. Stems were harvested from an existing foundation block of Tifton 85 at the research unit, transported to the experimental site, and spread evenly across the area by hand. Sprigs were then disked into the soil and the soil was firmed with a cultipacker. Bermudagrass main plots were fertilized with 45 kg N ha^{-1} using ammonium sulfate on 5 July 2011 and 45 kg N ha^{-1} using ammonium nitrate on 8 Aug. and 1 Sept. 2011 to enhance grass establishment and spread. Main plots were divided into five 7- x 13-m subplots to accommodate the five production system treatments. Arrangement of areas planted to the respective species is described below and in Figure 5-1.

Overseeded treatments were planted with Florida 401 rye at a rate of 110 kg ha^{-1} on 8 Nov. 2011 and 13 Nov. 2012. Plots that were not overseeded to rye were not defoliated during winter and did not receive any fertilization. For all areas overseeded with rye, 30 kg N ha^{-1} was applied on 30 Nov. 2011 and 28 Nov. 2012 after seedlings had emerged. In winter 2012, grazed and hayed areas also received 30 kg N ha^{-1} on 24 January and 21 February following defoliation events. Phosphorus was applied at a rate of 15 kg ha^{-1} and K was applied at 55 kg ha^{-1} on 21 Feb. 2012. During the winter 2013 season, 30 kg N ha^{-1} was applied on 23 January, but no additional N fertilizer was applied due to relative poor establishment and vigor of rye in that year. No P and K were applied in winter 2013.

For BG plots, 45 kg N ha^{-1} as ammonium nitrate was applied on 3 Apr. 2012 to promote spring growth. Defoliation of grazed and hayed treatments was initiated on 23 and 25 May 2012, respectively, and the final grazing and clipping events of the season occurred on 8 and 9 Oct. 2012. Nitrogen fertilizer was applied monthly to all BG plots following a defoliation event at a rate of 45 kg N ha^{-1} for a warm-season total of 225 kg N ha^{-1} yr^{-1}. Rhizoma peanut and BG plots were fertilized with muriate of potash at a rate of 55 and 75 kg K ha^{-1}, respectively, on 4 June 2012 according to soil test recommendations.

Herbicide applications occurred throughout the establishment period and during the experiment to control encroaching broadleaf weeds and grasses. Rhizoma peanut main plots were sprayed with ammonium salt of imazapic (0.07 kg a.i. ha^{-1}; Impose^{TM}, MANA, Raleigh, NC) on 23 May 2011, clethodim (SelectMax®, Valent, Walnut Creek, CA) on 6 July 2011, and imazapic (0.07 kg a.i. ha^{-1}) + 2,4-D (0.26 kg a.i. ha^{-1}; dimethylamine salt of 2,4-D-dichlorophenoxyacetic acid) on 2 Apr. 2012. Aminopyralid and 2,4-D (GrazonNext™; rate 1.10 kg a.i. ha^{-1}; Dow AgroSciences, Indianapolis, IN) were applied on 15 Sept 2011 and Chapparal™ [rate 0.12 kg a.i. ha^{-1}; aminopyralid and metsulfuron methyl; Dow AgroSciences) on 2 Apr. 2012 to BG plots.

Irrigation was applied during establishment and occasionally throughout the experimental period to supplement rainfall when it was less than the 30-yr monthly average. During establishment in 2011, total irrigation applied was 50, 38, 50, 20, and 25 mm during April, May, June, July, and November, respectively. During 2012, 25 mm was applied each month in April, May, and September.

Response Variables

Herbage Mass, Accumulation, and Harvested

Herbage mass from both summer and winter forage components was measured prior to each grazing or haying event. In the hayed treatments, a 2- × 1-m area was harvested using a sickle bar mower to a 10-cm stubble height, weighed fresh, subsampled for DM determination, and dried. In the grazed treatments, pre-grazing and post-grazing herbage mass was determined for all grazing events. The double sampling technique used settling height of an aluminum disk as the indirect measure and hand clipping to 5-cm stubble as the direct measure for pre- and post-grazing samples during the winter and a 10-cm stubble in the summer. The disk was calibrated at each grazing event by taking both indirect and direct measures from two 0.25-m^2 quadrats per plot. Twenty indirect measures were taken pre- and post-grazing at each grazing event using a stratified site selection approach (fixed distance between disk drops so that the pasture was well represented). The average disk height of the 20 measures was inserted into a calibration equation to predict herbage mass, and the resultant values were used to calculate herbage accumulation and harvested. Grass and legume herbage accumulation was measured as the difference between herbage mass after a defoliation event and prior to the next defoliation event. Herbage harvested was calculated as the difference between pre-grazing and post-grazing herbage mass of the same grazing cycle.

Herbage Nutritive Value

For each grazed pastures, 10 hand-plucked samples were taken to a 10-cm stubble height prior to a grazing event during the winter and to a 15-cm height during the summer management season. Locations were selected in a grid pattern to represent the entire plot, and individual samples were harvested using hand shears to the target stubble. The 10 samples were composited for subsequent grinding and laboratory analysis.

For the haying treatments, a subsample was taken from the DM sample (clipped to 10-cm stubble) for determination of nutritive value. Samples were dried at 60˚C until constant weight.

Nutritive value analyses included crude protein (CP) and in vitro digestible organic matter (IVDOM) concentrations. Crude protein was measured using a micro-Kjeldahl technique for N (Gallaher et al., 1975) and the two-stage technique for IVDOM (Moore and Mott, 1974). In winter 2012, samples from each defoliation event were analyzed for CP and IVDOM. For the summer systems, samples from each species x system treatment were selected from the August and October harvest dates and analyzed. Data from each defoliation event for winter 2013 is reported for CP.

Residual Litter Mass, C and N Concentration, and C:N Ratio

Litter in this study was defined as the post-harvest stubble plus dead plant biomass on the soil surface. Litter mass sampling occurred at the end of the 2012 and 2013 winter grazing/haying period and at the end of the 2012 summer grazing/hay season prior to overseeding rye. The purpose of this measurement was to quantify the amount of plant material remaining above ground that could potentially contribute to soil C. Four 0.25-m^2 quadrats were sampled per experimental unit. Sites for sampling were chosen to reflect average stubble mass. Plant stubble was harvested to soil level and collected with dead plant biomass within a quadrat to provide a single sample. Plant litter was bagged and dried at 60°C until dry.

Litter C and N concentration were determined from winter 2012 and summer 2013 samples. Total organic C and total N were determined by dry combustion using a Flash EA 1112 C/N analyzer. The amount of C and N in litter was calculated as the litter mass (kg DM ha^{-1}) multiplied by the percentage of C and N, respectively. Finally, litter and stubble C:N ratio were calculated for each treatment. The C:N ratio was determined as the g kg^{-1} of C divided by the g kg^{-1} of N.

Root-rhizome Mass

Root-rhizome mass was quantified immediately after the last grazing event in October 2012 (following one winter and summer of management). Five samples were taken per experimental unit using a 10-cm diameter soil coring device to a depth of 20 cm. Root cores were washed and dried to constant weight at 60°C.

Soil C and N

Soil bulk density samples were collected from each experimental unit prior to treatments being imposed in 2011 and for surface layers (0 to 10 and 10 to 20 cm) at the end of 1 yr of imposing treatments in fall 2012. In 2011, two undisturbed soil cores were collected to a depth of 100 cm in each experimental unit for bulk density determination. Three additional cores were augured from each experimental unit to provide sufficient sample for C and N analysis. The soil cores were taken to a depth of 100 cm and divided into layers of 0 to 10, 10 to 20, 20 to 40, 40 to 70, and 70 to 100 cm. Samples from these layers were dried at 105°C for ≥ 3 d, and bulk density was determined using soil from the undisturbed cores as the total dry weight of the soil divided by the volume of the coring device. For the initial soil samples in 2011, total organic C and total N of each soil layer were determined by dry combustion using a Carlo Erba NA-1500 C/N/S analyzer on subsamples ground in a ball mill for 5 min. Final sampling for bulk density and total C and N will occur at the end of summer 2013 following 2 yr of each management system.

Aggregate Size Distribution

Distribution of soil size classes was determined for samples from experimental units under year-round grazing or haying (Treatments SG-WG and SH-WH). A 50-g sample was taken before planting and 1 yr after initiation of treatments (October 2012) from the 0- to 10-cm and 10- to 20-cm soil layers. Samples were sieved through a 2-mm screen and particles greater than 2 mm were discarded. Aggregate separation was done by wet sieving through two sieves (250 and 53 µm) according to the procedure of Six et al. (1998). This allowed for separation into three particle size classes of ≥ 250, 53 to 250, and ≤ 53 µm, which represent macroaggregates, fine sand and silt-size microaggregates, and silt-plus clay-size particles, respectively (Cambardella and Elliot, 1994; Six et al., 2004). After sieving, samples were dried at 60°C, weighed, and analyzed for C and N using a Flash EA 1112 C/N analyzer.

