STRIP-PLANTING OF RHIZOMA PEANUT IN BAHIAGRASS PASTURES TO INCREASE PRODUCTION AND SUSTAINABILITY OF LOW-INPUT FORAGE-LIVESTOCK SYSTEMS IN FLORIDA

By

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To José Bolívar and Tania
Your love is infinite

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LIST OF ABBREVIATIONS

ADF	Acid detergent fiber
CP	Crude protein
DM	Dry matter
IVOMD	*In vitro* organic matter digestibility
NDF	Neutral detergent fiber
PAR	Photosynthetically active radiation
RP	Rhizoma peanut (*Arachis glabrata* Benth.)
TNC	Total nonstructural carbohydrates

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Rhizoma peanut (*Arachis glabrata* Benth.; RP) is a subtropical legume with potential to be grown in association with grasses like bahiagrass (*Paspalum notatum* Flüggé) to increase/maintain productivity and sustainability of extensive low-input forage-livestock systems of the southeastern USA. In this work, four studies were conducted in Florida to investigate the viability of planting 'Florigraze' RP in strips into existing bahiagrass pastures. Using this approach, the specific objectives were to evaluate: 1) defoliation options during the year-of- and year-after establishment, 2) weed management, 3) N fertilizer application to establishing RP, and 4) seedbed preparation effects on RP establishment success. The results indicate that a single application of the herbicide glyphosate to kill bahiagrass followed by mowing the above-ground biomass to 5-cm stubble height before planting RP provides adequate seedbed for RP establishment and may reduce costs compared to conventional practices that include several passes of heavy equipment to plant RP in a fully prepared seedbed. Regardless of method of seedbed preparation in the strip, it should be followed by a single application of herbicides imazapic (0.07 kg a.i. ha^{-1}) or imazapic + 2,4-D amine

(0.07 and 0.28 kg a.i. ha^{-1}, respectively) when broadleaf and grass weeds reach 5- to 10-cm height to provide extended control of weeds. Light environment at the RP canopy height was ≥ 96% of the incident photosynthetically active radiation (PAR) when imazapic and imazapic + 2,4-D amine herbicides were used compared to ≤ 82% for the other treatments. The use of imazapic stunts bahiagrass growth temporarily providing time for RP establishment. Thus, it is the end of the season until bahiagrass actively regrows, resulting in a bahiagrass-RP mixture in the strips. Greatest RP canopy cover and frequency during the establishment year were ~35 and 80%, respectively, and occurred in plots where imazapic and imazapic + 2,4-D amine were applied. Application of 50 kg N ha^{-1} following herbicide application of imazapic or imazapic + 2,4-D amine increased RP canopy cover (+10 percentage points) and frequency (+15 percentage points) in plots where weeds had been controlled successfully. Measurements indicated that early in stand life RP spread at a rate of ~36 cm yr^{-1} into the adjacent bahiagrass sward. During the year of establishment, utilization of the establishing RP should be hay production to prevent loss of RP plants in the strip under grazing due to animal preference for plants in the strip and resultant overgrazing. During the year after establishment, grazing management strategies should be targeted to favor the RP in the strip, i.e. maintaining at least a15-cm stubble in the planted strip regardless of the height of the adjacent bahiagrass. Based on these results it is concluded that strip planting of RP is an option for incorporating the legume into grass-based pastures, but critical management factors for establishment success include avoiding excessive defoliation by grazing during the first 2 yr of stand development and controlling competition to RP in the strip by use of herbicides.

CHAPTER 1
INTRODUCTION

The capacity of legumes to fix atmospheric N through a symbiotic association with soil bacteria (Hirsch et al., 2001), is a *sine qua non* characteristic that has encouraged the use of legumes as a source of high nutritive value forage for livestock (Muir et al., 2011), and as a sustainable alternative to expensive fertilizer N (Cherr et al., 2006). In addition, benefits of incorporating legumes in agricultural ecosystems include acceleration of N cycling (Craine et al., 2002) and improvement of physical, chemical, and biological soil properties (Thomas, 1995).

Inclusion of legumes in forage-livestock systems has significant potential to contribute to animal production in the tropics (Rusland et al., 1988; Sollenberger et al, 1989; Shelton et al., 2005) by reducing cost associated with providing high quality forage and preventing pasture degradation while increasing/maintaining pasture productivity. Tropical regions are dominated by grasses that have the C_4 photosynthetic pathway and lower nutritive value compared to temperate grasses with the C_3 photosynthetic pathway (Minson et al., 1981). While there is greater potential to increase livestock productivity in the tropics, it is precisely in warm-climate environments where forage legumes have contributed less to livestock production compared to temperate-climate areas. In temperate areas it is more common to find perennial grass-legume associations in pasture-based livestock production systems.

A challenge in warm climates is that C_3 legumes are overwhelmed when competing with vigorous C_4 grasses (Dunavin, 1992; Sollenberger and Collins, 2003). There are documented management strategies (e.g., physical separation, grazing management, deferred utilization, timing of planting) that limit the competition by C_3

legumes from vigorous C_4 grasses (Lesleighter and Shelton, 1986; Sollenberger et al., 1987; Whitebread et al., 2009), but Sollenberger and Kalmbacher (2005) indicated that in general the difficulties of consistently establishing and maintaining legumes with C_4 grasses have been underestimated. They cite the specific example of sustaining warm-season annual legumes over time. This requires deferment of grazing during late summer to allow seed set and development of a soil seed bank for re-establishment year after year; further, this period of grazing deferment coincides with the time when legumes can have the greatest potential benefit in terms of animal responses. Thus, annual legumes are particularly challenging to maintain suggesting an advantage for use of perennial legume species.

One legume with demonstrated persistence and productivity under a variety of uses (grazing, haying, cover crop), and possessing the ability to perennate for many years in the USA Gulf Coast is rhizoma peanut (RP; *Arachis glabrata* Benth.). The versatility of RP makes it a top candidate for inclusion in grass-legume associations in low-input forage-livestock systems that are typically dominated by monocultures of C_4 grasses. To this point, however, the use of RP has been limited to production of high quality hay, due to the cost associated with vegetative establishment, management of weeds, and removing land from production for one or several years to allow RP establishment.

Currently, most RP-grass associations exist because of failure to control grass weeds growing in fields that initially were intended to be pure stands of RP for the production of hay. An alternative approach for achieving mixed pastures is to plant RP in strips in existing grass pastures. It may take a period of time for RP to spread from the planted strip to surrounding areas; nevertheless, if this can be achieved, it would provide a relatively low-cost option for establishment of mixed grass-legume pastures. Thus, the focus of this research is developing technology for strip-planting RP into existing pastures. It is hypothesized that planting method, defoliation management and weed control during the year of establishment, and grazing management in the year after establishment will be critical factors affecting success of the technique.

The general objective of the dissertation research was to develop cost-effective management strategies for successful establishment of RP-bahiagrass mixtures. The specific objectives were to evaluate the effects on RP establishment success of: 1) defoliation management options during the year of establishment (Chapter 3); 2) grazing management strategies in the year after establishment (Chapter 4); 3) weed management strategies and N fertilization in the establishment year (Chapter 5); and 4) seedbed preparation and post-plant competition-control strategies (Chapter 6).

CHAPTER 2
LITERATURE REVIEW

Overview of the Research Problem

Lack of maintenance fertilization and inadequate grazing management are the primary factors resulting in degradation of grasslands in low-input systems in some warm-climate environments (e.g., Brazil; Boddey et al., 2004; Miles et al., 2004). Degraded grasslands have limited potential to serve their primary function as a source of forage for livestock or to provide ecosystem services. Addition of N fertilizer, with N generally being the most limiting nutrient in grasslands, can certainly reduce the occurrence of degradation (Vitousek et al., 1997); however, the practicality and economic viability of this practice is questionable for many forage-livestock systems (Graham and Vance, 2003; Vitousek et al., 2009). Due to their capacity to fix N_2 from the atmosphere and their higher nutritive value than tropical grasses (Muir et al., 2011), legumes are an alternative source of N for grasslands with potential to improve the likelihood of long-term persistence, prevent pasture degradation, and increase animal production in warm climates (Sollenberger et al., 1989; Shelton et al., 2005). Rhizoma peanut (*Arachis glabrata* Benth.; RP) is a perennial legume with documented persistence in the USA Gulf Coast. To date, RP has not been widely used in grazed pasture in low-input production systems. The dissertation research will explore options for establishment of RP in existing grass pastures as a lower-cost alternative to current establishment practices.

The objectives of the literature review are to: 1) provide the reader with the framework from which the dissertation research evolved, 2) discuss previous trials to address the issue of sustainability in grasslands and specifically establishment, management, and persistence of tropical grass-legume pastures, and 3) discuss the potential of RP in the USA Gulf Coast. The review is directly targeted to the species and problems being investigated. It starts with an overview of grass-legume mixtures for grazing systems in temperate and tropical environments and then focuses on bahiagrass (*Paspalum notatum* Flüggé) and RP research.

Grass-Legume Mixtures for Grazing Systems

Across environments and production systems, several factors can interact and ultimately determine the fate of a grass-legume mixture in time. They include: environmental factors such as light, temperature, and rainfall; growth habit of each species in the mixture (a function of occupying different niches in time and/or space); nodulation ability and capacity for N fixation; edaphic factors (pH, nutrient availability and form), frequency and intensity of defoliation by grazing animals; ability to survive drought periods; seed production capacity; and pest and disease tolerance. This section compares and contrasts temperate and warm-season grass-legume pastures, with a focus on tropical perennial grasslands under grazing in terms of species composition, establishment, management, and persistence.

Species Composition

In temperate environments, white clover (*Trifolium repens* L.), is the main legume found in pastures and meadows due to its well-developed stolon mass and prostrate growth habit (Sheath and Hay, 1989; Rochon et al., 2004). Neither red clover (*T. pratense* L.) nor alfalfa (*Medicago sativa* L.) are considered as well adapted as white clover to repeated grazing because of observed reduced persistence and slower recovery following defoliation. Nevertheless, efforts to select traits related to grazing tolerance in red clover (Hyslop et al., 1999) and alfalfa (Smith et al., 2000) have had some success. Morphological characteristics of interest for grazing tolerant legumes have included: a deep-set, large crown and underground spreading ability of the plant through rhizomes or horizontal (creeping) roots, like the ones found in the yellow-flowered *M. sativa* subsp. *falcata* (L.) Arcangeli (Piano et al., 1996; Pecetti and Piano, 2005).

There are several other temperate legumes with the ability to successfully perennate in association with grasses in temperate grazing systems, such as: strawberry clover (*T. fragiferum* L.), Kenya white clover (*T. semipilosum* Fres.), greater lotus (*Lotus penduculatus* Cab.), and birdsfoot trefoil (*L. corniculatus* L.) (Gramshaw et al., 1989). Associations occur frequently with perennial ryegrass *(Lolium perenne* L.), tall fescue (*L. arundinacea* Schreb.), kikuyu (*Pennisetum clandestinum* Nees ex Steud), orchardgrass (*Dactylis glomerata* L.), and Kentucky bluegrass (*Poa pratensis* L.) (Gramshaw et al.,1989; Matches, 1989; Sheath and Hay, 1989; Burns and Bagley, 1996; Harris et al., 1998).

Perennial grazing systems in temperate regions have been mainly based on herbaceous forages (grass alone or in combination with legumes). In some countries of Western Europe and the British Isles, the route chosen to provide quality forage for livestock production was mainly through N fertilization. In contrast are the New Zealand and Australian experiences, which were based to a greater degree on exploiting the potential of legumes to fix atmospheric N (Templeton, 1976; Hodgson et al., 2005) in year-long production systems and to match animal requirements with pasture growth (Sears, 1962) under intensive rotational stocking.

Studies on plant population dynamics and effects of defoliation converge on the bases that the successful association of grasses and legumes growing intermingled in temperate regions (i.e., white clover + perennial ryegrass) is founded on the competitive ability of the legume in low N environments (Hill, 1990). The equilibrium of botanical composition in white clover-grass system has been described as dynamic (clover is present in patches and patches move around) with a “biological clock” that resets itself automatically every ~ 4 yr (Parsons et al., 2006). The working hypothesis described by Schwinning and Parsons (1996) is based on ‘exploitation’ interactions (e.g., N fixed by clover is exploited by the grass) which results in a self-regulating system. This occurs because as legume contribution increases the amount of N made available to the companion grass increases followed by an increase of grass competition to the legume. As legume contribution is negatively impacted by grass competition the amount of N available to the grass decreases and is followed by a decrease in grass contribution. There are no similar studies of population dynamics conducted under tropical environments; the first limitation being the management practices required to establish and most importantly to maintain grass-legume associations compared to temperate environments.