Statistical Analysis

Data were analyzed using PROC MIXED of SAS (SAS Institute, Cary, NC, 1996). Data are reported for the winter seasons of 2012 and 2013 and the summer season of 2012 only. Species, management system, year, and their interactions were considered fixed effects. Block and block × species interaction were considered random effects. Species was the main plot and forage system the sub plot in the randomized complete block design. Means were compared using the PDIFF option of LSMEANS. Differences were declared when $P \leq 0.05$, and trends were evaluated when $P > 0.05$ and ≤ 0.10. Interactions were described when $P \leq 0.10$. Where multiple observations of a response occur across intervals of time, observation date was considered a repeated measure. Because of the presence of unequal variances, herbage harvested data were log transformed. Non-transformed means are reported, and transformed values were used for statistical comparisons.

Results and Discussion

Plant Responses

Herbage harvested

Across the 2-yr observation period for winter rye production, there were species x system (Table 5-2; $P = 0.0013$) and year x system (Table 5-3; $P < 0.0001$) interactions for herbage harvested. When BG was overseeded with rye, SH-WH had greater herbage harvested (1080 kg ha^{-1}) than SG-WG (480 kg ha^{-1}) and SH-WG (580 kg ha^{-1}) treatments. Overseeded RP followed a similar pattern, and rye harvested for hay had greater total herbage harvested at the end of the season (1350 kg ha^{-1}) than grazed treatments (270 and 248 kg ha^{-1} for SG-WG and SH-WG, respectively). Rye production decreased in 2013 compared with 2012. Differences among forage management systems were apparent in Year 1, and hay treatments produced more herbage harvested (2060 kg ha^{-1}) than those under rotational stocking (500 and 360 for SG-WG and SH-WG, respectively). No differences were observed among systems in Year 2, and mean rye harvested was 390 kg ha^{-1}. Decreased rye production in Year 2 was primarily associated with weak stand establishment which reduced production and the number of defoliation events compared with Year 1. Moyer and Coffey et al. (2000) suggested that early small grain growth could be suppressed by competition or inhibitory effects of bermudagrass sod when interseeded. The practice of interseeding also reduces production potential of small grains to a greater degree than when grown in monoculture in a prepared seedbed (Utley et al., 1976). Although rye herbage harvested in the present study is lower than reported yields of Florida 401 in the literature (Day et al., 2012), this experiment illustrates the potential for utilizing overseeding of dormant warm-season forage systems as a means to provide winter forage.

A species x system interaction (Table 5-4; $P < 0.0001$) occurred during summer 2012. Bermudagrass herbage harvested was greater when harvested for hay every 28 d than when grazed. Decreased herbage harvested for grazed BG in the present study is primarily a function of the inability to achieve the target postgraze stubble height during a grazing event. However, the reported values for herbage harvested for hay treatments are within the range reported in the literature. Forage production potential of Tifton 85 bermudagrass varies with harvest frequency and intensity (Pedreira et al., 1999). Mislevy and Martin (1998) reported mean total season production of 13 700 kg ha^{-1} for Tifton 85 under a 2-, 4-, 5-, or 7-wk grazing frequency. In a 2-yr evaluation of the effect of harvest frequency (21, 24, 27, or 35 d) and post-harvest stubble height (8 or 16 cm) on Tifton 85 herbage production, Clavijo et al. (2010) observed herbage harvested of 7900 kg ha^{-1} for BG clipped every 27 d. First harvest of RP did not occur until August 2012, and was during the year-after-establishment, which explains reduced herbage production potential compared with other RP studies (Butler et al., 2007; Mislevy et al., 2007). Differences were observed among RP-based forage systems, and clipped RP had less total herbage harvested (mean 270 kg ha^{-1}) than grazed treatments (mean 930 kg ha^{-1}).

Based on these data, there was no apparent reduction in herbage harvested in the summer for winter-overseeded treatments compared with no overseeding. When Florida 401 was released, Pfahler et al. (1986) noted 50% greater herbage production during the early winter season compared with other varieties at the time of release, and similar production levels by mid-season. Because of the early-season production potential of this cultivar, this may have reduced competition with spring growth of warm-season perennials and avoided a negative impact on herbage production.

Nutritive value

In winter 2012, there was an effect of date ($P < 0.0001$) and date x system ($P = 0.0172$) on rye nutritive value. Crude protein decreased for rye across sampling dates (240 to 165 g kg^{-1} DM from January to March, respectively). The interaction occurred (Figure 5-2) because CP was not different among treatments in January (mean 235 g kg^{-1}), but CP was greater for SG-WG than SH-WH in February (222 vs. 187 g kg^{-1}, respectively), and was greater for both grazed treatments than the hay treatment in March (190 and 185 for SH-WG and SG-WG, respectively, vs. 123 g kg^{-1} for SH-WH).

There was a strong trend for differences in CP between rye overseeded into RP or BG (*P* = 0.0559). For rye overseeded into BG, CP was 197 g CP kg^{-1} DM compared with 210 g CP kg^{-1} DM for rye seeded into RP. This response is likely associated with greater uptake of soil N in the legume-based system. The nutritive value of rye varies with management, cultivar selected, and the production environment. Average CP of rye generally ranges from 120 to 230 g kg^{-1} DM across the season (NRC, 1996; Muir and Bow, 2009; Newell and Butler, 2012).

There was a date x system interaction ($P < 0.0001$) for rye IVDOM in winter 2012. At the beginning of the winter, there was greater IVDOM for grazed treatments than clipped (775 vs. 673 g kg^{-1}) prior to treatments being imposed, but by March 2012 IVDOM was not different among treatments (mean 680 g kg^{-1}). Myer et al. (2008) reported mean IVDOM of 792 g kg^{-1} for a mixture of ‘Wrens 96’ rye and ‘Horizon 474’ oat when sod seeded into dormant bahiagrass (*Paspalum notatum* Flügge) or planted in clean-tilled soils during a 2-yr evaluation in north Florida. These data reflect a similar level of digestibility for rye and small grain mixtures in a similar production environment.

During summer 2012, a date x species interaction (*P* = 0.0317; Figure 5-3) was observed for CP in BG and RP. Crude protein concentration increased from May to June (130 to 154 g kg^{-1}) for BG, and remained at this level until August. Beginning in September, CP declined to 146 g kg^{-1} and decreased further to 104 g kg^{-1} by October. Rhizoma peanut CP was lower than BG from August to October, with the highest CP observed in August (139 g kg^{-1}) and decreasing to 120 g kg^{-1} by September. Beltranena et al. (1981) observed decreasing leaf percentage of RP across the season when harvested for hay production every 56 d, which may negatively impact nutritive value.

Also, the presence of weeds in the RP stand may have decreased CP values relative to BG.

There were species x system (*P* = 0.0014) and date x species interactions (*P* = 0.0022) for IVDOM of summer forage production systems. A species x system effect (Figure 5-4) was observed because grazed RP had greater digestibility than hayed treatments whereas there was no effect of production system on BG. The date x species interaction occurred because in August RP had greater IVDOM than BG (698 vs. 552 g kg^{-1}), however, IVDOM decreased by October for both species. Although digestibility decreased across the season, IVDOM of RP remained greater than BG (620 vs. 430 g kg^{-1}). Eckert et al. (2010) observed slightly greater values with an IVDOM of 670 and 520 g kg^{-1} for the first cutting of RP hay compared with BG harvested every 5 wk, respectively. Saldivar et al. (1990) attributed decreasing RP digestibility across the season to a decreasing percentage of leaf and during early fall. Holt and Conrad (1985) observed a decrease in IVDOM of BG harvested for hay production with advancing season. These results also agree with Johnson et al. (2001) who observed a quadratic effect of harvest date on IVDOM of bermudagrass where IVDOM was highest at first harvest in early June, but a reduction occurred by mid-summer (July). Although IVDOM increased again for BG in August, IVDOM plateaued throughout the remainder of the production season, illustrating a decrease in IVDOM relative to the first harvest date.

Residual litter mass

There were year x species (*P* = 0.0002), year x production system (*P* = 0.0022), and species x production system (*P* = 0.0068) interactions for residual litter mass at the end of the winter. The year x species interaction (Figure 5-5) occurred because overseeded BG and RP plots had greater residual herbage mass in 2013 than 2012

(Figure 5-5). At the end of the winter of 2012, residual litter mass was similar between species (1900 vs. 1600 kg ha^{-1} for BG and RP, respectively), whereas overseeded BG plots had greater residual litter mass (3850 kg ha^{-1}) compared with RP (2400 kg ha^{-1}) at the end of winter 2013. More residual litter in 2013 was associated with the accumulation of litter following more than 1 full year of imposing treatments compared with only a single winter season in 2012. Greater herbage harvested of BG than RP during the summer likely contributed to greater litter mass at the end of winter season for BG plots.

The year x production system interaction occurred because litter mass was greater for clipped, overseeded plots (2150 kg ha^{-1}) during winter 2012 compared with those that were grazed (1480 and 1730 kg ha^{-1} for SG-WG and SH-WG systems, respectively). At the end of winter 2013, SG-WG had greater litter mass (3490 kg ha^{-1}) compared with those that were clipped (2800 kg ha^{-1} for SH-WH), but SH-WG was not different from either treatment (3040 kg ha^{-1}).

A species x production system interaction (Figure 5-6) occurred because overseeded BG had greater residual litter for SG-WG treatments (3220 kg ha^{-1}) than SH-WH and SH-WG rye (2870 and 2550 kg ha^{-1}, respectively). No differences were observed among systems for overseeded RP, and RP production systems had an average residual litter mass of 2100 kg ha^{-1}. Franzluebbers et al. (2000) reported that the practice of hay production reduces the amount of decomposable substrates added to the soil through the removal of above ground plant material. Thus, the contribution of residual plant litter is often less than in grazed ecosystems.

Residual litter C and N concentration and C:N ratio

Total C concentration in litter mass differed among years ($P < 0.0001$), but there was no effect of warm-season species or production system on C concentration in litter at the end of the winter season. Average total C concentration in litter mass was 364 and 421 g kg^{-1} DM in 2012 and 2013, respectively. Increased C concentration in 2013 may have been to greater carryover of lower quality, more recalcitrant litter from the summer growing season in the second year vs. the first.

Litter N concentration at the end of the winter seasons was affected by warm-season perennial species ($P = 0.0127$) and was greater for RP than BG (27 vs. 24 g kg^{-1} DM). This coincides with the increased CP of rye overseeded into RP compared with BG. There also was a year x production system interaction ($P = 0.0467$), and it occurred because litter from treatments that included overseeded rye under hay production had slightly lesser N concentration (27 g kg^{-1} DM) than grazed treatments (28 and 29 g kg^{-1} DM for SG-WG and SH-WG, respectively) in 2012, but concentrations were similar in 2013 (mean 22 g kg^{-1} DM for all treatments). Ruffo and Bollero (2003) evaluated rye and hairy vetch (*Vicia villosa* Roth.) cover crops as a source of N for corn (*Zea mays* L.). They observed a peak value of 1500 kg C ha^{-1} and 50 kg N ha^{-1} in rye residue prior to chemical burndown and planting of corn. These values are slightly greater than the C and N associated with residual litter mass in the present study because the rye was not defoliated in the cover crop experiment.

The C:N ratio of plant litter from the winter season was affected by species x system ($P = 0.0382$) and year x species ($P = 0.0228$). A species x system interaction (Figure 5-7) occurred primarily because litter from winter haying of rye in BG plots resulted in a lower C:N ratio (15.7) than winter grazing treatments (17.0 for both SG-WG and SH-WG). However, the C:N ratio of litter at the end of winter from overseeded RP was not different among grazed vs. hayed plots (14.5). There was an increase in C:N ratio from 2012 to 2013 for overseeded RP and BG. In 2012, residual litter C:N was 12.0 and 13.2 for overseeded RP and BG, respectively. By 2013, the ratio increased to 16.9 for RP and 19.7 for BG. These data are likely a function of the increased accumulation of lower quality litter mass arising from the summer of 2012. A year x production system interaction ($P = 0.0669$) occurred because there was an increase in C:N ratio across years for all treatments. For the SH-WH treatment, C:N ratio increased from 12.7 in 2012 to 18.0 in 2013 ($P < 0.001$) compared with 12.2 to 19.0, respectively, for SG-WG treatment ($P < 0.0001$). Additionally, C:N ratio increased from 13.0 to 18.1 for the SH-WG production system ($P < 0.001$) during this time. This suggests that litter quality decreased with increasing amount of litter following 1.5 yr of imposing treatments. In plant material, mineralization is favored when C:N ratio is 20:1 or less, and immobilization occurs at a C:N ratio of 30:1 or greater (Dubeux et al., 2007; Lambers et al., 2008). However, although C:N ratio has been broadly used as an indicator of OM susceptibility to decomposition, a number of biotic and abiotic factors can affect mineralization and immobilization processes outside of this ratio. Litter C:N increased at the end of summer 2012 for BG, but decreased in winter 2013 when overseeded with rye. This is likely because of the greater quality of rye than bermudagrass residue that was being returned to the system at that time.

At the end of the summer in 2012, there were differences in residual litter mass among species ($P < 0.0005$). Bermudagrass had greater residual litter mass (3990 kg DM ha^{-1}) than RP (2190 kg DM ha^{-1}). Greater productivity of BG contributed to greater litter mass at the end of the season compared with RP. There was also a species x system interaction (*P* = 0.0613). Grazed bermudagrass plots had greater residual litter (3690 vs. 4050 kg DM ha^{-1} for SG-WH and SG-WG, respectively) than hayed (mean of 2650 kg DM ha^{-1} for SH-WH and SH-WG), but there were no differences in litter mass among RP-based systems (mean 2200 kg DM ha^{-1}).

Difficulty in achieving the target stubble height for grazed bermudagrass plots likely increased contribution to litter mass. Greater herbage mass under less intensive management strategies (i.e., low stocking rate) may cause more litter deposition because of a lower forage utilization rate and an increase in senescent herbage (Thomas,1992; Dubeux et al., 2007). During Year 1 of a 2-yr evaluation, Valéria et al. (2013) observed less litter mass accumulation for signalgrass (*Brachiaria decumbens* Stapf.) under a high stocking rate [3.9 or 5.8 AU (450 kg cattle live weight) ha^{-1}; 2,090 and 2,210 kg OM ha^{-1}, respectively] than the lowest stocking rate of 2.0 AU ha^{-1} (2750 kg OM ha^{-1}). However, litter mass in Year 2 was similar among treatments (3,130 kg OM ha^{-1}). The authors attributed the lack of differences in the second year to the cumulative effect of N fertilization increasing net primary productivity and equilibrating grazing pressure at greater stocking rates. Liu et al. (2011b) evaluated the effect of postgraze stubble height on plant- and soil-nutrient pools in ‘Tifton 85’ bermudagrass pastures. As stubble height increased from 8 to 24 cm, there was a linear increase in plant litter (did not include residual stubble in the Liu experiment) during the summer from 2,040 to 3,580 kg ha^{-1}. These data also correspond with the herbage harvested, with lower productivity of RP during the first year of management likely explaining lesser residual litter mass deposition.

Concentration of C and N in plant litter at the end of the summer season of 2012 differed (*P* < 0.0001 for both C and N, respectively) among species. Litter in RP systems had 358 g C kg^{-1} DM at the end of 1 yr of imposing treatments, while BG litter had an average of 415 g C kg^{-1}. The total N concentration was 15.3 and 18.6 g kg^{-1} DM, respectively, for RP and BG (species effect; $P = 0.0027$). Finally, the C:N ratio differed among RP and BG (species effect; $P < 0.0001$), and BG had a greater C:N ratio (27.5) than RP (19.5). A decreased C:N ratio for RP is typical for legumes relative to C_4 grasses (Thomas and Asakawa, 1993; Knops and Tillman, 2000). Franzluebbers et al. (2004) suggested that surface residues with a lower C:N ratio have the potential to be more rapidly mineralized and contribute to soil fertility in the surface soil (0 to 10 cm). Thus, RP litter likely had greater potential for mineralization than BG.

Root-rhizome mass

There was no effect of production system on root-rhizome mass when sampled at the end of 1 yr of imposing treatments, however, there were differences among warm-season species ($P = 0.0307$). Bermudagrass had a greater root-rhizome mass (5,910 kg ha^{-1}) compared with RP (2,130 kg ha^{-1}). The observed values for BG and RP are lower than reported in the literature when measured at similar depths (Ortega-S. et al., 1992b; Rice et al., 1995; Liu et al., 2011a), but may reflect the relatively short establishment period and subsequent use of these warm-season perennials during the year after planting.

Soil Responses

Aggregate size distribution

The aggregate size distribution of soil from the 0- to 10- and 10- to 20-cm depths did not differ among treatments. Macroaggregates of ≥ 250 µm represented 506 g kg^{-1}

of total soil. For the microaggregate fraction (53-250 µm), there was a trend for differences among management systems (*P* = 0.0635) in the 0- to 10-cm soil layer whereby SH-WH had a greater contribution from this soil size class than SG-WG (471 vs. 440 g kg^{-1} soil, respectively). The microaggregate fraction consisted of 464 g kg^{-1} of total soil in the 10- to 20-cm stratum and was not affected by treatment. Dubeux et al. (2006) evaluated the effect of four levels of grazing management (combinations of stocking rate and N fertilization) on soil fractions under bahiagrass. The soil particle size distribution did not differ due to forage management regime, but the macro- and microaggregate fractions (53-2000 µm) represented 990 g kg^{-1} of total soil. In that Spodosol (sandy siliceous, hyperthermic Ultic Alaquods), the dominant fraction was coarse sand (250-2000 µm). In the present study, the macro plus microaggregate fraction of the soil represented 960 g kg^{-1} of total soil.