In tropical environments the occurrence of associations of grasses and legumes in perennial forage-based grazing systems is less frequent and more diverse (types of species and establishment approaches) compared to temperate regions. Greater adoption has occurred in Asia and Australia than in Africa, USA, or Latin America (with the exception of Brazil; Valentim and Andrade, 2005). Main reasons for limited adoption are: lack of perceived benefits of legumes (realization of economic benefits), failure of technology (diseases, persistence), and failure in approach (no extension support) (Shelton et al., 2005; Sollenberger and Kalmbacher, 2005). Nevertheless, there exist success stories of production systems that have not only included herbaceous species but also shrub and tree legumes. Species used in grazing systems include: stylo (*Stylosanthes spp.*), leucaena [*Leucaena leucocephala* (Lam.) de Wit], sesbania [*Sesbania sesban* (L.) Merr.], clitoria (*Clitoria ternatea* L.), phasey bean [*Pueraria phaseoloides* (Roxb.) Benth.], pintoi peanut (*A. pintoi* Krapov. & W.C. Greg.), rhizoma peanut (*A. glabrata* Benth.), aeschynomene (*Aeschynomene americana* L.), and carpon desmodium (*Desmodium heterocarpon* L). Grasses growing in association include: bahiagrass (*P. notatum* Flüggé), buffelgrass (*Cenchrus ciliaris* L.), brachiarias (*Brachiaria spp.*), gramalote or guineagrass (*Panicum maximum* Jacq.), and gambagrass (*Andropogon gayanus* Kunth.) (Shelton el al., 2005).

Establishment

Successful establishment of grass-legume mixtures has been achieved in both temperate and tropical environments. Establishing a mixture can occur by simultaneously planting seed of several species or by planting one species in an existing sward of the companion species (over-seeding) (Vengris, 1965; Cook, 1980; Mueller and Chamblee, 1984; Cook et al., 1993; Cuomo et al., 2001; Schlueter and Tracy, 2012). In temperate environments, either method is commonly used. In tropical environments, some additional form of management is required to account for the additional plant competition that emerging C3 legumes will encounter from vigorous emerging or existing C4 grasses. Grasses have fibrous root systems that give them an advantage when competing for shallow moisture and soil nutrients. Only when soil N is low are grasses at a disadvantage relative to legumes (Muir et al., 2011). Cook et al.

(1993) have referred to the process of creating favorable conditions for plant establishment as searching for “ecological gaps”. A concept with similar implications referred to as “general ecological combining ability” was used by Hill (1990).

Specific approaches reported in the literature to account for additional management required to establish tropical grass-legume mixtures include: physical separation of the grass and legume components, grazing management, deferred utilization, and timing of planting. Whitebread et al. (2009) proposed simultaneously planting mixtures of burgundy bean [*Macroptilium bracteatum* (Nees & Mart.) Marechal & Baudet], lablab bean [*Lablab purpureus* (L.) Sweet], and *Clitorea ternatea* (L.) in association with guinea grass (*Panicum maximum* Jacq.), yellow bluestem (*Dichanthium aristatum* Poir C.E. Hubb), and creeping bluegrass (*Bothriochloa insculpta* Hochst. Ex A. Rich. A. Camus). Their methodology was based on planting alternating rows of species in strips in a prepared seedbed. Thus, physical separation of the legume and the grass components was the strategy used to manage interspecific competition. For sod-seeding aeschynomene into existing limpograss pastures [(*Hemarthia altissima* (Poir.) Stapf & Hubb.], Sollenberger et al. (1987) proposed grazing limpograss to a low stubble height (8 cm) until aeschynomene seedlings emerged and were ~ 5 cm tall. Cattle were then removed to allow the legume to fully establish, delaying utilization of the mixed pasture until the legume was at least 20-cm tall. Thus, utilization of the pastures was delayed until late July (middle of the growing season).

Associations of forage tree legumes, such as leucaena and sesbania, with grasses have also been successfully achieved. Due to the very slow growth at seedling stage of the legume species, management practices are based on providing a competition-free environment (above and below ground) for growth of the legume until it has reached a certain height followed by planting the grass species. Thus, the tradeoff is minimizing utilization during the year of establishment and allowing for an extended establishment period before introducing the companion grass (Lesleighter and Shelton, 1986; Catchpoole and Blair, 1990; Shelton, 1994).

Studies on the effect of land preparation techniques (seedbed preparation) and management of plant competition through the use of herbicides or defoliation have provided critical information leading to the establishment of mixtures and strategies to lower costs. However, the success of these management practices is dependent upon environmental factors (e.g. rainfall, temperature, soil fertility). In addition, the ultimate fate of these technologies and the degree of their adoption by producers depends in large part on the level and cost of management required to maintain a functional grass-legume mixture under grazing in the long-term (Sollenberger and Kalmbacher, 2005).

Persistence

The capacity to regrow after defoliation and to survive from season to season and year to year are critical determinants of whether a legume will be a successful companion for grass species. For perennial legumes distinguishable as discrete plants (e.g., alfalfa), poor persistence can be clearly defined as reduction in plant density. Defining persistence is more difficult for non-discrete plants that vegetatively propagate by stolons or rhizomes. For these plants, it is not the death of a stolon unit that is viewed as a decrease in persistence, but the relative difference between rate of stolon death and replacement (Sheath and Hay, 1989).

In both temperate and tropical environments, low growing stoloniferous or rhizomatous forage legumes are generally considered better suited to defoliation by grazing rather than erect-growing species. Reasons include the growing points are lower in the sward canopy and are less likely to be grazed, in contrast with upright growth habit types that are better adapted to infrequent defoliation (Pitman et al., 1988; Frame, 2005).

Legume Contribution to Forage-Livestock Systems

Greater voluntary intake, nutritive value, and nutrient availability of forage legumes compared to grasses, often leads to greater animal performance when legumes are present (Dewhurst et al., 2009). Therefore, it is precisely in N-restricted tropical grasslands that inclusion of legumes in forage-based production systems has greater potential positive impact. Nevertheless, legumes remain an under-exploited resource for tropical farming systems (Thomas, 1995; Pengelly et al., 2003; Shelton et al., 2005). The focus of this section of the review is specific examples of how inclusion of legumes in warm-climate grasslands can improve provision of forage for livestock, animal responses, nutrient cycling, and ultimately prevent grassland degradation and advance the goal of sustainable systems.

Forage nutritive value

In general, tropical grasses have lower nutritive value than temperate species for livestock production. Johnson et al. (2001) evaluated the effects of N fertilization (range from 0 to 157 kg N ha^{-1} cutting^{-1}) on yield, digestibility, fiber and protein fractions of 'Tifton 85' bermudagrass (*Cynodon spp*.), 'Florona' stargrass (*C. nlemfuensis* Vanderyst), and 'Pensacola' bahiagrass, harvested every 28 d. The authors reported a quadratic effect of N on digestibility of bermudagrass (ranged from 571 to 599 g kg^{-1}), linear effect for stargrass (ranged from 517 to 576 g kg^{-1}), and no effect for bahiagrass (ranged from 521 to 526 g kg^{-1}). Neutral detergent fiber (NDF) across N rates ranged from 777 to 757 g kg^{-1} for bermudagrass, 769 to 720 g kg^{-1} for stargrass, and 761 to 739 g kg^{-1} for bahiagrass. Acid detergent fiber (ADF) ranged from 330 to 328 g kg^{-1} for bermudagrass, 332 to 317 g kg^{-1} for stargrass, and 362 to 359 g kg^{-1} for bahiagrass; total N (% of forage DM) increased for all three species. Forage CP concentrations were from 98 to 178 g kg^{-1} for bermudagrass, 96 to 176 g kg^{-1} for stargrass, and 90 to 150 g kg^{-1} for bahiagrass. In contrast, temperate grasses like annual ryegrass fertilized with 280 kg N ha^{-1} yr^{-1} clipped every 30 d had CP, digestible dry matter, and NDF concentrations of 232, 848, and 388 g kg^{-1} , respectively (Redfearn et al., 2002). Haby and Robinson (1997) reported that ryegrass CP commonly averages 150 to 200 g kg^{-1} with no N applied and increased to 280 g kg^{-1} at a N rate of 448 kg ha^{-1}.

Minson (1981) presented relative frequency data for crude fiber and CP from six tropical and seven temperate species. The author indicated that 75% of the samples from tropical grasses had between 290 and 370 g kg^{-1} crude fiber (mode of 350), compared to temperate grasses where 60% of the samples had between 170 and 290 g kg^{-1} crude fiber (mode of 230). In terms of CP, 67% of the samples were between 30 and 120 g kg^{-1} for tropical grasses (mode of 80), compared with temperate grasses where 68% of the samples were between 60 and 180 g kg^{-1} CP (mode of 90). Among legumes (tropical vs. temperate), differences in nutritive value are not as marked as among grasses. The mode of both distributions was 16% for CP with 60% of temperate legumes between 120 and 180 g kg^{-1}, and 60% of tropical legumes within 120 and 210 g kg^{-1} CP. Tropical legumes, like temperate ones, are higher in protein and lower in NDF (Van Soest, 1982) compared to grasses.

Muir et al. (2011) conducted a meta-analysis for CP and digestibility of warm-season herbaceous legumes and grasses sampled throughout a complete growing season in the northern hemisphere. Species included that are of particular interest in Florida were: bahiagrass (two cultivars), bermudagrass (three cultivars), elephantgrass (*Pennisetum purpureum* Schumach), limpograss, stargrass, aeschynomene, carpon desmodium and rhizoma peanut (two cultivars). Results indicated that throughout the growing season CP concentration decreased at a similar rate for grasses and legumes; nevertheless, minimum CP concentration was lower for grasses compared to legumes (78 vs. 151 g kg^{-1}, respectively). Digestibility ranged from 493 to 586 g kg^{-1} for grasses and 624 to 793 g kg^{-1} for legumes. Digestibility of grasses decreased at a greater rate than legumes throughout the growing season. Intake is expected to be limited when CP concentration is below 70 g kg^{-1} (Poppi and Mclellan, 1995). Thus, because of increased CP and digestibility, inclusion of legumes in grass-dominated grasslands has the potential to provide higher nutritive value forage for livestock and ultimately increase animal responses.

Animal responses

Increased animal production has been reported in the literature for grazing systems using forage legumes growing in association with grasses. Fribourg et al. (1979) evaluated the effect of four levels of N fertilization (0, 112, 224, and 448 kg ha^{-1}) on ‘Midland’ bermudagrass and compared those responses with that of common bermudagrass fertilized with 112 kg N ha^{-1} and a mixture of orchardgrass (*Dactylis glomerata* L.) and ladino clover (*T. repens* L.). The authors reported greater total beef production (kg ha^{-1}) for the orchardgrass-ladino clover mixture (561) compared with all other treatments except the highest fertilized bemudagrass (605). Stricker et al. (1979) conducted an experiment to determine if calf production could be economically increased by use of N fertilizer and/or creep feeding of spring-born calves grazing tall fescue-ladino clover pastures. The authors concluded that when productive legumes can be maintained in fescue sods, the return from increased carrying capacity by applying N fertilizer was not sufficient to offset the additional cost.

In experiments conducted in the southeastern USA, Rusland et al. (1988) reported greater mean gain ha^{-1} (+113 kg) for a limpograss-aeschynomene mixture compared to N-fertilized limpograss (>100 kg N ha^{-1} yr^{-1}). Pitman et al. (1992) evaluated mixtures of bahiagrass-aeschynomene and bahiagrass-phasey bean vs. fertilized bahiagrass (0, 56, and 224 kg ha^{-1} yr^{-1}). The authors concluded that in 2 yr (out of three), animals grazing bahiagrass-aeschynomene had greater average daily gains and greater total gain compared to 0-N bahiagrass pastures. Greater animal responses due to inclusion of legumes is attributed to greater CP concentration, digestibility, and mineral composition of livestock diets, resulting in greater forage intake and animal performance (Kretschmer et al., 1973; Wilson and Minson, 1980; Minson, 1981; Marten, 1985).

Nutrient cycling

Nutrient inputs and forage utilization are generally greater in temperate forage systems. As a consequence, in intensively managed temperate systems, the greatest contribution associated with more efficient recapture of nutrients may be minimizing loss of nutrients to the environment (Dubeux et al., 2007). In contrast, in many low input tropical pastures efficient recapture of nutrients is critical for increasing productivity to meet increasing demand for beef and milk on already cleared land and to limit expansion of pastoralism into fragile environments such as tropical forests (Thomas, 1992).

Nutrients in a grassland ecosystem reside temporarily and cycle among various “reservoirs” or pools (Dubeux et al., 2007), and fluxes (transfers) connect those pools (Chapin et al., 2002). Nutrient pools in forage systems include: soil organic matter, living plant biomass (above- and below-ground), plant residues (dead, relatively undecomposed plant tissues), living animal biomass, and soil nutrients. In the case of N, inputs that make up an ecosystem’s N supply rate are: mineralization (defined as microbially mediated release of NH_4^+ and NO_3^- from soil organic matter and plant residues), biological N fixation, N returned by grazing animals, and fertilizer or atmospheric N inputs (Wedin and Russelle, 2006).

Nitrogen mineralization and immobilization processes occur simultaneously in the soil, with the relative magnitudes determining whether the overall effect is net N mineralization or net N immobilization (Cabrera et al., 2005). Although biological transformations of N in soils are complex, mineralization largely depends on the quantity and quality (composition) of organic matter (OM) and reflects the influence of the environment, principally temperature and moisture, on biological activity (Goncalves and Carlyle, 1994).

A commonly used index of substrate quality and mineralization-immobilization potential is the C:N ratio. This is based on the premise that for the assimilation of C to occur, N also has to be assimilated in an amount determined by the C:N ratio of the microbial biomass. If the amount of N present is larger than that required by the microbial biomass, mineralization occurs with the release of inorganic N. If the amount of N is equal to that required by the microbial biomass, there will be no net N mineralization. On the other hand, if the amount of N in the material is lower than that required by the microbial biomass, there will be immobilization (Cabrera et al., 2005). Research suggests that the break-even point between net N mineralization and N immobilization can be found between C:N ratios of 20 to 40 (Whitmore, 1996). The existence of a range instead of a single value for the break-even point has been related to variation in the C:N ratio of the decomposing microbial biomass as well as the existence of organic components with different susceptibility to decomposition (Cabrera et al., 2005). Due to their greater N concentration, legume plants have potential to shift the balance toward N mineralization and provide greater plant-available N compared to grasses (Thomas and Asakawa, 1993). Results reported by Sainju et al. (2006) indicate that long-term productivity of RP increased soil C and N pools due its greater N contributions and its lower C:N ratio compared to perennial weeds.

If all other environmental factors are accounted for, the first limitation to N cycling in tropical agro-ecosystems is the lack of N among pools. Thus legumes, through atmospheric N fixation, have the potential to introduce N to the grassland and to increase soil fertility (Drinkwater et al., 1998). Estimates of N fixed by tropical legumes vary depending on species, growing conditions (alone or in association) and method of estimation. Some estimates of N fixed by tropical legumes are: 370, 157, and 63 kg ha^{-1} for calopo (*Calopogonium mucunoides* Desv.), vigna (*Vigna sinensis* L.), and greengram (*Phaseolus aureus* Roxb.) (Agboola and Fayemi, 1972); Cadish et al. (1989) reported ranges from 44 to 132 kg ha^{-1} of N fixed (above ground) for *Centrosema acutifolium* Benth., *C. macrocarpum* Benth., *Zornia glabra* Desv., tropical kudzu

[*Pueraria phaseoloides* (Roxb.) Benth.], desmodium [*Desmodium heterocarpon* (L.) DC subsp. ovalifolium (Prain) H. Ohashi], macrocephala (*Stylosanthes macrocephala* M.B. Ferreira & Sousa Costa), *S. guianesis* (Aubl.) Sw., and *S. capitata* Vogel (Heichel and Henjum, 1991). With an estimated yield of ~10 Mg ha^{-1} yr^{-1}, and N concentration from the above-ground tissue of ~30 g N kg^{-1} dry matter, monocultures of RP grown in Florida potentially fix ~300 kg N ha^{-1} yr^{-1}. To date, there are no studies investigating N fixation and transfer of N when RP is grown in association with other species.

Fixed legume N is transferred to companion grasses indirectly through legume root decay and legume litter decomposition (mineralization processes). Defoliation by grazing or cutting accelerates the rate of turnover of root nodules, and grazing results in N from the grazed forage being returned to the pasture in the form of animal excreta. Research conducted by Thomas (1992) indicated that to maintain a sustainable tropical pasture (without causing a drain on soil organic N reserves), with generally low levels of utilization of 10 to 40%, biologically fixed N or plant litter are likely to have the greatest impact on variation in the amount of internally cycled N. This is compared with temperate climates where utilization is often much greater (70%), and where variation in the recovery of excreta N is likely to have the greatest effect on the requirement for N to balance the cycle. Thomas (1992) suggests that legume content of 20 to 45% of the herbage dry matter could provide the N requirements for a productive and sustainable pasture.

The Southeastern USA Experience

The foundation of grazing systems for the beef cattle industry in the lower latitude states of the southeastern USA (Texas, Louisiana, Mississippi, Alabama, Georgia and Florida) is perennial tropical and sub-tropical forage species. Native as well as planted pastures furnish viable grazing (Chambliss and Lord, 2001). In Florida specifically, bahiagrass, limpograss, stargrass, and hybrid bermudagrasses are the most planted grass species.

In general, temperature is the most important environmental determinant of seasonal forage limitations (quantity and quality) as well as the degree to which perennial and annual species contribute to the system. In terms of quantity, unless winter annuals are introduced in the production system in much of the Lower South, available forage for grazing is severely limited during periods of cool weather (November – April). In addition there are anticipated periods of shortfall due to spring (May through early or mid-June) and fall (October through November) drought (Sollenberger and Chambliss, 1991). Within a growing season, forage quality is highest in spring and decreases as temperatures rise in mid-summer through the fall (Wilson and Minson, 1980; Sollenberger and Chambliss, 1991). Energy concentration in bahiagrass forage, for example, decreases substantially as the season progresses, regardless of fertility or defoliation management; thus, it is not considered well suited to meet the nutritional requirements of young, growing animals or lactating dairy cows (Gates et al., 2004). The same pattern of decrease for bahiagrass in vitro organic matter digestibility (IVOMD) was demonstrated by Sollenberger et al. (1989). They reported a decrease from ~600 to < 500 g kg^{-1} during the August through September period for bahiagrass. In contrast, IVOMD of RP remained above 700 g kg^{-1} throughout the growing season. The authors supported the argument that the so called “summer slump conditions” in the South result primarily from environmental effects on plant characteristics as opposed to a direct effect on the animal (i.e., heat stress). Kretschmer et al. (1973) evaluated CP of associations of *S. humilis* HBK., hairy indigo (*Indigofera hirsuta* L.), siratro (*Phaseolus atropurpureus* DC.), greenleaf [*D. intortum* (Mill.) Urb.], carpon desmodium (*D. heterocarpon* L. DC.); and *Glycine wightii* Willd, grown in combination with digitgrass (*Digitaria eriantha* Steud.), bahiagrass and *Setaria anceps* Stapf. The authors concluded that inclusion of legumes in what were formerly grass pastures has the potential to improve forage quality even when compared to fertilized tropical grasses (up to 126 kg N ha^{-1} yr^{-1}). Crude protein yields for a 2-yr-period were greatest for the grass-greenleaf association (1475 kg ha^{-1}) compared to 172 and 423 kg ha^{-1} for grass with and without fertilization, respectively.

Two legumes that received attention in the past were aeschynomene and carpon desmodium. Aeschynomene was the first palatable, highly nutritious legume determined to be adapted to seasonally wet, relatively infertile soils of the region. Carpon desmodium was the first perennial (in southern Florida at least) identified, and although it lacks palatability and the nutritional qualities of aeschynomene it was found to be persistent under close grazing. While reviewing adoption/inclusion of legumes in grass swards in the region, Sollenberger and Kalmbacher (2005) explained that although partnership between cattlemen, seedsmen, research, and extension personnel was strong, the difficulty of consistently establishing and maintaining these legumes in pasture had been underestimated. Aeschynomene seedlings emerge in the spring, but late spring drought (April-May) can be devastating to initial establishment and re-establishment from natural reseeding in many years. Erratic stand establishment and poor seedling vigor under moisture stress have also limited use of carpon desmodium.

Pitman et al. (1998) evaluated 50 tropical legume accessions, representing 33 species and 17 genera, for persistence under two stocking rates (5 and 2 head ha^{-1}), as single row entries in bahiagrass pastures. Grazing was deferred for one year to allow for establishment. Grazing stubble height was 15 cm based on the bahiagrass component. Their results indicated that accessions with prostrate growth habit and seed production had the greatest potential for inclusion in grazing systems in Florida. Similar conclusions were reached by Muir and Pitman (1991). Hernández Garay et al. (2004), likewise, reported similar results when looking at the growth habit of RP Florigraze and Arbrook subjected to grazing. The authors attributed the greater decrease in the proportion of RP in the herbage mass (-23 vs. -3 percentage points for Arbrook vs. Florigraze, respectively) over 3 yr to the more upright growth habit of Arbrook compared to Florigraze, suggesting that Arbrook was less grazing tolerant than Florigraze.

The majority of the experiments conducted in this region have utilized deferment of grazing during late summer, as a strategy to allow seed set and development of a soil seed bank of naturally reseeding legumes for re-establishment year after year. This period coincides with the time where inclusion of legumes can have the greatest impact in animal responses due to decreasing quality of warm-season grasses. Thus, use of legume species that perennate by means of regrowth from stolons or rhizomes, as opposed to seeds, seems to be better suited for regional grazing systems than annuals which require reseeding each year. This supports investigation of the potential of RP for grass-legume mixtures.

Regional literature on animal responses while grazing grass-legume mixtures (growing intermingled) is limited. Most of the research has been done in Florida. While there is documented methodology to establish grass-legume mixtures [i.e., for aeschynomene in limpograss pastures see Sollenberger et al. (1987); for mixtures of aeschynomene, phasey bean (*Macroptilium lathyroides* [L.] Urb.) and carpon desmodium in bahiagrass pastures see Aiken et al.(1991b)], measurements were limited to portions of the growing season due to the management strategies required to allow establishment and/or to sustain persistence of the legume component of the pasture. For example, Rusland et al. (1988) reported greater animal responses (i.e. average daily gain and gain ha^{-1} over a 3-yr period) for a limpograss-aeschynomene association compared with fertilized limpograss. In that study, measurements were limited to mid-summer to early fall allowing for establishment of the legume in the mixture in early summer. Additionally, the legume was over-seeded each year. In another study, Aiken et al. (1991a) used yearling steers to graze a mixture of carpon desmodium, aeschynomene, and phasey bean growing intermingled with bahiagrass. Desmodium is persistent under grazing but difficult to establish, while aeschynomene and phasey bean are easier to establish but are short-lived legumes. They reported that during the first summer aeschynomene and phasey bean contributed the most to the animal diets while during the second summer (year) contribution from carpon desmodium was greater while that of aeschynomene and phasey bean was limited.

Bahiagrass

Bahiagrass is the most widely planted forage species in the state of Florida and represents the foundation of the beef cattle industry. It is not the purpose of this section to provide a thorough review of the bahiagrass literature. Such work has been published by Gates et al. (2004). Rather, the objective is to discuss the potential benefits of growing associations of RP and bahiagrass.

Two-thirds of improved pastures are planted with bahiagrass in Florida, which accounts for almost 1 million hectares (Newman et al., 2011). Bahiagrass is a perennial with strong, shallow, horizontal rhizomes formed by short, stout internodes usually covered with old, dry leaf sheaths. Leaves are mostly crowded at the base. ‘Pensacola’ bahiagrass belongs to *P. notatum* var. saurae, and when compared to common bahiagrass, it is taller, spreads faster, has longer and narrower leaves, smaller spikelets, and can have more racemes per inflorescence.

Most of the agricultural land area planted to bahiagrass is used for pasture in extensive cow-calf production systems (Gates et al., 2004). Bahiagrass is particularly well suited to this use because of its persistence, even under low soil fertility, and tolerance of environmental stresses and severe grazing by livestock. Bahiagrass has good forage quality during spring, but forage quality drops in July and August due to the high temperatures and abundant rainfall. With low levels of fertilization (≤ 50 kg N ha^{-1} yr^{-1}) bahiagrass is moderately productive during spring and summer, but it offers very little fall growth. While other improved perennial grasses such as stargrass and bermudagrass are higher in quality and more productive than bahiagrass throughout the year, they also require more management in order to maintain good stands and prevent overgrazing (Chambliss and Loor, 2001; Johnson et al., 2001). Bahiagrass is relatively free of pests with the exception of mole cricket (*Scapteriscus spp.*).

In summary, while morphological and agronomic characteristics have proven bahiagrass to be the best adapted species grown in Florida for extensive production systems, it is the relative low nutritive value of bahiagrass that sets the upper limit to animal responses, especially in low-input (N limited) forage-livestock systems. This situation has long been recognized and provides an opportunity to investigate the inclusion of legumes, like RP, in mixtures with bahiagrass as a potential source of N for the pastures, to increase animal production, and ultimately to take a step toward sustainable systems that are not dependant on N fertilization.

Rhizoma Peanut

Origin, Distribution, and Adaptation

The genus *Arachis* is native to South America. *Arachis glabrata* is indigenous to Argentina, Paraguay, Uruguay, Bolivia, and Brazil (Bogdan, 1977; Gregory and Gregory, 1979). It is scattered between the Paraguay and Paraná River basin north of their junction in Corrientes, Argentina (Gregory et al., 1980). It is found from altitudes of 50 m and higher above sea level and has been reported at latitudes from 8 to 35° south. In the USA, cultivation of RP has been typically limited to the warm, humid climates with well-drained soils in the Gulf Coast Region. Nevertheless, efforts exist to select and cultivate cold-tolerant RP lines across the Gulf Coast Region and to higher latitudes.

The first record of introduction of *A. glabrata* into the USA was an addition to the USDA National Plant Germplasm System in 1936 when a collection from Matto Grosso, Brazil, became PI 118457 (Quesenberry et al., 2010). Selections 'Arb' (PI 118457) and 'Arblick' (PI 262839) were released as germplasm in the 1960s, but their use was very limited due to slow establishment and low productivity (Williams et al., 2008). Commercial acceptance of rhizoma peanut did not occur until after the release of the cultivars Florigraze (PI 421707) in 1978 and Arbrook (PI 262817) in 1986 (Prine et al., 1981; 1986a,b; Williams et al., 2008) by the University of Florida. In general, cultivars selected for use in Florida are adapted to well-drained sandy soils (Prine et al., 1981; Prine et al., 1986a,b).

Niles et al. (1990) reported that establishment of Florigraze was negatively associated with increasing soil pH (pH range from 5.2 to 7.9). Reed and Ocumpaugh (1991) evaluated Fe-deficiency chlorosis using Arbrook, Florigraze, a Florigraze off type, and 69 rhizoma peanut PIs on a Parrita soil (pH 8). Their results indicated that Line 35 and Arbrook were the highest yielding; however, Line 35 was superior to Arbrook in resistance to Fe-deficiency chlorosis. A selection named ‘Latitude 34’ that was originally collected near Trinidad, Paraguay (27° 8´S 55°37´W, elevation 50 m) was selected for persistence and early spring production under cold, dry climatic conditions up to 34°N latitude. Efforts to identify/select cold tolerant RP are an active area of research (Interrante et al., 2011).