There were differences in particle size distribution of the < 53-µm fraction across years (*P* = 0.0047) for the 0- to 10-cm layer. At the beginning of the experiment in 2011, this fraction represented 22 g kg^{-1} total soil. However, it decreased to 17 g kg^{-1} soil by the end of the first full year of imposing treatments. These results suggest that aggregation occurred after one year of management, and is an important factor defining soil quality. In the 10- to 20-cm layer, there was year x production system interaction (*P* = 0.0522) because the soil particle size distribution decreased for clipped treatments in 2012 (24 to 15 g kg^{-1}), but was maintained for grazed swards (21 to 18 g kg^{-1}).

Particle size fraction C, N, and C:N ratio

Total C concentration differed among particle size classes (Table 5-5). There was a year x production system interaction (*P* = 0.0057) observed for the > 250 µm particle size class in the 0- to 10-cm layer. Prior to imposing treatments, SOC concentrations in the bulk soil did not differ among management strategies and was 5.20 and 4.91 g kg^{-1} soil fraction for SH-WH and SG-WG treatments, respectively. However, after 1 yr of imposing treatments, there was a decrease in SOC for the SH-WH system (4.38 g kg^{-1} soil fraction), while total C increased under year-round grazing (SG-WG; 6.98 g kg^{-1}). Six et al. (2002) suggested that newly incorporated organic material is often associated with larger particle size fractions. Furthermore, under the warm and humid conditions at the experimental site, rapid decomposition of organic C inputs can occur, which contribute to soil C pools (Cambardella and Elliott, 1992). Greater C in the large particle fraction can be attributed in part to greater residual litter inputs associated with grazed vs. hayed systems. For the 53 to 250 μm fraction, no differences were observed between warm-season species or among production system treatments within the 0- to 10- or 10- to 20-cm layers (5.64 and 5.65 g kg^{-1}, respectively).

In the surface 10 cm of soil, there were no differences in C contribution from the < 53 μm size class following 1 yr of imposing treatments. Mean total C concentration associated with this fraction was 59.6 g kg^{-1} soil fraction for the 0- to 10-cm layer. This illustrates that although this particle size class makes up a smaller proportion of the total soil by weight, it serves an important source of C in this soil type. A year effect (P = 0.0035) was observed for the C associated with the < 53-μm size class for the 10- to 20-cm soil layer. Total C associated with this fraction decreased from prior to initiation of the experiment to 1 yr after initiation of treatments (69.2 vs. 53.7 g kg^{-1} soil fraction, respectively). There was also a year x system effect (P = 0.0964) for this soil depth. Total C of < 53-μm particles was similar among year-round hay production and grazing treatments prior to treatments being imposed (67.8 vs. 70.5 g kg^{-1} soil fraction, respectively), however, at the end of the first year, grazed systems had less total C concentration (47.4 g kg^{-1}) compared with those harvested for hay (60.1 g kg^{-1}).

In less sandy soils, C associated with small particle size classes is considered to be relatively stable with a slow turnover rate (Six et al., 2000). However, Silveira et al. (2013) suggested that due to the low silt plus clay content in many Florida soils, the ability for chemical and physical protection of soil OM is limited, resulting in the accumulation of SOC in the fine-particle size fractionthat may more readily undergo degradation. Tisdall and Oades (1992) stated that the products of microbial decomposition (i.e., polysaccharides) that bind C in fine particle size fractions (< 53 µm class) can be affected by land management strategy. Thus, physical disruption of the soil from tillage prior to planting may have caused an initial decrease in soil C in this experiment. Decreased C under grazing may also be related to disturbance of the soil from cattle, particularly in the RP plots which had not achieved full ground cover during the first year of this study.

Differences in total N concentration were found among soil particle size classes (Table 5-6). In fractions ≥ 250 µm, there was a year x system interaction ($P = 0.0503$) within the 0- to 10-cm soil depth. At the beginning of the experiment, total N was similar among SH-WH and SG-WG systems (0.23 and 0.25 g kg^{-1} soil fraction, respectively). After 1 yr of imposing treatments, total N concentration increased under year-round grazing (0.42 g kg^{-1}) compared with hay production (0.18 g kg^{-1}). Increased soil N for grazed systems is likely a result of N return in livestock excreta and increased litter deposition. Dubeux et al. (2006) suggested that the high C:N ratio of decaying plant and root material may immobilize soil N during the decay process, and subsequently increase N concentration in the soil organic matter. No differences were observed for the 10- to 20-cm layer for the ≥ 250 μm and mean total N was 3.1 g kg^{-1}. Total N concentration of soil particles from the 53 to 250 μm size class did not differ among production systems at either soil depth. Average total N was 0.30 g kg^{-1} of this size class. The largest amount of N was associated with the < 53 μm particle size fraction. Concentration of N in this fraction differed between years (P = 0.0228) in the surface 10 cm of soil, and decreased from before treatment imposition to 1 yr later (4.91 vs. 3.77 g kg^{-1} soil fraction, respectively). In the 10 to 20-cm soil layer, total N for the < 53-μm size class averaged 4.21 g kg^{-1} soil fraction. These results agree with other studies conducted in Florida showing that the < 53-μm fraction serves as an important source of C and N in the soil, although the concentration of this particle size fraction is relatively low in total soil (Dubeux et al., 2006; Silveira et al., 2013).

The macroaggregate fraction (≥ 250 μm) had a greater C:N ratio (system effect; P = 0.0380) for SH-WH (28.9) than SG-WG (19.8) in the top 10 cm of soil. A species x system interaction (P = 0.0040) occurred for the 10- to 20-cm layer. Grazed BG had a lower C:N ratio (24.0) than SH-WH (34.2), but grazed RP had a greater soil fraction C:N ratio (34.9) than clipped treatments (20.5). There was a species x production system interaction (P = 0.0635) for the 53- to 250-μm fraction to a depth of 10 cm, although there was no difference in C:N ratio from 10 to 20 cm (mean of 25.2). The interaction occurred because grazed RP had a greater C:N ratio than clipped (29.1 vs. 18.0, respectively), but C:N was similar among BG systems (21.0 and 24.2 for SH-WH and SG-WG, respectively). In the < 53-μm size class, C:N ratio did not differ among treatments within the 0- to 10-cm layer (14.3 and 14.5 for BG and RP, respectively), but there was a system effect (*P* = 0.0150) for the 10- to 20-cm layer. Grazing increased the fraction soil C:N ratio (14.4) compared with those under year-round hay production (13.9), although the difference was fairly small. The C:N ratio of this size class is lower than the coarse and fine sand classes. This observation supports the decrease in C across time and increased contribution of N for this size fraction relative to the others. A smaller C:N ratio indicates that this fraction is potentially labile and may undergo degradation more readily when not in a physically protected form.

Implications of the Research

Year-round forage production system affected the amount of herbage harvested and contribution of herbage to residual plant litter. The greater inherent productivity of BG compared with RP and use of grazing vs. hay harvest increased plant litter pools and the potential for C and N contribution. The greater C:N ratio of plant residue from RP-based systems favored mineralization over that from BG systems, which may more readily impact short-term soil C and N pools. Overseeding RP and BG with an early-maturing rye did not influence subsequent herbage production of the warm-season perennials during Year 1 of the study. Interseeding cool-season annuals into these systems may provide an additional winter forage option for producers when planting in clean-tilled soils is not an option. However, further evaluation should be conducted with other combinations of winter annual forages (i.e., legumes and grasses) to determine impacts on subsequent herbage production and soil C and N dynamics, particularly for RP for which there are few published studies.

Although there was a decrease in soil C for the < 53 μm fraction, the increase or maintenance of C in larger soil fractions illustrates newly added organic material in the soil, and suggests that production systems used in the present study were contributing to the accumulation of soil C and N. Greater C accumulation in the > 250 μm fraction for the summer-winter grazing management system compared with year-round hay production illustrates the short-term contribution of nutrient return from plant litter and excreta from livestock. Continuing evaluation of these management practices is necessary to determine the long-term effects of grazing and hay production on soil quality and the capacity of Florida soils to retain C within different particle size classes.

Table 5-1. Description of management treatments for warm-season perennial based forage production systems.

	Forage management options		
System abbreviation[†]	Management of summer perennial	Overseeded with rye	Management of rye
SH-No	Hay harvest (28 d)	No	
SH-WH	Hay harvest (28 d)	Yes	Hay harvest (28 d)
SG-No	Rotational stocking (28 d)	No	
SG-WG	Rotational stocking (28 d)	Yes	Rotational stocking (28 d)
SH-WG	Hay harvest (28 d)	Yes	Rotational stocking (28 d)

[†] Treatments include summer hay production-no winter overseeding (SH-No), summer and winter hay production (SH-WH), summer grazing management-no winter overseeding (SG-No), summer and winter grazing management (SG-WG), and summer hay-winter grazing management (SH-WG).

Table 5-2. Species x system interaction (*P* = 0.0013) for total rye herbage harvested (kg DM ha^{-1}) from overseeded bermudagrass and rhizoma peanut. Data are means of three overseeded production systems across three replicates within a species (n = 9).

	Warm-season species		
System[‡]	Bermudagrass	Rhizoma peanut	*P* value
	-----------------------kg ha^{-1}--------------------		
SH-WH	1080[a†]	1360[a]	0.0840
SG-WG	480[b]	270[b]	0.0359
SH-WG	580[b]	350[b]	0.0148
SE	104		

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

[‡] Systems include summer and winter hay production management (SH-WH), summer and winter grazing management (SG-WG), and summery hay production-winter grazing (SH-WG).

Table 5-3. Year x system interaction ($P < 0.0001$) for total rye herbage harvested (kg DM ha^{-1}) from overseeded bermudagrass and rhizoma peanut. Data are means of three overseeded forage systems across three replicates within a species (n = 9).

	Year		
System[‡]	2012	2013	*P* value
	------------------------kg ha^{-1}------------------------		
SH-WH	2060[a†]	360	<0.001
SG-WG	360[b]	390	0.5649
SG-WH	510[b]	410	0.1278
SE	102		

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

[‡] Systems include summer and winter hay production management (SH-WH), summer and winter grazing management (SG-WG), and summery hay production-winter grazing (SH-WG).

Table 5-4. Species x system interaction ($P < 0.0001$) for total herbage harvested (kg DM ha^{-1}) during the 2012 summer season. Data are means of five forage production systems across three replicates within a species (n = 15).

	Species		
System[‡]	BG	RP	*P* value
	-----------------------kg ha^{-1}-------------------------		
SH-No	10 500[a†]	320[b]	<0.0001
SH-WH	9710[a]	280[b]	<0.0001
SG-No	5580[b]	1010[a]	<0.0001
SG-WG	5080[b]	860[a]	<0.0001
SH-WG	12 200[a]	210[b]	<0.0001
SE	621		

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

[‡] Systems include summer hay production-no winter overseeding (SH-No), summer and winter hay production management (SH-WH), summer grazing management-no winter overseeding (SG-No), summer and winter grazing management (SG-WG), and summer hay production-winter grazing (SH-WG).

Table 5-5. Year x system interaction for total C concentration in various soil aggregate size fractions prior to the beginning of the experiment in 2011 and at the end of the first year of the study in 2012.

	Forage Management System					
	0- to 10-cm			10- to 20-cm		
	SH-WH	SG-WG	*P*-value	SH-WH	SG-WG	*P*-value
Size Class	----------------------------------g C kg^{-1} soil fraction--------------------------------					
> 250 µm						
2011	5.20	4.91 b	0.2030	5.16	4.68	0.4976
End 2012	4.38	6.98 a	0.0052	5.05	5.25	0.3010
SE	0.56			0.65		
53-250 µm						
2011	5.13	5.83	0.6008	5.03	5.66	0.7777
End 2012	5.51	5.25	0.8125	6.01	5.93	0.8190
SE	0.68			0.91		
< 53 µm						
2011	60.8	63.2	0.7546	67.8	70.5 a	0.2221
End 2012	50.7	64.2	0.0910	60.1	47.4 b	0.0060
SE	6.29			6.03		

[a,b]Within a column, means without common superscripts differ $P < 0.05$.

Table 5-6. Year x system interaction for total N concentration in various soil aggregate size fractions prior to the beginning of the experiment in 2011 and at the end of the first year of the study in 2012.

	Forage Management System					
	0- to 10-cm layer			10- to 20-cm layer		
	SH-WH	SG-WG	*P*-value	SH-WH	SG-WG	*P*-value
Size Class	---------------------------------g kg soil fraction-----------------------------------					
≥ 250 µm						
2011	0.23	0.25 b	0.8078	0.23	0.20	0.7980
End of 2012	0.18	0.42 a	0.0045	0.23	0.21	0.8156
SE	0.05			0.05		
53 to 250 µm						
2011	0.30	0.28	0.6546	0.21	0.26	0.5640
End of 2012	0.25	0.28	0.8652	0.26	0.28	0.7692
SE	0.05			0.01		
≤ 53 µm						
2011	4.90	4.91	0.8888	4.21	4.40	0.8130
End of 2012	4.76	4.86	0.5546	3.91	4.48	0.6532
SE	0.34			0.47		

[a,b]Within a column, means without common superscripts differ $P < 0.05$.

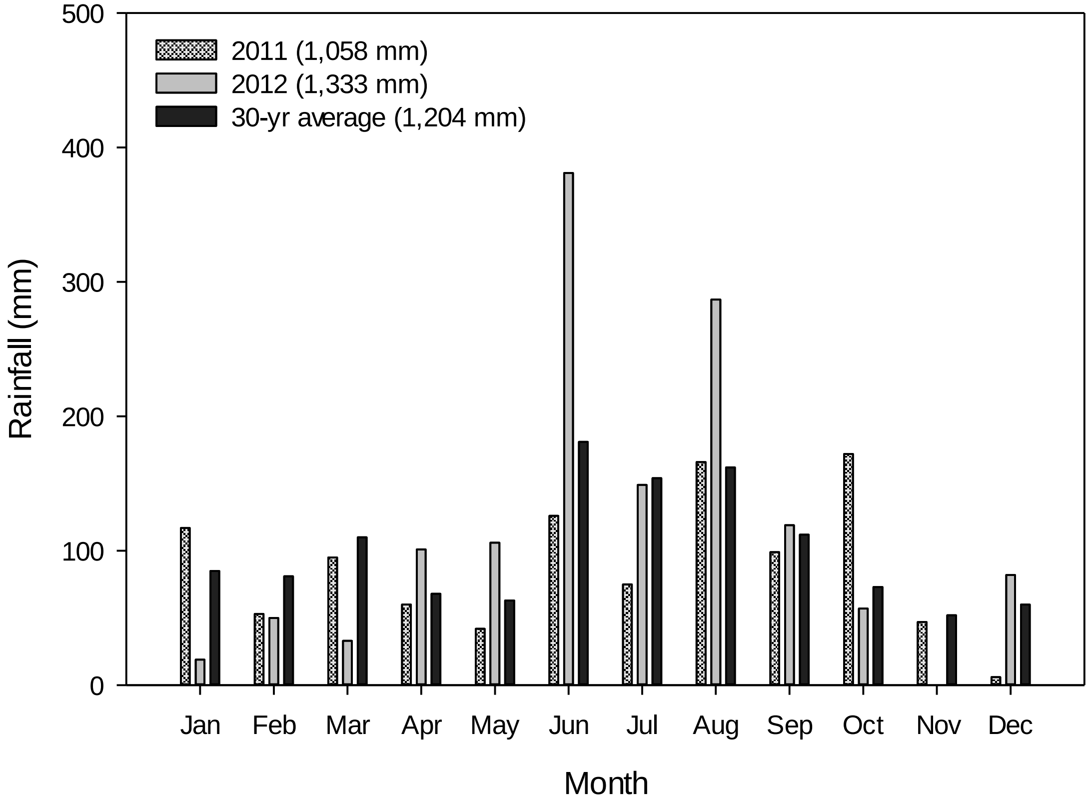

Figure 5-1. Monthly rainfall for 2011 and 2012 for the experimental location and the 30-yr average for Citra, FL.