Taxonomy and Morphology

Arachis glabrata was named rhizoma peanut because of its rhizomes. It belongs to the section VIII *Rhizomatosae* Series *Rhizomatosae*. Rhizomes are underground stems with buds in the axils. The rhizome grows year after year and shoots emerge from buds on the rhizome. *Arachis glabrata* is a self-pollinated, decumbent, long-lived warm season perennial. Leaves are tetrafoliolate. Stipules are subulate, villous to glabrous, sometimes with bristles. Leaflets are oblong, elliptical or obovate, with the margin somewhat marked on the underside. The upper leaf surface is usually glabrous, but younger leaves may exhibit some very short, scattered hairs. The lower leaf surface is described as having adpressed hairs to subglabrous, and frequently with hairs somewhat longer on the midvein. The hypanthium is well developed and villous. The calyx is villous. Flower color is standard orange and rarely yellow (Krapovickas and Gregory, 2007).

Breeding and Selection

All of the cultivars of rhizoma peanut grown in the USA are either plant introductions or naturally occurring seedlings that were isolated and increased. Breeding of rhizoma peanut is limited, mainly because there is very little (or none in some of the released cultivars) seed production and propagation of the crop is done with vegetative tissue (rhizomes). Low occurrence of cross pollination by insects and parthenogenesis has been reported for RP, as is the case for Florigraze, which is thought to be a chance hybrid that originated from a naturally occurring plant between 1-yr-old plots of P1118457 and P1151982 (Prine et al., 1986a). Nevertheless, a hybridization process, which could help to make improvements in the population under a more systematic approach, is practically non-existent for RP.

Four forage-type cultivars of RP have been released by the University of Florida (Florida Agricultural Experiment Station). Cultivars Florigraze and Arbrook were released in 1978 and 1986, respectively (Prine et al., 1981; Prine et al., 1986a,b; Prine et al., 1990), and UF Tito (PI 262826) and UF Peace (PI 658214) were released in 2008 (Quesenberry et al., 2010). Arbrook has larger stems and leaflets than Florigraze, is better adapted to excessively-drained soils and makes more rapid upright growth, but it spreads laterally slower and is less cold tolerant than Florigraze (Prine et al., 1986b). UF Tito and UF Peace showed improved field tolerance to peanut stunt virus (PSV; member of the cucumo virus) compared to Florigraze. UF Peace had greater lateral spread than the others and UF Tito was reported to be more competitive with common bermudagrass (Quesenberry et al., 2010). In addition, two low growing ornamental types of RP were released as germplasm with potential for forage. These were called Ecoturf (PI 658529) and Arblick (PI 658528). Numerous experimental lines and plant introductions have been evaluated in Louisiana (Venuto et al., 1995; Venuto et al., 1997) under the same selection criteria, but none of them out-yielded Florigraze.

As pointed out by Prine et al. (2010), the selection process so far has mainly focused on yield, and accessions that were relatively low growing with excellent ground cover potential were not included in later stages of the selection process. Thus, the fact that selection was done mainly in an environment free of any type of competition is more similar to a hay production system rather than the grazed forage-livestock system toward which RP is being targeted in the current research program. Other efforts for selecting RP have been conducted in Australia using additional criteria such as spread in pure stands and in combination with ‘Argentine’ bahiagrass (Bowman and Gogel, 1998). The authors reported that accession CIP 93483 (PI 231318), which has been released as cv. Prine, and CPI 93469 (PI 262833) have the ability to persist and spread on the north coast of New South Wales.

Pest and Diseases

Rhizoma peanut is generally recognized as resistant to economically serious pests and diseases (i.e., early and late leaf spot caused by *Cercospora arachidicola* and *Cercosporidium personatum*, respectively, and rust caused by *Puccinia arachidis*; Ruttinger, 1989). Rhizoma peanut has been documented to be infested with cotton root rot (*Phymatotrichopsis omnivore*) (Barnes, 1990). Cotton root rot, also known as Texas root rot, is a naturally occurring fungal pathogen found throughout Texas and southern Oklahoma, prevalent in calcareous clay-loam soils with a pH range of 7.0 to 8.5 in areas with high summer temperatures. Infected areas appear as circular patterns throughout the field where the rhizoma peanut initially dies back. Arbrook suffers greater losses from cotton root rot than Florigraze. Also, isolated cases of leaf spot caused by

Phyllosticta sp., *Stemplylium sp.*, and *Leptosphaerulina sp*. have been observed in Florida, but no long term damage has been reported (French et al., 1994). To date, peanut stunt virus (PSV) may be the one most important disease in Florida affecting RP fields. Symptoms of PSV include: stunted plants, chlorosis, malformed leaves, and reduced foliage yield (Blount et al., 2002). The majority of RP fields in Florida are planted to Florigraze which is susceptible to PSV. Nevertheless, it is expected that acreage planted to cultivars UF Tito and Peace, reported as showing field resistance to PSV, will increase over time as an alternative to control PSV infection.

Establishment

Establishment is a key phase in the life of a sward since it lays the foundation for future productivity, resistance to weed invasion, tolerance of stock trampling if grazed, and resistance to wheel traffic if cut for conservation. The aim is to provide the best conditions for germination of the sown forage seeds, for vigorous shoot and root development of the seedlings, and finally for the formation of a dense sward. Nevertheless, if RP is to be to be grown in association with grasses, then the parameters of selection for establishment could potentially be modified.

Rhizoma peanut is propagated vegetatively using rhizomes, most often with equipment designed for establishment of vegetatively propagated tropical grass pastures (e.g. conventional bermudagrass sprig digger/planter) (Williams et al., 1997; Williams et al., 2002). Establishment is also possible by broadcasting the rhizomes on the surface of a prepared seedbed followed by disking for soil incorporation.

Research conducted in Florida provided recommendations for RP establishment. Reliable soil moisture (for 60 to 90 d after planting), a planting date with the longest frost-free period (Williams, 1993; Williams et al., 1997), and chemical composition of planting material (Rice et al., 1995) were reported as major determinants of the overall success of RP establishment. Patterns of carbohydrate and rhizome mass accumulation have led to recommendations that defoliation of nursery areas be minimized or avoided when rhizomes are to be used as planting material (Saldivar et al., 1992a,b). Rice et al. (1995) suggested that to minimize the risk of stand failure, RP producers should plant rhizomes with pre-plant total non-structural carbohydrates (TNC) and N concentrations ≥ 228 and ≥ 20 g kg^{-1}, respectively. The minimum planting rate generally recommended is 8–10 Mg ha^{-1} (packed at ~ 79 kg m^{-3}), and the rule of thumb is that 1 ha of well-managed nursery area produces enough rhizomes to plant 15 to 20 ha of RP (Williams et al., 2011).

Canudas et al. (1989) evaluated planting rates (0.3, 0.6, 1.2, 2, and 3.4 Mg ha^{-1}) of Arbrook and Florigraze RP rhizomes planted with a row spacing of 0.5 m. For the treatments where herbicides were used to control broadleaf and grass weeds, ground cover showed a quadratic response as planting rate increased. Ground cover measured in October of the planting year peaked at an approximate planting rate of 2.2 Mg ha^{-1} for Arbrook (80%) and 2.7 Mg ha^{-1} for Florigraze (60%). They reported that Arbrook out-yielded Florigraze across their set of treatments (herbicide × planting rate). There was a linear and quadratic response of RP dry matter (DM) harvested to planting rate for both cultivars in the year-of and year-after establishment. The authors suggested that due to the cost of establishment, planting rates of 1 Mg ha^{-1} or lower are most likely to occur. Prine et al. (1986a) reported that rhizome yields range from 70 to 175 m^3 ha^{-1} and recommended a planting rate of 3.6 m^3 ha^{-1} or greater. Indeed, at that rate of planting a full stand of peanut is generally achieved by the beginning of the third year. Canudas et al. (1989) reported that during the year of establishment DM harvested increased linearly as planting rate increased (at a planting rate of 3 Mg ha^{-1}, dry matter yield was ~2.5 and ~1.5 Mg ha^{-1} for Arbrook and Florigraze, respectively) compared to a quadratic effect during the year after establishment where maximum yield leveled off at a planting rate of 3 Mg ha^{-1} with ~11 and 9 Mg ha^{-1} for Arbrook and Florigraze, respectively.

Williams (1993) evaluated planting dates (winter: December to March; and summer: June to August) and three pre-plant tillage (well prepared, moderate grass competition, and no pre-plant tillage) effects on RP establishment in existing bahiagrass swards. The swards were burned or mowed before treatments were applied in winter and summer. Regardless of treatment, first sprout emergence was 5.1 and 3.1 wk after winter and summer plantings, respectively. Sprout emergence declined to zero 6 to 7 wk after first sprout emergence. The effect of pre-plant tillage varied with planting date and year, but the trend was: well prepared > moderate grass competition = no pre-plant tillage. She concluded that RP should be planted in well-prepared fields during winter. Similar recommendations were given by French and Prine (1991) who suggested a planting time of February through March in Florida.

Cultivar (Arbrook vs. Florigraze), planting date (February, April, June, August, and December), and location (Brooksville, Gainesville, and Quincy, FL) effects on emergence (at 2 to 12 wk post-planting) and rate of cover of RP were investigated by Williams et al. (1997). The authors indicated that number of sprouts m^{-2} at 12 wk post-planting ranged from 0 to >200 and, in most cases, the sprout counts obtained for April, June, August, and December planting dates were lower or equal to those from the February planting date, regardless of location or cultivar. On average, February plantings achieved >60% RP ground cover 26 wk earlier than any of the other planting dates. Also, correlations of sprout emergence and estimated ground cover were greatest ($r = 0.69$) for sprout emergence measured at 12 wk with ground cover measured at 26 wk post-planting.

Effects of planter type (no-till vs. conventional sprig planter), ground preparation (undisturbed sod vs. rotovated), planting date (winter vs. summer), and herbicide (glyphosate [N-(phosphonomethyl) glycine] vs. none), on establishment and survival of RP were evaluated by Williams et al. (2002). The authors concluded that there was no planter type effect on RP establishment (at emergence and final sprout counts measured 12 wk post-planting). Further, they reported that RP ground cover was greater for rotovated+herbicide (22%), compared to rotovated no herbicide (13%), herbicide not rotovated (6%), and no herbicide not rotovated (2%). The authors concluded that there are options in terms of management practices to establish RP that can be adapted to production goals; i.e., clean cultivation establishment for hay production or dairy cattle grazing, and sod planting without herbicide for less intensive situations.

Responses to Clipping and Grazing

Literature on responses to clipping and grazing is more prevalent for monocultures of RP than for RP-grass mixtures. Reports of RP-grass mixture responses to clipping and grazing are limited, probably because establishment of pure stands of RP has been the assumed goal. It is likely that RP-grass mixtures have occurred primarily because of failure to control grass weeds in existing swards that initially were intended for production of RP hay. Thus, studies that look at the equilibrium/dynamics of RP-grass systems (i.e. botanical composition, nutrient cycling) under grazing, similar to the white clover-grass systems described for temperate environments (Parsons et al., 2006), remain an area of research to be explored.

One of the few studies that evaluated botanical composition in a grazed RP-grass mixture as a function of N fertilization (0 and 35 kg ha^{-1}) and stocking rate (1.5 vs. 2.5 animals ha^{-1}) was conducted by Valencia et al. (1999). The authors concluded that N fertilization increased grass herbage mass (+8 percentage points), and that over time there was a decrease in the RP component (-9 percentage points). The authors reported that there was no change in population of the weed Mexican tea (*Chenopodium ambrosioides* L.) as a function of increased grass contribution due to N fertilization. Further, they attributed the lack of botanical composition response to stocking rate to the stocking rates used being in the low range. The authors suggested that application of N may be more useful for weed control in RP-grass swards when used as a preventative measure; also, that longer term experiments (> 3 yr) would probably explain better the changes in botanical composition as a function of the treatments.

Above-ground biomass

Under clipping, dry matter yields of RP harvested for hay range from ~7 to 13 Mg ha^{-1} yr^{-1} for Florigraze (Prine et al., 1986a) and up to ~16 Mg ha^{-1} yr^{-1} for Arbrook (Beltranena et al., 1981; Prine et al. 1981, 1986b, 1990). Annual forage yields are reduced when RP is cut at intervals less than 6 wk (Beltranena et al., 1981). In a multi-location study across Florida, DM yield (total of two harvests per year) of UF Tito was generally equal or greater than Florigraze, and UF Peace yield was similar to UF Tito (Quesenberry et al., 2010).