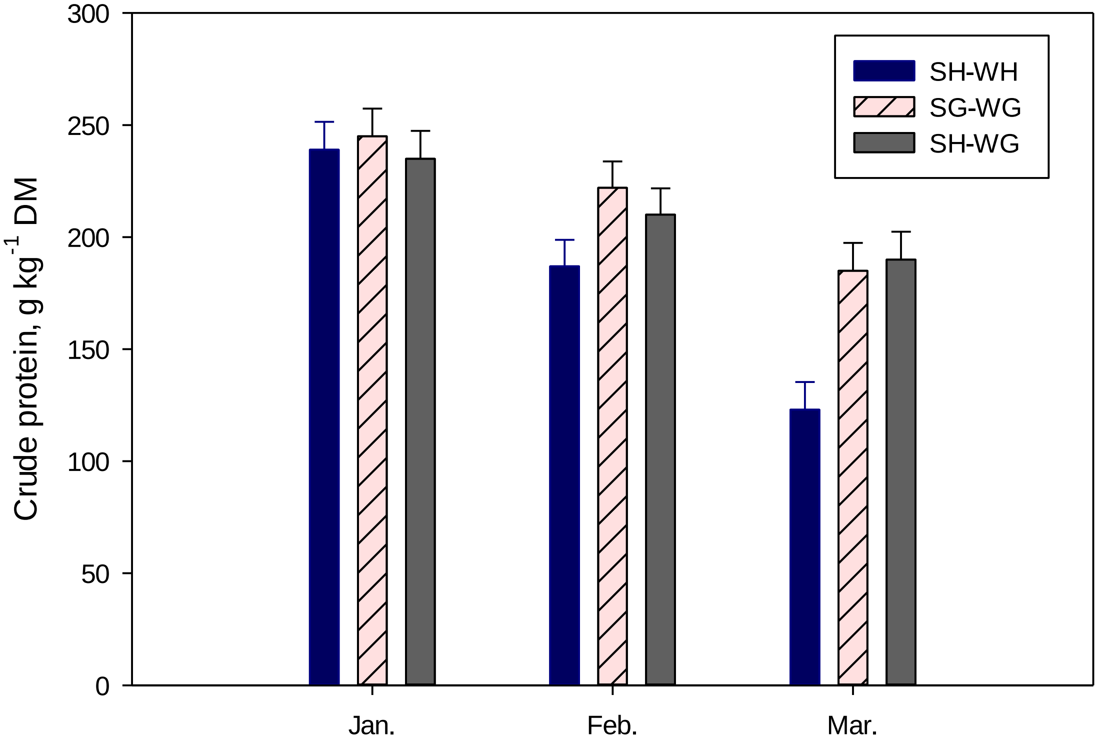

Figure 5-2. Date x system interaction (*P* = 0.0172) for crude protein (g kg^{-1} DM) of winter rye overseeded forage systems. Data are means across two overseeded warm-season perennials and three replicates (n = 6). Systems include summer and winter hay production (SH-WH), summer and winter grazing management (SG-WG), and summer hay-winter grazing management (SH-WG).

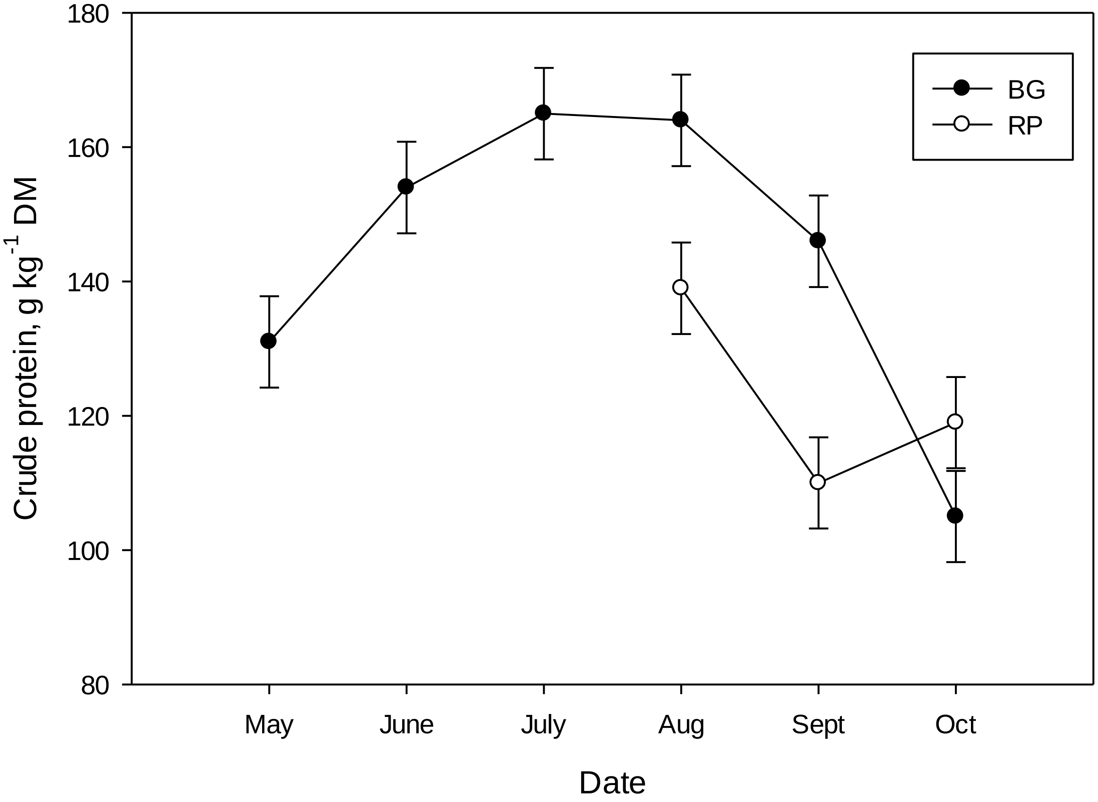

Figure 5-3. Date x species interaction (*P* = 0.0317) for crude protein (g kg^{-1} DM) of ‘Florigraze’ rhizoma peanut (RP) and ‘Tifton 85’ bermudagrass (BG) in summer 2012. Within a species, data are means across five forage production systems and three replicates (n = 15).

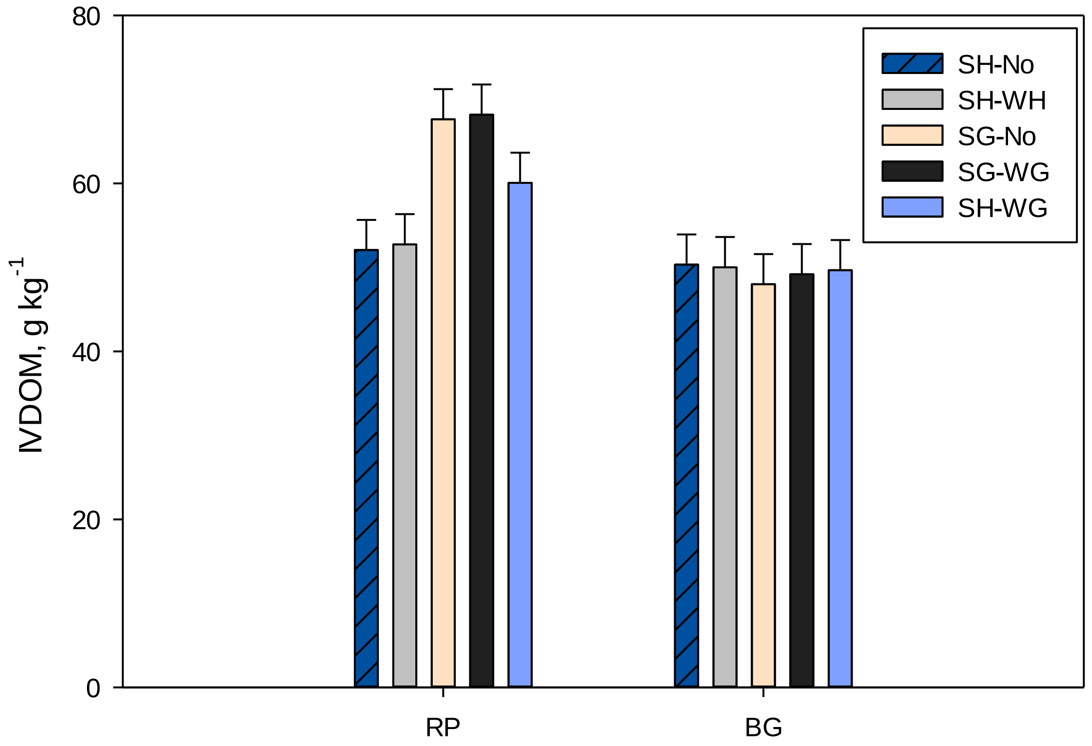

Figure 5-4. Herbage in vitro digestible organic matter (IVDOM) of warm-season perennial forage systems in summer 2012. Data are means across two sampling dates and three replicates for each system (n = 6). Systems include summer hay production-no winter overseeding (SH-No), summer and winter hay production (SH-WH), summer grazing management-no winter overseeding (SG-No), summer and winter grazing management (SG-WG), and summer hay production-winter grazing management (SH-WG).