Mislevy et al. (2008) evaluated harvest management (2.5- vs 10-cm stubble height) for several RP entries [Arbrook Select (local ecotype), Arbrook (released cultivar), PI 262839, PI 262826, Florigraze (released cultivar), Ecoturf (PI 262840), and PI 26283] on above-ground biomass yield, nutritive value (IVOMD, CP), root mass, and persistence on Florida flatwood soils (Ona series). The plots were harvested every time the RP canopy reached 30-cm height. The authors reported that harvesting RP to 2.5-cm stubble height resulted in greater DM yields during the first 2 yr (average across entries was 7 Mg ha^{-1}) compared to 10-cm stubble height (4 Mg ha^{-1}). Dry matter yield was not different between stubble heights in Years 3 (4.2 Mg ha^{-1} for 2.5-cm stubble height, and 3.9 Mg ha^{-1} for 10-cm stubble height) and 4 (6.5 Mg ha^{-1} for both stubble heights). Also, the authors reported that entries Ecoturf, PI 262833, and Florigraze exhibited DM yield increases of +89%, +26%, and +54%, respectively, between Year 1 and 4, compared to the others which were similar or lower in Year 4. The authors reported that CP (3-yr averages) was greater for Ecoturf (192 g kg^{-1}) and PI 262833 (189 g kg^{-1}) compared to Florigraze (160 g kg^{-1}) and Arbrook (150 g kg^{-1}). The authors suggested that greater CP may have been the result of greater leaf to stem ratio for the Ecoturf and PI 262833 entries, although such measurements were not taken. For IVOMD, PI 262833 (799 g kg^{-1}; 3-yr average) was greater than Arbrook Select (667 g kg^{-1}) and Arbrook (669 g kg^{-1}), with the other entries falling in between these values. Florigraze (3-yr average) IVOMD averaged 700 g kg^{-1}. Overall, the authors reported that CP and IVOMD were not affected by stubble height. In spite of greater RP yields for the 2.5-cm stubble height during the first 2 yr, the authors recommended that RP producers on Florida Spodosols maintain a 10-cm stubble height to prevent invasion from weeds based on ground coverage data showing that after 4 yr the 10-cm stubble height had 38% greater RP cover than the 2.5-cm stubble height,.

In a clipping study at three locations in Louisiana, Redfearn et al. (2001) evaluated the effects of harvest frequency (every 30 and 60 d) and N fertilization (0, 110, and 220 kg N ha^{-1}) on CP, NDF, and in vitro true digestibility (IVTD) of Florigraze RP. The locations were conducted at latitude slightly below 31° N. The plots were clipped at 8-cm stubble height. Averaged across locations, CP concentration was 205, 207, and 205 g kg^{-1} for 0, 110, and 220 kg N ha^{-1}, respectively, when harvested at a 30-d interval, and 165, 166, and 169 g kg^{-1} for 0, 110, and 220 kg N ha^{-1}, respectively, when harvested at a 60-d interval. The authors concluded that responses of CP yield and nutritive value were influenced more by environment (primarily rainfall) than by N fertilization and harvest management. In a similar study conducted in Louisiana, Venuto et al. (1998) reported that DM yield of RP is not likely to be increased by N fertilization.

Ortega et al. (1992) evaluated the effects of grazing frequency (grazing cycles of 7, 21, 42 and 63 d; a grazing cycle consisted of 2 d or fewer of grazing plus the resting period between grazing events) and grazing intensity (residual above-ground dry matter after grazing of 500, 1500, and 2500 kg ha^{-1}) on RP productivity (herbage accumulation) and persistence (botanical composition by weight). The study was conducted on a well-established Florigraze RP pasture (5-yr-old stand) with an average botanical composition at the start of the experiment of 90% RP and 10% common bermudagrass.

Year 1 RP herbage accumulation ranged from 6130 to 10 240 kg ha^{-1} and increased linearly as length of grazing cycle and amount of residual dry matter increased. In Year 2, herbage accumulation increased as length of grazing cycle increased when residual dry matter was low, but length of grazing cycle had less effect as residual dry matter increased. Rhizoma peanut percentage was greatest with high residual dry matter and long grazing cycle, but values of 80% or greater in the second year were achieved with residual dry matter as low as 1300 kg ha^{-1} when grazing cycle was 63 d, or with grazing cycle as short as 7 d when RDM was above 2300 kg ha^{-1}. The authors concluded that to maintain 80% RP or greater when grazing cycle was 42 d required a residual dry matter after grazing of ~1700 kg ha^{-1} (~16-cm stubble height) or greater, but if grazing cycle was 21 d or shorter a residual dry matter of 2300 kg ha^{-1} (~20 cm) was required. In terms of nutritive value, RP grazed to 1800 kg ha^{-1} residual dry matter every 35 d had CP > 150 g kg^{-1} and IVOMD >700 g kg^{-1} (Sollenberger et al., 1989).

Below-ground biomass

In a study by Mislevy et al. (2008), the authors reported that harvesting RP to 2.5-cm stubble height reduced below-ground (root + rhizome) biomass compared to harvesting to 10-cm stubble height. Over a 4-yr period, below-ground biomass was 242 and 135 g m^{-2} for 10- and 2.5-cm stubble heights, respectively. The authors reported the same trend for all entries evaluated and suggested that lower below-ground biomass for the 2.5-cm stubble height treatment was the result of new shoot development at the expense of underground carbohydrate reserves, since most of the above-ground photosynthetically active machinery (leaves) was removed.

A series of studies conducted by Saldivar et al. (1992a,b) near Gainesville, FL, evaluated the effect of defoliation frequency (2, 6, and 8 wk) on above- and below-ground biomass production, total non-structural carbohydrate (TNC) and N concentration. The authors reported that during the year of establishment, accumulated total dry matter (above- + below-ground biomass) increased until September, when above-ground (shoot) growth plateaued or declined while below-ground (rhizome) growth continued. Shoot/rhizome ratios increased from zero at planting to about 1.5 to 2 by late summer, and then declined to about 0.5 in autumn. Further, the authors indicated that as defoliation frequency increased, rhizome dry matter production decreased by one half (8 wk) to two-thirds (2 and 6 wk) compared to undefoliated plants during the year of establishment. In general, belowground TNC and N concentration were more responsive to defoliation management compared to above-ground tissue. The authors reported that when growth (active shoot emergence) was initiated, TNC concentration in the rhizomes declined and generally ranged between 100 and 200 g kg^{-1} during the summer season. Toward the end of the growing season (autumn), TNC concentration increased again to levels of about 400 g kg^{-1}, which was coupled with increasing rhizome mass. The authors indicated that N concentration in the rhizome declined in spring and then leveled off after sufficient shoot development was reached; but in general, patterns of N concentration were less marked compared to TNC.

Under grazing conditions, Ortega et al. (1992) reported similar patterns of TNC as a function of defoliation intensity and frequency as reported by Saldivar et al. (1992a,b). The authors reported that lower values of RP rhizome mas were associated with low levels of residual dry matter and short grazing cycle. They indicated that rhizome mass increased with increasing length of grazing cycle when residual dry matter was 1000 kg ha^{-1}, and that at residual dry matter of 1700 kg ha^{-1}, or greater, the effect of grazing cycle was negligible. Further, lower TNC values in the rhizomes were associated with lower residual dry matter as a function of less residual leaves left for photosynthesis after defoliation.

Weed Control

Weed control in RP swards is an active area of research. The literature reported has mainly focused on the use of herbicides for weed management during establishment and for maintenance of monoculture RP fields. To this point, chemical control has been the most effective practice to control competition from weeds. A short list of the most problematic weeds for forage managers in Florida for RP and bahiagrass fields include: common bermudagrass, nutsedges (*Cyperus sp.*), cogongrass [*Imperata cylindrical* (L.) P. Beauv.], smutgrass [*Sporobolus indicus* (L.) R. Br.], dogfennel [*Eupathorium capillifolium* (Lam.) Small], Mexican tea, Florida pusley (*Ricardia scabra* L.), tropical soda apple (*Solanum viarum* Dunal); blackberry (*Rubus sp.*), and thistle [*Cirsium vulgare* (Savi) Ten.].

Canudas et al. (1989) evaluated the effect of post-emergence herbicides paraquat (0.56 kg a.i. ha^{-1}), sethoxydim (0.44 kg a.i. ha^{-1}), basagran (1.12 kg a.i. ha^{-1}) and dicamba + 2,4-DB amine (0.49 kg a.i. ha^{-1}) to control broadleaf and grass weeds during establishment of Florigraze and Arbrook. In that experiment, seedbed preparation consisted of disking during January and application of herbicides vernolate (2 kg a.i. ha^{-1}) and benefin (1.7 kg a.i. ha^{-1}) for pre-emergence control of grass and broadleaf weeds. The authors reported that greatest canopy cover during the year of establishment was achieved when broadleaf and grass weeds were controlled; nevertheless, Arbrook plots in which broadleaf weeds were controlled had lower RP canopy cover than the no-herbicide control. They attributed this response to growth habit differences between the RP cultivars; Arbrook with a more up-right growth habit was better able to compete for light with broadleaf weeds than was Florigraze, while Florigraze was more competitive with the shorter grass weeds than with broadleaf weeds. The authors reported that by the end of the year of establishment RP yield was almost double in the broadleaf+grass weed controlled treatment compared to no application of herbicides. Differences between herbicide treatments in the second year were not as great as in the first, partially due to uniform control of broadleaf weeds over all plots and because peanut competes well for light and nutrients after it is established. The authors indicated that rope-wick applications of herbicides like dicamba+2,4-DB amine were effective management practices for control of dogfennel in establishing peanut. No specific reference was made regarding injury of RP plants due to herbicides.

In a RP field (>10 yr old) infested mainly with Mexican tea and cogongrass, Valencia et al. (1999) evaluated the application of glyphosate (1.12, 2.24, and 3.36 kg a.i. ha^{-1}) and triclopyr (0.56, 1.12, and 1.68 kg a.i. ha^{-1}) during the summer on dry matter yield and botanical composition of the sward. The authors reported that 2 mo after herbicide application Mexican tea dry matter yield decreased with increasing rate of glyphosate (86% reduction at the highest rate compared to control); nevertheless, after 4 mo dry matter yield of Mexican tea increased from recovering treated plants, as opposed to emerging seedlings. Thus, the authors concluded that more than a single application of glyphosate might be needed to control Mexican tea. There was no effect of glyphosate on cogongrass or other grasses, but there was a linear decrease in RP dry matter yield as rate of glyphosate increased. The injury (phytotoxic) effect of glyphosate on RP was observed even 4 mo after application. The authors reported no effect of increasing rates of triclopyr to control Mexican tea; at the low rates there was

81% reduction in dry matter yield and this was consistent when measured 4 mo after treatment. Triclopyr did not control cogongrass, and it increased linearly with increasing rates of triclopyr.

Ferrell et al. (2006) evaluated the use of post-emergent herbicides (in kg a.i ha^{-1}) 2,4-D amine (0.56); 2,4-DB (0.48); imazamox (0.06); imazapic (0.07); and hexazinone (0.28 and 0.56) on injury and yield of well-established (10-yr-old plots) Florigraze and Arbrook swards. Their results showed that 2,4-DB, imazamox, and imazapic can be applied either at 3 or 21 d after clipping RP with minimal risk of visual injury or yield loss, as opposed to hexazinone which could only be applied at 3 d after clipping. Further, the authors reported that the effect of 2,4-D amine on RP injury and yield was cultivar dependent. For Arbrook, application of 2,4-D amine had no effect on yield with little visual injury at either 3 or 21 d after clipping. In contrast, when it was applied 21 d after clipping Florigraze there was 21% yield reduction compared to that observed when 2,4-D was applied 3 d after clipping. Yield from plots treated 3 d after clipping was no different than the control and the other herbicides.

There are resources to provide reasonably effective control of weeds growing in monoculture RP fields and in bahiagrass pastures. However, control of weeds in RP-bahiagrass mixtures may present a challenge because herbicides targeted to a specific weed species may injure either the desired grass or RP component of the mixture. In addition, herbicides used to control weeds in bahiagrass pastures may not be used in RP fields, and herbicides that have proven effective in control of weeds and cause little injury to the desired species may not be labeled for use in a specific state (e.g., imazamox in Florida in RP fields). Ferrell and Sellers (2012) compiled a list of herbicides to be used in RP fields in Florida. The list consists of the herbicides 2,4-D amine, imazapic, and clethodim. Further studies are needed to determine the economic/biological threshold for herbicide application for controlling weeds in RP-grass swards for both grazing and hay production.

Potential for Use in Grazed Pastures in the Gulf Coast USA Region

In Florida and across the lower southeastern USA, RP use is mainly in hay production systems. Within these systems, the costs associated with vegetative establishment, management for weeds and water, and taking land out of production for one or more growing seasons to allow adequate establishment of the RP crop may be affordable (Adjei and Prine, 1976; Prine et al., 1986a; Rice et al., 1995). Rhizoma peanut is rarely planted in association with or into existing pastures; RP-grass mixtures exist because of failure to control weeds in fields that initially were intended for the production of pure RP hay.

In contrast to these relatively high-input systems, the presence of even relatively small amounts of RP in low-input, warm-climate grazing systems, typically dominated by C4 grasses, may increase the nutritive value of the sward and the overall productivity of the system (Lascano, 1994), and reduce the need for N fertilization. Prine (1980) found that Florigraze, once established, grows well in mixtures with digitgrass, bermudagrass, or bahiagrass if no N was applied.

Several experiments have reported the performance of animals in RP swards compared to monoculture grasses (with and without fertilization). For example, Sollenberger et al. (1989) reported greater animal live weight gain and gain ha^{-1} for animals grazing RP swards compared with N-fertilized bahiagrass. Similar studies have been reported in the literature using pinto peanut (Lascano, 1994). Nevertheless, it is not known at this point the relative contribution of RP in terms of animal responses and N contribution to the sward as a function of varying quantities of RP in the RP-grass mixture. Further, it is not known if management practices may be able to account for the slow establishment characteristic of RP plants and allow utilization of the pastures planted to RP during the year-of or year-after establishment.

In terms of nutritive value, all released RP lines have similar characteristics. Quesenberry et al. (2010) provided estimates for all the released lines in Florida. They indicated that Florigraze, Arbrook, Ecoturf, UF Peace, and UF Tito ranged from 170 to 200 g kg^{-1} for crude protein, and 340 to 400, 420 to 510, and 80 to 90 g kg^{-1} for acid detergent fiber (ADF), neutral detergent fiber (NDF) and lignin, respectively. Also, total digestible nutrients (TDN) ranged from 510 (Arbrook) to 570 (Ecoturf) g kg^{-1}; relative feed value ranged from 105 (Arbrook) to 132 (Ecoturf) compared to the industry standard, alfalfa, which ranged from 110 to 160. In summary, RP has the potential to provide high quality forage for livestock in warm climates comparable to that provided by alfalfa (Romero et al., 1987) in temperate regions.

Several positive attributes of RP contribute to the perception of it having high potential in Florida and areas of the southern Gulf Coast USA. In terms of grazing systems, one of the most important characteristics is persistence. Persistence of RP has been reported under a wide range of management systems for hay, silage, grazing, and as an understory forage crop (Prine et al., 1981; Ortega et al., 1992; Johnson et al., 2002). Nevertheless, such studies and others that have evaluated animals responses have been conducted in monocultures of well-established (≥ 5 yr old) RP swards.

Information is needed regarding the opportunity to utilize forage during the legume establishment phase, so that land is not totally removed from the grazing rotation.

Novel approaches for overcoming the barriers to successful growth of legumes in association with grasses in warm climate pastures and to identify low-cost, long-term solutions to the problem of N limitation in low-input systems are needed. A cost-effective strategy to include RP in the diet of grazing animals may be very attractive to forage-livestock systems that do not require feed value as high as that of pure RP stands (e.g., cow-calf operations) and for which the cost of annual N fertilizer inputs to a pure grass sward can be prohibitive. An approach that may have potential is to plant RP in strips in already existing bahiagrass pastures.

The Strip-Planting Approach for Rhizoma Peanut in Existing Bahiagrass Pastures

Strip-planting RP is proposed as a cost-effective approach for achieving mixed pastures without having to undertake costly deep tillage and herbicide applications of the entire sward when starting from an already existing bahiagrass pasture. Using this strategy, a legume is planted that has potential to spread into surrounding grass areas. In Florida, the only legume that has demonstrated sufficient persistence and spread to function in such a system is RP. It may take a period of time for RP planted in strips to spread throughout the entire pasture, but if this can be achieved it may provide a relatively low-cost option for establishment of mixed legume-grass pastures.

The theory behind strip-planting is based on the temporal physical separation of species to favor establishment of the less vigorous species. Such an approach has been widely used in Australia, especially in systems that use forage tree legumes such as leucaena and sesbania growing in association with grasses (Lesleighter and Shelton, 1986; Catchpoole and Blair, 1990; Shelton, 1994). Additionally, by virtue of physical separation of the active grass component (growing in the edges of the strip) and the establishing RP in the strips, the strip-planting approach provides opportunities to investigate a combination of seedbed preparation strategies as well as cultural, chemical, and mechanical weed management practices that may lower inputs (i.e., number of herbicides used and/or number of applications per growing season) while allowing successful establishment of a RP-bahiagrass mixture.

Additional Benefits Attributed to Spatial Separation of Species

Although not the approach being evaluated in this dissertation, long-term spatial separation of grasses and legumes has been evaluated. Recent literature from temperate environments, mainly using white clover and ryegrass, has reported greater animal response when the forage is presented to animals in separate grazing units (monoculture legume next to monoculture grass) rather than species growing intermingled. The basis for this response is the demonstrated preference of grazing animals for clover when given the opportunity to freely choose (Parsons et al., 1994). On average, studies have shown that cows freely chose approximately 70 to 80% clover and 20 to 30% ryegrass (Cosgrove et al., 1999; Chapman et al., 2007). This level of clover selection may be greater than the actual proportion offered to the animals grazing mixed pastures.

As pointed out by Chapman et al. (2007), the challenge for grassland management is to present feed to animals at pasture in ways that allow them to meet their dietary preferences, while also allowing high rates of animal production per hectare. Marotti et al. (2001) reported that milk yield (kg d^{-1}) was 11 and 28% greater when animals were offered a free choice of white clover and ryegrass each growing in monoculture compared to grass and legume growing intermingled and grass alone, respectively. Solomon et al. (2011) evaluated animal and sward responses as a function of stocking rate (low: 3 animals ha^{-1}, and high: 6 animals ha^{-1}) and four forage systems (spatially separated on a 50:50 ratio for grass and legume as function of paddock size, monoculture legume, monoculture grass, and grass and legume intermingled) using white clover and annual ryegrass. The authors reported that at high stocking rate herbage mass was similar among forage systems components, but at low stocking rate, monoculture grass had the greatest herbage mass. Further, they indicated that average daily gain for animals was greater on the spatially separated system compared to monoculture legume, but neither was different from monoculture grass and grass-legume intermingled.

Summary

Based on the literature reported, there appears to be potential for strip planting RP in existing bahiagrass pastures with the long-term goal of achieving RP-bahiagrass mixtures that increase/maintain productivity and sustainability of tropical forage-livestock systems. This approach may provide opportunity to reduce establishment costs compared to preparation of a seedbed followed by planting RP in pure stands, and may offer the opportunity to utilize grass forage from the sward during the legume establishment phase so that land is not totally removed from the grazing rotation. The following chapters describe studies investigating 1) the degree to which defoliation management of the overall sward during RP establishment affects the presence and subsequent success of the legume, 2) grazing management effects during the year after establishment, 3) the challenges of weed management and competition for nutrients and light when RP is planted in strips, and 4) planting options for peanut establishment in strips.

CHAPTER 3
STRIP PLANTING A LEGUME INTO WARM-SEASON GRASS PASTURE: DEFOLIATION EFFECTS DURING THE YEAR OF ESTABLISHMENT

Overview of Research Problem

Lack of maintenance fertilization and poor grazing management are the primary factors resulting in degradation of grasslands in low-input systems in some warm-climate environments (Boddey et al., 2004; Miles et al., 2004). Due to their capacity to fix N_2 from the atmosphere and their higher nutritive value compared to tropical grasses (Muir et al., 2011), legumes may be an alternative source of N for grasslands (Thomas, 1995) improving the likelihood of long-term persistence while maintaining and/or improving productivity and forage quality. Nevertheless, forage legumes have contributed less to livestock production systems in the tropics and sub-tropics than in temperate regions. Often, C_3 legumes are overwhelmed when competing with vigorous C_4 warm-climate grasses (Dunavin, 1992; Sollenberger and Collins, 2003; Muir et al., 2011).

Research is critical to develop novel approaches for overcoming the barriers to successful growth of legumes in association with grasses in warm climates and to identify low-cost, long-term solutions to the problem of N limitation in low-input systems. One possible approach to legume establishment is strip-planting in grass swards (Cook et al., 1993; Whitbread et al., 2009). Using this strategy, legumes are planted that have potential to spread into surrounding grass areas. It will take a period of time for legumes to spread throughout the entire pasture, but if this can be achieved it may provide a relatively low-cost option for establishment of mixed legume-grass pastures. In the USA Gulf Coast Region the only legume that has demonstrated sufficient persistence and potential for spread to function in such a system is rhizoma peanut.

Rhizoma peanut is a warm-season, vegetatively propagated, perennial legume that was introduced to Florida, USA from South America in the 1930s. Positive attributes include: drought tolerance (French, 1988), dry matter yields up to 10 to 12 Mg ha^{-1} yr^{-1} under natural rainfall conditions (Beltranena et al., 1981; Ocumpaugh, 1990), similar crude protein concentration and digestibility to alfalfa (*Medicago sativa* L.) (Prine et al., 1981; Beltranena et al., 1981), and persistence under a wide range of management systems for hay, silage, grazing, and as an understory forage crop (Prine et al., 1981; Ortega et al., 1992; Johnson et al., 2002). Four forage-type cultivars of RP have been released by the University of Florida (Florida Agricultural Experiment Station). 'Florigraze' (PI 421707) and 'Arbrook' (PI 262817) were released in 1978 and 1986, respectively (Prine et al., 1981; Prine et al., 1986a,b; Prine et al., 1990), and 'UF Tito' (PI 262826) and 'UF Peace' (PI 658214) were released in 2008 (Quesenberry et al., 2010).

Despite demonstrated potential of RP for grazing systems in the southeastern USA, it has not been used widely in pastures. High costs associated with vegetative establishment, management for weeds, and removal of land from production to allow adequate time for establishment (Adjei and Prine, 1976; Prine et al., 1986; Rice et al., 1995) have limited RP use primarily to high-quality hay for dairy and equine rations, uses where RP production costs can be recovered in the sale of a high value commodity. Unlike hay production systems, where the presence of forbs and grasses are undesirable due to reduction of the feed and market value of RP hay (Williams et al., 1991), low-input forage-livestock systems (e.g., cow-calf operations) may not require as high a feed value. These systems would benefit from the presence of even relatively small amounts of RP in grazed pasture through increased nutritive value of the sward (Lascano, 1994) and reduced need for N fertilization.

The premise of this experiment is that strip-planting RP in existing bahiagrass pastures may offer the opportunity to utilize grass forage during the legume establishment phase, so that land is not totally removed from the grazing rotation, while allowing successful establishment of the legume. The specific objectives were to quantify the effect of a range of grazing and haying treatments on: 1) RP canopy cover, frequency of occurrence, and spread; 2) the light environment of establishing RP plants; and 3) bahiagrass herbage harvested or unutilized.

Materials and Methods

Experimental Site

The experiment was conducted for 2 yr (2010 and 2011) at the University of Florida Beef Research Unit (29°43' N; 82°21'W) near Gainesville, FL. A new area was planted each year with RP. The site was chosen because of available well-established (at least 10 yr) and uniform 'Pensacola' bahiagrass pastures and because nearby RP pastures at this site have persisted for 30 yr, indicative of adaptation to the area. The soils at the experimental site were classified as Sparr fine sand (loamy, siliceous, subactive, hyperthermic Grossarenic Paleudults) and Pomona sand (sandy, siliceous, hyperthermic Ultic Alaquods). Initial characterization of the surface soil (0 to 15 cm) indicated soil pH of 5.5 and Mehlich-1 extractable P, K, Ca, and Mg of 35, 44, 290, and 46 mg kg^{-1}, respectively. Based on a recommended target pH of 6.0 for growth of RP, 1 Mg $ha^{-1}$of dolomitic lime [$(CaMg)(CO_3)_2$] was applied to the experimental area before planting in 2010. Soil samples taken in 2011 confirmed the increase of soil pH to 6.2. Also, each year the area was fertilized at the beginning of the growing season with 60 kg ha^{-1} of K, using muriate of potash (KCl, 600 g K_2O kg^{-1}, and 500 g Cl kg^{-1}). Rainfall data are presented for both years (Figure 3-1). Total rainfall was 1103 and 1029 mm in 2010 and 2011, respectively. Last freeze events before planting in spring occurred on 8 and 14 March 2010 and 2011, respectively. First freeze events at the end of the growing season occurred on 10 and 14 Nov. 2010 and 2011, respectively. The timing of these freeze events was typical for this location.

Land Preparation and Planting

In preparation for strip-planting RP rhizomes into existing bahiagrass sod, strips were plowed in February with a moldboard plow and heavily disked several times to ensure grass- and weed-free planting area. The strips were 4-m wide and accommodated eight rows of RP, with spacing between rows of 0.5 m. The first and last rows of planted rhizomes were 0.25 m from the undisturbed edge of bahiagrass sod. The planted strips were bounded on both sides by a 2.5-m strip of undisturbed bahiagrass sod. Florigraze RP rhizomes were planted in the prepared strip using a conventional Bermuda King sprig planter on 25 March 2010 and 5 April 2011. The planting material was obtained from a commercial farmer cooperator. The rhizomes were planted at a rate of 1000 kg ha^{-1} (packed at ~ 79 kg m^{-3}) to approximately a 5-cm depth. After planting, the plots were cultipacked to ensure adequate soil-rhizome contact.

Planted RP strips were sprayed with herbicides Select Max® (a.i. clethodim; (E)-2-2[1-[[3-chloro-2-propenyl)oxy]imino]propyl]5-[2(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) and Impose® (a.i. ammonium salt of imazapic; +/- -2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1 *H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylicacid) at a rate of 0.10 kg a.i. ha^{-1} and 0.07 a.i. ha^{-1}, respectively. The herbicides were sprayed in a single application when weeds were 5- to 10-cm tall to control a broad spectrum of weeds (Ferrell and Sellers, 2012). Select Max® was applied on 10 May 2010 and 10 June, 2011, and Impose® was applied on 18 June 2010 and 5 July 2011. The application was done using a CO_2-pressurized backpack sprayer calibrated to deliver 187 L ha^{-1} at 310 kPa. The strips were sprayed using a 3.04-m wide boom, so that the bahiagrass at the edges of the strips was not sprayed. Toward the end of the growing season in both years, all plots were mowed to 10-cm stubble height to prevent seed dispersion from flowering plants of the weed Mexican tea (*Chenopodium ambrosioides* L.). Irrigation was applied during April and May each year such that weekly rainfall plus irrigation equaled the 30-yr average weekly rainfall (18 and 20 mm per week in April and May, respectively). Total irrigation applied in April and May 2010 was 67 and 0 mm, respectively, and in April and May 2011 was 60 and 50 mm, respectively Defoliation treatments were initiated in June and no further irrigation was provided.