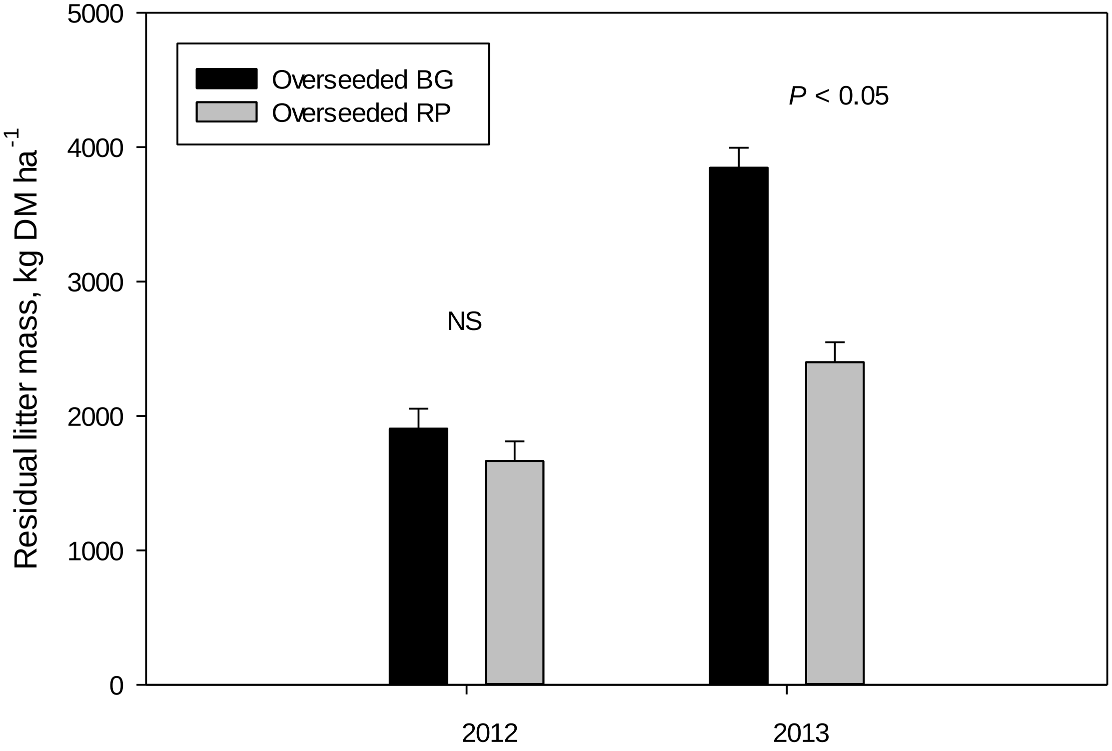

Figure 5-5. Year x species interaction ($P = 0.0002$) for residual litter mass (kg ha^{-1}) of winter overseeded bermudagrass (BG) and rhizoma peanut (RP). Data are means across three overseeded forage systems and three replicates (n = 9).

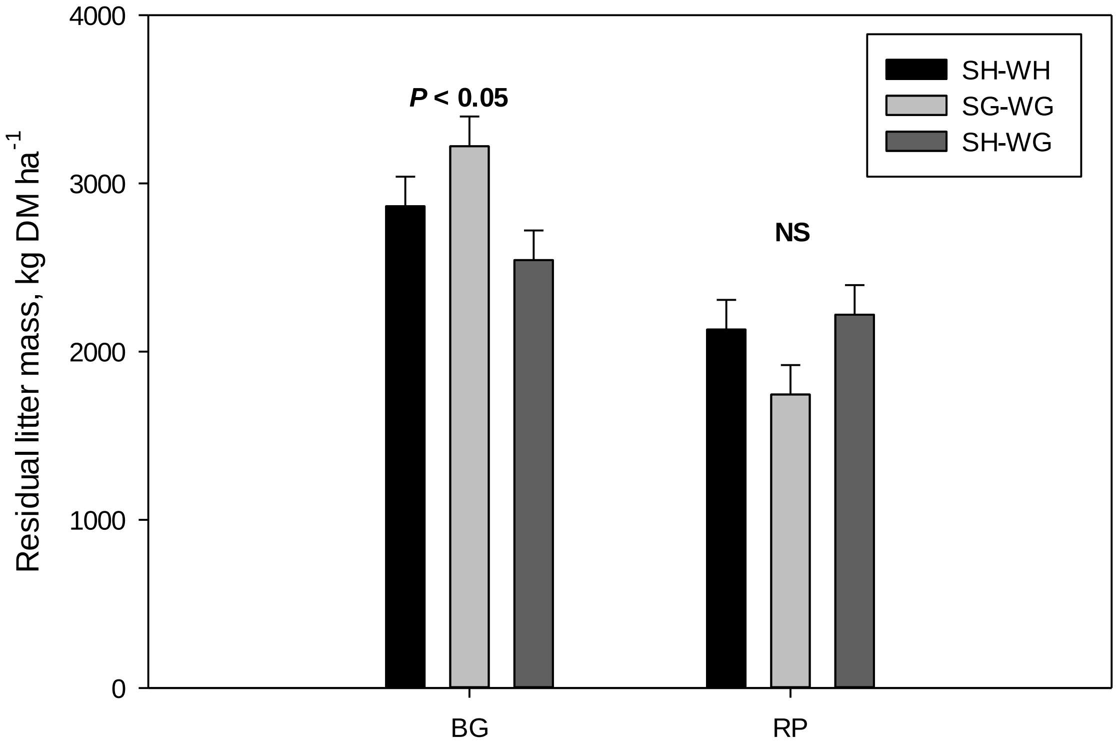

Figure 5-6. Species x system interaction ($P = 0.0068$) for residual litter mass (kg DM ha^{-1}) of winter overseeded bermudagrass (BG) and rhizoma peanut (RP) after 2 yr of imposing winter management treatments. Data are means across three replicates within a species (n = 3). Systems include summer and winter hay production (SH-WH), summer and winter grazing management (SG-WG), and summer hay production-winter grazing management (SH-WG).

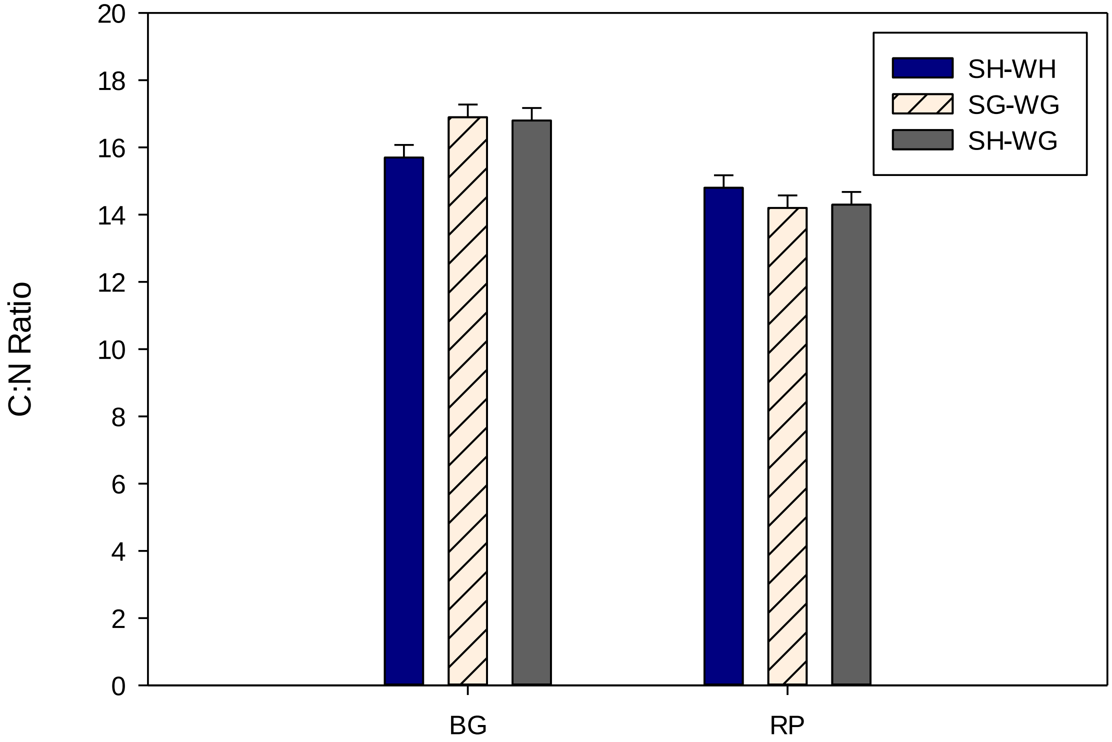

Figure 5-7. Species x system interaction (*P* = 0.0382) for C:N Ratio of residual litter for winter overseeded bermudagrass (BG) and rhizoma peanut (RP) forage systems. For each system, data are means across three replicates within a species (n = 3). Systems include summer and winter hay production (SH-WH), summer and winter grazing management (SG-WG), and summer hay production-winter grazing management (SH-WG).

CHAPTER 6
CONCLUSIONS

Increasing input costs, especially fuel and fertilizer, have made the incorporation of legumes an increasingly attractive option for beef cattle producers. Rhizoma peanut (RP; *Arachis glabrata* Benth.) is a warm-season perennial legume with documented persistence (Ortega-S. et al., 1992) that is well-adapted to Florida and has potential for incorporation into grazing systems. Because of the high cost of establishment, alternative establishment strategies, such as strip-planting, are needed if RP is to make significant contributions to grazing-based systems in the future.