Treatments and Design

Treatments were four defoliation strategies: 1) Control (no defoliation of the planted RP strip during the establishment year with adjacent bahiagrass harvested for hay production every 28 d during the growing season to a 10-cm stubble height); 2) Hay Production (RP strip and adjacent bahiagrass both harvested for hay production every 28 d to a 10-cm stubble height); 3) Simulated Continuous Stocking (pastures grazed weekly throughout the entire growing season to a 15-cm bahiagrass stubble height); and 4) Rotational Stocking (pastures grazed every 28 d to a 15-cm bahiagrass stubble height). Bahiagrass stubble height was chosen as a reference point because RP plants were expected to be short early in the establishment period. A taller stubble height was chosen for the grazed treatments because animal preference was not certain before the study began, and it was not considered desirable to impose undue stress on the establishing peanut. The four treatments were replicated three times in a randomized complete block design for a total of 12 experimental units. The area of an experimental unit was 9-m wide × 15-m long, and each consisted of one 4-m wide strip of RP running the length of the plot and bounded on each side by 2.5-m strips of bahiagrass that also ran the length of the plot.

Initiation of defoliation treatments was targeted for the end of the RP sprout emergence period, and actual timing was based on research conducted in Florida by Williams (1993) and Williams et al. (1997). They reported that RP sprout emergence began 3 to 5 wk after planting in summer and winter, respectively, and ceased by 7 wk after first-sprout emergence was observed. Based on these data, defoliation treatments were initiated 7 wk after sprout emergence began. First sprout emergence occurred 4 wk after planting in both years, so treatments were applied for the first time at 11 wk after planting on 10 June 2010 and 21 June 2011.

Mowing for the Control and Hay Production treatments was done using a riding lawn mower adjusted to leave a 10-cm stubble. After mowing, the clippings were removed from the plots using lawn rakes. For the grazed plots, animals used were 350-kg yearling cross-bred beef heifers (*Bos* sp.). The 9-m × 15-m experimental units were individually fenced to maximize control over animal grazing. When defoliation occurred on a plot, the animals had access to both the planted RP strip and the bahiagrass bounding it. The methodology used was mob stocking meaning that a high stocking density (10 animals per plot) was used for a short grazing period (~ 0.5 to 1 h). While the animals were grazing, bahiagrass height was monitored frequently using a ruler and animals were removed from the plots when the average height of 10 measures per experimental unit reached 15 cm.

Response Variables

Canopy Cover

Rhizoma peanut canopy cover in the planted strip was estimated visually every 28 d for all treatments, and it was measured on the day after each defoliation event (except for the weekly events on the Simulated Continuous Stocking treatment). A 1-m^2 quadrat (0.5 × 2 m) was placed in the center of the RP strip at two permanently marked locations in each experimental unit, so that canopy cover was estimated on the same areas over time. The 0.5-m side of the quadrat was oriented parallel to the RP rows. Thus, the area enclosed by the quadrat included four rows of RP with the ends of the quadrat positioned so that they rested midway between the outermost RP row that was included in the quadrat and the RP row that was located just outside the quadrat. The quadrat was divided into 100, 10- by 10-cm squares (five rows of 20), and canopy cover was estimated visually by the same observer in 20 stratified 10- by 10-cm squares (four squares in each row of 20 squares) per quadrat and averaged to obtain an overall cover per quadrat location. The average of two locations provided an estimate for each experimental unit (Appendix A; Interrante et al., 2009).

Frequency

Frequency was determined on the same dates at the same quadrat locations that were used to estimate RP canopy cover. Presence or absence of RP was determined in 20 stratified 10- by 10-cm squares in each of two quadrat locations per plot. Frequency was calculated as the percentage of the total number of cells assessed where RP was present. The average of two locations provided an estimate for each experimental unit.

Light Environment

Ambient light environment at the top of the RP canopy was measured on the day before treatments were applied for the first time, 2 wk after application of treatments (middle of a regrowth period), and every 28 d thereafter. This sampling time was chosen to represent average light environment during a regrowth period. Light environment was characterized using a SunScan Canopy Analysis System (Dynamax Inc., Houston, TX). The system consisted of a 1-m-long quantum sensor that was placed at the height of the RP canopy to measure transmitted photosynthetically active radiation (PAR), and an unshaded beam fraction sensor that was placed outside the plots to measure incident PAR. Thus, the light environment experienced by RP plants was characterized as percent of incident PAR that reached the RP canopy and was calculated by dividing the transmitted PAR by incident PAR level and multiplying by 100 to express it as a percentage. The light environment was calculated as the average of four observations in each experimental unit.

Spread

Rhizoma peanut spread was measured once each yr on the day before the last clipping/grazing event of the season. A transect was positioned through the center of the RP strip running the length of the each plot. At the 5- and 10-m points along the 15-m transect, a line, perpendicular to the transect, was extended on each side. Spread was defined as the distance from the center of the planted RP strip to the farthest point where identifiable RP plant parts (above ground) were found. The average of the four measurements provided the estimate of RP spread for each experimental unit.

Bahiagrass Herbage Harvested

Herbage harvested was measured every 28 d prior to each grazing or clipping event for each treatment except Simulated Continuous Stocking. In the Hay Production and Control treatments, a 1 × 2-m area was cut to a 10-cm stubble height using a sickle bar mower in the bahiagrass portion of the plot. The collected herbage was weighed fresh, and a subsample was dried at 60°C until constant weight to determine dry matter concentration and to calculate herbage harvested. In the grazed treatments, two representative 0.25-m^2 quadrats were clipped to the target 15-cm stubble in the bahiagrass portion of the experimental unit. Less area was sampled in the grazed plots to minimize the impact of sampling on grazing time and behavior of the animals. In the Simulated Continuous Stocking treatment, sampling occurred biweekly before every second grazing event. This treatment was sampled more frequently because a cage technique was used to restrict grazing from sampling units and cages should not remain in one area for an extended period lest forage mass or sward structure become very different than the surrounding pasture. Thus on Simulated Continuous Stocking pastures, two 0.5-m^2 circular exclusion cages per plot were positioned at representative locations in the bahiagrass strip. A 0.25-m^2 area from the center of each caged area was harvested biweekly before grazing. The cages were moved to a new location for the next 2-wk period as soon as grazing was completed on that plot. Herbage harvested was not measured in the RP strip because RP plants generally did not reach the target stubble height (10 and 15 cm for clipping and grazing, respectively) during the year of establishment.

Statistical Analysis

Data were analyzed as repeated measures using PROC GLIMMIX of SAS (SAS Institute, 2010). Collection date was considered a repeated measurement with an autoregressive covariance structure. Year and block were considered random effects. Year was considered random because a new set of plots was established each year. Treatments were fixed effects. Mean separations and pre-planned contrasts were done based on the SLICEDIFF and LSMESTIMATE procedures of LSMEANS in SAS. Plots of model residuals were used to check normality, and in the case of non-normal distributions, data transformations were used. Square root transformation was used for canopy cover and frequency. Treatments were considered different when $P \leq 0.05$.

Results and Discussion

Canopy Cover

Defoliation method, sampling date, and their interaction affected canopy cover. From July through the remainder of the establishment year, grazing (Rotational or Simulated Continuous Stocking) reduced RP canopy cover compared to the Control and Hay Production treatments (Figure 3-2). The greatest RP canopy cover was achieved in August at 32 and 29% for the Control and Hay Production treatments, respectively, compared with 5 and 4% for Simulated Continuous and Rotational Stocking, respectively (Table 3-1). When measured in late June of the year after establishment, defoliation method in the establishment year continued to affect canopy cover. Cover was similar for Control and Hay Production treatments (32 and 35%, respectively), and both were greater than the grazing treatments which did not differ from each other (Table 3-1; 7 and 8% for Simulated Continuous and Rotational Stocking, respectively).

Decreasing RP canopy cover in the grazing treatments can be attributed to apparent animal preference for RP and the other herbage that occurred in the strips planted to RP. When entering the pasture, animals first grazed closely the RP strips before beginning to graze the adjacent bahiagrass. Livestock selection for *Arachis* sp. has been reported previously for mixtures where the grass and legume components grew intermingled (Bennett et al., 1999; Lascano, 2000; Valencia et al., 2001). Thus, while physical separation of the legume and grass components of the mixture provide advantages to manage plant competition (Castillo, Chapter 5 and 6), animal selection behavior can offset these advantages and negatively affect legume establishment.

Frequency

There were defoliation method, sampling date, and method × sampling date interaction effects. Rhizoma peanut frequency of occurrence in the planted strip followed the same pattern of response as canopy cover. By August of the establishment year, frequency was 67% for both Control and Hay Production treatments and 21% for both Simulated Continuous and Rotational Stocking (Figure 3-3). Measurements taken in late June of the year after establishment also followed the same trend as canopy cover. Control and Hay Production treatments were similar (82 and 76%, respectively) and both were greater than either Simulated Continuous or Rotational Stocking treatments (26 and 32%, respectively) (Table 3-1). Thus, by 14 mo after planting, RP was present in ~ 80% of quadrats assessed in the planted strip if grazing did not occur compared to only ~ 30% where grazing occurred.

Light Environment

Light environment was considered to be an important response because previous research in Florida showed that it had a major impact on success of aeschynomene

(*Aeschynomene americana* L.) establishment in existing bahiagrass sods (Kalmbacher and Martin, 1983). In the current study, there was effect of sampling date and a strong trend (*P* = 0.059) toward an effect of defoliation method on light environment. Greatest numerical differences among treatments occurred in August and September (Figure 3-4), so treatments were compared within those dates. In August, Control and Hay Production treatments were similar (87 and 90%, respectively; *P* = 0.38), Rotational Stocking (95%) was similar to Hay Production (*P* = 0.08) but greater than Control (*P* = 0.03), and Simulated Continuous Stocking (96%) was similar to Rotational stocking (*P* = 0.74). In September there was a trend toward treatment differences (*P* = 0.11) with 86 and 87% of incident PAR reaching RP for Control and Hay Production treatments and 92% for both Rotational and Simulated Continuous Stocking treatments. Unlike the situation in which aeschynomene was overseeded into bahiagrass (although not strip-planted), the current data indicate that light environment was not the critical factor influencing RP establishment and was clearly less important than defoliation method. This conclusion is supported by data showing that treatments (Simulated Continuous and Rotational Stocking) with the greatest or tending to have the greatest percentage of incident PAR in August and September had the lowest establishment year RP canopy cover.

Spread

At the end of the establishment year, average distance from the center of the planted strip to the most distant above-ground RP plant part was 182 cm for Control and Hay Production treatments, 168 cm for Simulated Continuous Stocking, and 177 cm for Rotational Stocking (Table 3-1). Single degree of freedom comparisons were made using LSMESTIMATES to test the average of mechanical (Control and Hay Production) vs. Simulated Continuous and Rotational Stocking defoliation methods. The average of the mowed treatments was similar to Rotational Stocking (*P* = 0.39) and 14 cm greater than Simulated Continuous Stocking (*P* = 0.02). Given that the outer row of RP was planted 175 cm from the center of the strip, spread was minimal in the first year in all treatments. Simulated Continuous Stocking actually resulted in loss of plants in the outer row of the strip closest to bahiagrass resulting in a reduction in spread. Results indicate that defoliation management under the strip-planting scheme is critical in order to allow potential spread of RP into the grass component of the pasture during the establishment year.

Herbage Harvested

Herbage harvested from the bahiagrass portion of the plots was 3.7, 3.4, 2.9, and 3.6 Mg ha^{-1} for the Control, Hay Production, Simulated Continuous Stocking, and Rotational Stocking treatments, respectively. Single degree of freedom comparisons indicate that herbage harvested from the Control and Hay Production treatments was similar to Rotational Stocking and there was a trend toward lower herbage harvested for Simulated Continuous vs. Rotational Stocking (*P* = 0.21). While there were no significant differences in herbage harvested due to defoliation method, the trend toward lower herbage harvested in continuously vs. rotationally stocked pastures agrees with previous reports in the literature (Jones, 1981; Parsons and Leafe, 1981; Parsons et al., 1988; Stewart et al., 2005). It is of significance to note that under the conditions of this experiment a producer who chooses not to use any type of defoliation during the establishment year would sacrifice approximately 3.5 Mg of bahiagrass forage for each hectare of bahiagrass strips in their pasture.

Implications of the Research

Grazing weekly (Simulated Continuous Stocking) or every 28 d (Rotational Stocking) reduced RP canopy cover and frequency. Greatest RP canopy cover during the year of establishment was achieved during August with 32 and 29% for the Control and Hay Production treatments compared to 5 and 4% for Simulated Continuous and Rotational Stocking, respectively. Frequency measurements followed the same trend as canopy cover. A measurement early during the following growing season revealed that differences in canopy cover and frequency carried over. Spread was lowest and there was a trend toward less herbage harvested in the Simulated Continuous Stocking treatment compared to the others. Competition for light was not an important factor affecting RP establishment under the strip-planting approach used in this study.

The results indicate that defoliation management is critical during the year of establishment when strip-planting RP into bahiagrass pastures. Due to apparent animal preference of forage in the legume-planted strips, production of hay is the best option for utilizing the grass forage during the year of establishment. It may be possible to decrease the negative impact of grazing by utilizing rest periods between grazing events longer than 28 d, but currently there are no data available to evaluate this option. Additional research is needed to evaluate the potential of longer rest periods between grazing events, and studies are needed to quantify the effect of grazing management during the year after establishment as well as the adaptation of other RP cultivars with different growth habits (i.e., more prostrate) to the strip-planting approach.