Multiple entries of RP have been developed and released as dual-purpose hay and grazing crops, and they exhibit a range in growth habit, which may interact with their ability to establish and persist under grazing management. Because long-term pasture productivity and persistence are of great importance in low-input systems, evaluation of performance of these lines under grazing is needed to guide genotype selection by producers. Finally, as increasing emphasis is placed on the ability of grasslands to provide ecosystem services, RP has potential to contribute significantly in this regard in Florida (French et al., 2006). Tropical and temperate grasslands play a major role in the global C cycle and serve as an important C sink (Scurlock and Hall, 1998). Management of grass-based forage systems (e.g., haying vs. grazing and grazing at a range of stocking rates) has been shown to affect their potential to store C (Franzluebbers and Stuedemann, 2002; Franzluebbers and Stuedemann, 2009), but no work has been done with warm-season, legume-based swards in the Southeast USA.

The overall objective of these projects was to evaluate the effect of RP genotypes on rate of establishment, response to grazing, and contribution to ecosystem services in various production systems in Florida. Specifically, the projects in this dissertation were developed to: i) determine the effect of growth habit and defoliation management of rhizoma peanut cultivars on establishment success and changes in soil C dynamics when strip-planted into bahiagrass (*Paspalum notatum* Flügge) sod (Chapter 3); ii) evaluate the effects of grazing frequency and intensity on recently-released rhizoma peanut genotypes in order to determine grazing management recommendations (Chapter 4); and iii) investigate the contribution of rhizoma peanut or N fertilized grass-based year-round forage management systems on soil C and N dynamics in Florida (Chapter 5).

Growth Habit of Rhizoma Peanut Cultivars Effects on Establishment and Spread When Strip-Planted in Bahiagrass Sod - Chapter 3

The establishment study was conducted at the Beef Research Unit in Gainesville, FL (29.72°N, 82.35°W) in 2011 and 2012, and year-after-establishment effects are reported for 2012. Four RP genotypes were strip-planted into clean-tilled soil in March of each year, and were defoliated under rotational stocking or hay management every 28 d beginning in June.

Rhizoma peanut shoot emergence was greatest for Florigraze and Ecoturf, which led to a trend for more favorable ground cover, frequency, and spread for these genotypes than UF Peace and Arblick throughout the experiment. Defoliation management did not negatively impact ground cover during the establishment year, but there was a reduction in spread potential when swards were grazed compared with harvested for hay. Hay production decreased the intensity of peanut removal from the planted strip during the establishment phase, and led to more favorable spread characteristics. Animal preference for RP in the planted strip is a key consideration when using strip planting, and it is likely that longer rest periods are needed between defoliation events as well as earlier removal of livestock in order to allow taller stubble in the planted strip. During the year-after-establishment, differences among genotypes were less prevalent. However, defoliation strategy continued to impact success of establishment, with reduced ground cover and spread for grazed than hayed treatments.

Finally, changes in soil dynamics occurred when converting from a C_4 to a mixed C_3/C_4 pasture system. A decrease in soil C illustrates the initial impact of tillage and land management on soil quality, although the contribution of C and N in the planted strip from RP began to increase during the first 2 yr after planting RP.

Sward Characteristics of Rhizoma Peanut Culvitars Under a Range of Grazing Management Strategies - Chapter 4

The defoliation management study was conducted at the Beef Research Unit in Gainesville, FL (29.72°N, 82.35°W) in 2012, and data from a second year of study are being collected in summer 2013. Four rhizoma peanut genotypes (Florigraze, Ecoturf, UF Peace, and UF Tito) were managed under two grazing frequencies (3- or 6-wk interval) and two grazing intensities (50 or 75% pregraze canopy height removal).

Grazing frequency and intensity are important considerations when selecting management criteria for forages, and they were observed to impact above- and below-ground sward characteristics during Year 1 of this study. Total herbage accumulation did not differ among entries, but greater accumulation occurred with a grazing frequency of 6 vs. 3 wk. When RP genotypes were grazed every 6 wk, there was i) maintenance of a high percentage of RP ground cover, ii) similar or greater pre-grazing herbage leaf-to-stem ratio, and iii) greater pre-grazing light interception than when grazed every 3 wk.

Less post-grazing residual leaf area and greater weed frequency for the 75% canopy removal level illustrated that greater grazing intensity can affect changes in the sward canopy. These results suggest that there may be an advantage for longer regrowth intervals, and visual observations during Year 2 suggest that this affect may become more pronounced over time.

Defoliation Management Effects on Soil Carbon Dynamics of Year-Round Production Systems - Chapter 5

The experiment was conducted at the Plant Science Research and Education Unit in Citra, FL (29.24°N, 82.10°W) during 2012. A second year of the study is currently being conducted, but those data were not reported. Five year-round forage management systems were imposed on both RP and N-fertilized bermudagrass (BG; *Cynodon* spp.), and their contributions to soil C and N were evaluated.

Herbage production of BG was greater than RP and was primarily a function of the greater inherent productivity of this species at the fertilization rates used. Nutritive value differed across the season, but all systems provided relatively high in vitro digestible organic matter (IVDOM) and crude protein (CP) until August. Residual litter mass was greater for the N-fertilized BG systems, further reflecting the greater production of BG than RP. Management systems that employed grazing vs. hay harvest had greater litter mass. Plant litter quality was greater for RP-based systems, suggesting that there may be greater potential mineralization of this material than that from BG pastures.

During the winter management season, total herbage production of rye was relatively low, but nutritive value was high. There was no effect of overseeding RP with an early-maturing rye on subsequent yield of RP.

The increased quantity of plant litter remaining at the end of winter 2013 for grazed vs. hayed systems illustrates increased potential for C and N contribution from the litter pool. Finally, soil C and N changes occurred over one full-season of management, and illustrated the contribution of newly added organic matter in soil macroaggregates (i.e., soil particle size class > 250 μm).

Implications of the Research

Strip-planting of RP is a viable approach for the establishment of grass-legume mixtures. Favorable establishment characteristics of RP genotypes like Ecoturf in this study may increase the need for distribution of planting material of less commonly utilized germplasms to producers in Florida. Following genotype selection, the choice of management practice during the establishment phase is critical. These results indicate that management for hay production may provide a way to effectively utilize the bahiagrass component of the system without sacrificing RP establishment success.

For established stands, the choice of grazing management may not affect herbage accumulation in the first year of grazing, but sward characteristics such as species botanical composition, ground cover, weed frequency, light interception, and residual leaf area index are good indicators of overall sward health. These traits can be utilized to determine the short-term impacts and perhaps predict longer-term effects of defoliation management.

Conversion from row cropping to warm-season perennial forage systems can increase soil C and N in the short term. Grazing these swards during the winter and summer months has potential to increase these pools to a greater degree than hay production through increased plant litter deposition and excreta from livestock.

Future Research Needs

The described experiments addressed how to increase RP contribution to low-input production systems in Florida. Based on the results of these studies, there are many new questions that have emerged relative to how to incorporate and promote management of RP in these systems. Specifically, when strip-planting RP, the choice of RP cultivar is an important consideration; however, the choice of a grass component should also be investigated to determine the best fit for establishing mixed-pasture systems. The growth habit of the companion grass may affect establishment success. Additionally, the species of grass utilized (i.e., bermudagrass) is an area of interest among producers considering this technology. Furthermore, on-farm evaluations of this approach would further quantify the efficacy of management of strip-planted areas on a larger production scale and under producer management.

Utilizing effective grazing management strategies for RP will insure long-term stand production potential. Although a second year of this evaluation is being conducted, continuing this work for a third year may provide further information on long-term stand persistence that could be of value for making recommendations to producers. Previous evaluations with RP have shown that multiple years of evaluation are typically needed before these effects become prevalent (Hernández-Garay et al., 2004), and an additional year may provide this information.

Overseeding RP with winter forages enables producers to have an additional forage resource when RP is dormant. Using cool-season annuals may provide this option, but further evaluation of grasses, legumes, and mixtures should be conducted to quantify the impact on subsequent production of RP in the summer months. Utilizing a grass-legume mixture may provide additional N to the system and serve as a source of high quality forage during the winter.

Finally, long-term evaluation of the effects of forage management practices on soil C and N is needed in Florida. It is important to define practices that not only optimize production and persistence of the forage component of the system, but also increase the contribution to soil quality and overall ecosystem health. As sustainability continues to be a global issue, understanding the effect of these practices in subtropical environments will provide the basis for best management practices in this region.

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BIOGRAPHICAL SKETCH

Mary Kimberly Mullenix is from Newnan, Georgia and is the 5th generation of her family on a farm which consists of small commercial cow-calf and hay production operations. She completed her B.S. in Animal Sciences in 2008 and M.S. in Animal Sciences with an emphasis in ruminant nutrition in 2010 from Auburn University. In summer 2010, she received a Graduate School Fellowship from UF and began a doctoral program in the area of forage management under the direction of Dr. Lynn E. Sollenberger. She completed her Ph.D. program in fall 2013 with a major in Agronomy and a minor in Agricultural Education and Communication. Her professional goals are to use her training to develop research-based solutions and educational programs to address issues facing beef cattle producers across the USA.