Table 3-1. Rhizoma peanut (RP) percentage canopy cover and frequency of occurrence in August of the establishment year, June of the year after establishment, and spread at the end of the establishment year following planting in strips in bahiagrass pastures and subjected to different defoliation treatments. Data are means across three replicates and 2 yr (n = 6).

Defoliation treatment†	Cover: Establishment year	Cover: Year after establishment	Frequency: Establishment year	Frequency: Year after establishment	Spread‡: Establishment year
	------ % ------				cm
Control (C)	32	32	67	82	182
Hay Production (H)	29	35	67	76	182
Simulated Continuous (SC)	5	7	21	26	168
Rotational (R)	4	8	21	32	177
Contrast *P* values§					
C + H vs. SC	<0.0001	<0.0001	<0.0001	<0.0001	0.0274
C + H vs. R	<0.0001	<0.0001	<0.0001	<0.0001	0.3976
SC vs. R	0.5691	0.5628	0.9632	0.2730	0.1932
SE¶	3.3	5.0	4.7	5.2	7.9

† C: Control treatment (no defoliation of the planted RP strip during the establishment year with adjacent bahiagrass harvested for hay production every 28 d during the growing season to a 10-cm stubble height); H: Hay Production (RP strip and adjacent bahiagrass both harvested for hay production every 28 d to a 10-cm stubble height); SC: Simulated Continuous Stocking (pastures grazed weekly throughout the entire growing season to a 15-cm bahiagrass stubble height); R: Rotational Stocking (pastures grazed every 28 d to a 15-cm bahiagrass stubble height).

‡Spread is the distance from the center of the planted RP strip to the farthest point where identifiable above-ground RP plant parts were found.

§Linear combinations of LSMEANS developed using the LSMESTIMATE statement of SAS®.

¶ Standard error of a defoliation treatment mean.

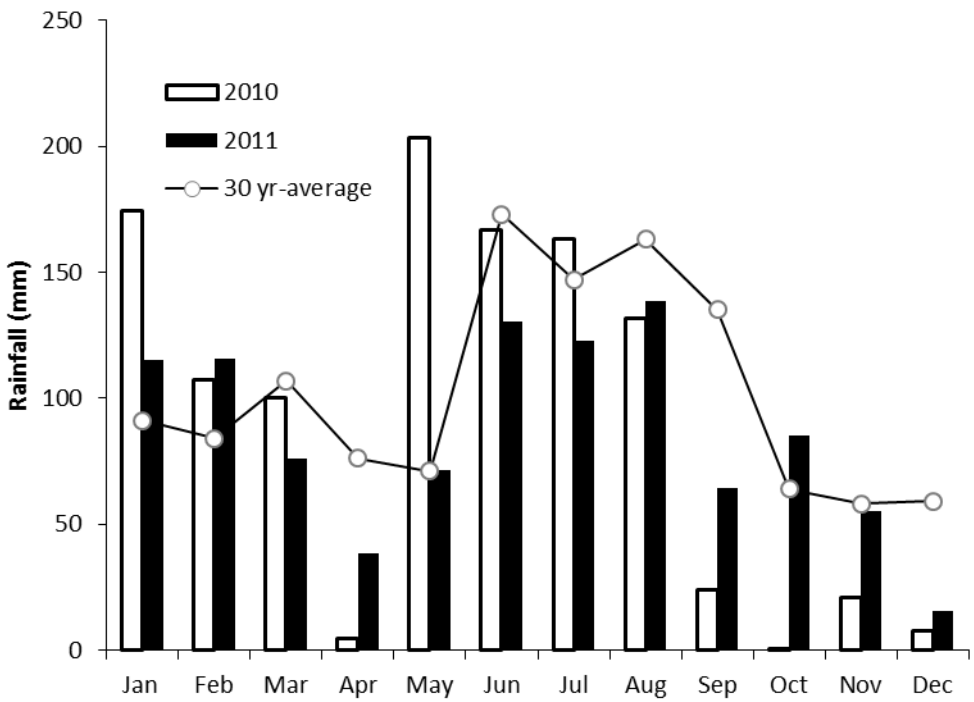

Figure 3-1. Monthly rainfall at the University of Florida Beef Research Unit, Gainesville, FL for 2010, 2011, and the 30-yr average.

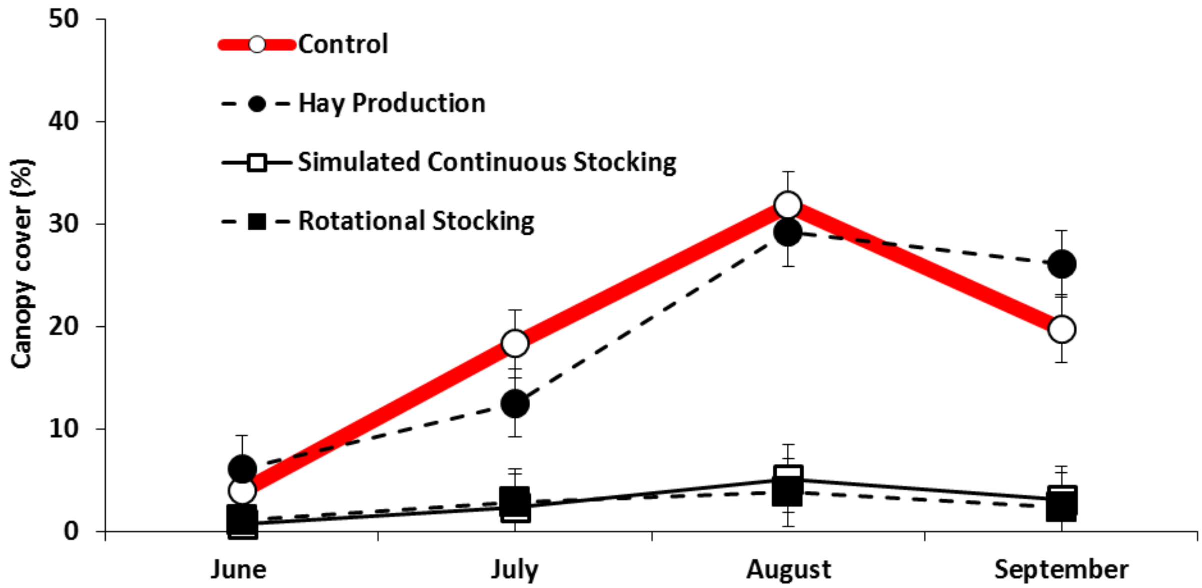

Figure 3-2. Canopy cover of rhizoma peanut planted in strips in existing bahiagrass pastures. Data are means of 2 yr. Errors bars represent treatment means (n = 6) ± one standard error.

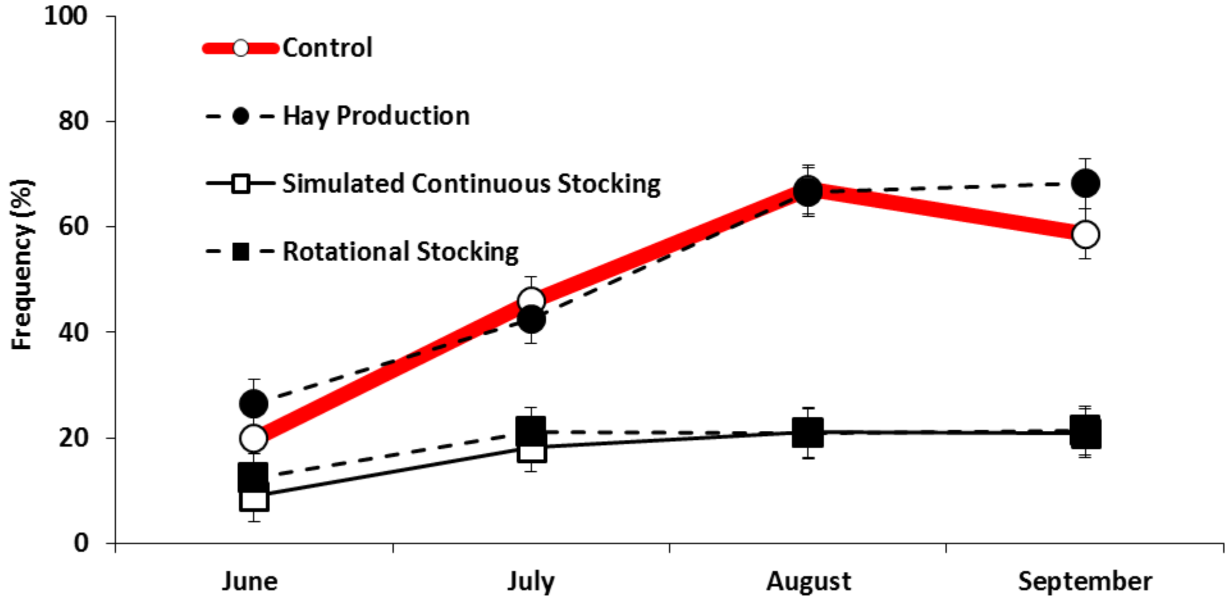

Figure 3-3. Frequency of occurrence of rhizoma peanut planted in strips in existing bahiagrass pastures. Data are averages of 2 yr. Error bars represent treatment means (n = 6) ± one standard error.

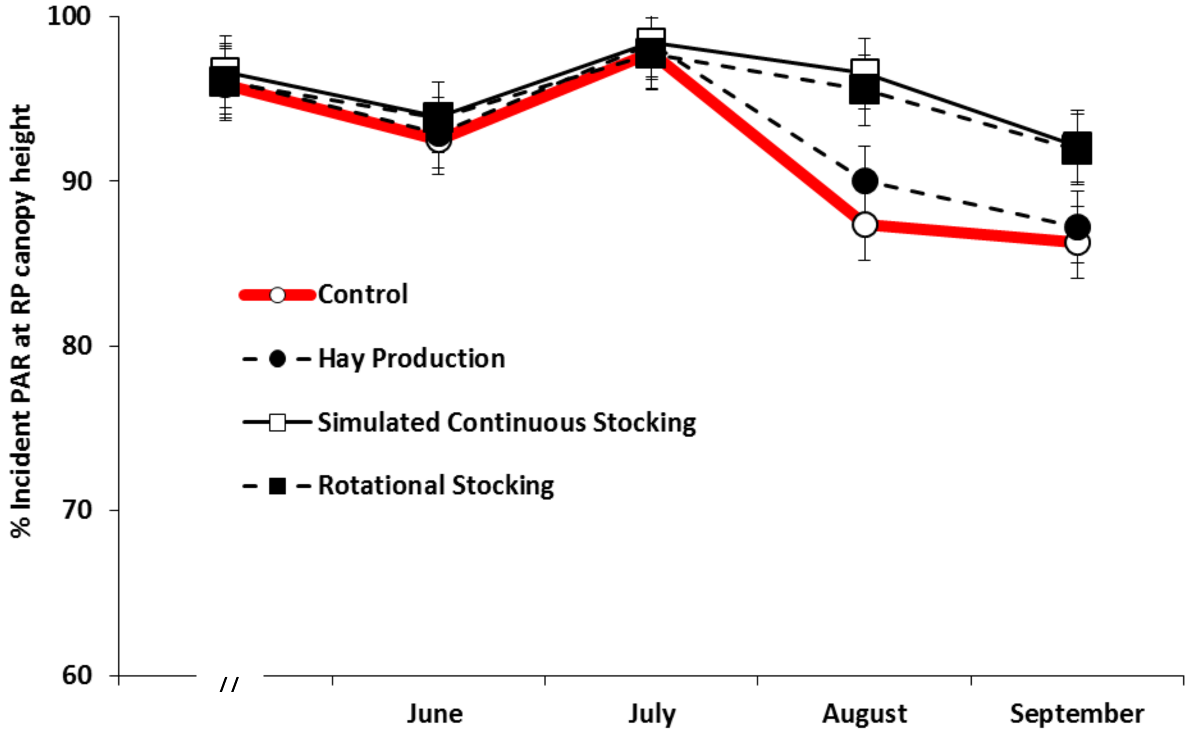

Figure 3-4. Light environment at the top of the rhizoma peanut canopy for strip-planted rhizoma peanut in existing bahiagrass pastures. Data are means across 2 yr. Error bars represent treatment means (n = 6) ± one standard error. PAR = Photosynthetically active radiation.

CHAPTER 4
GRAZING MANAGEMENT STRATEGIES AFFECT YEAR-AFTER ESTABLISHMENT PERFORMANCE OF A LEGUME STRIP-PLANTED INTO WARM-SEASON GRASS PASTURE

Overview of Research Problem

Rhizoma peanut (*Arachis glabrata* Benth.; RP) is a warm-season perennial forage legume that has documented persistence under grazing (Ortega et al., 1992) and ability to compete effectively with perennial grasses in mixed pastures (Williams, 1994). It is high in nutritive value, and in multi-year grazing studies has resulted in gains of yearling beef steers (*Bos* sp.) of 0.97 kg d^{-1} (nearly pure stands of RP) (Sollenberger et al., 1989) and gains of 6- to 12-mo-old dairy heifers (*Bos taurus*) of 0.6 kg d^{-1} (botanical composition of ~ 90% RP) (Hernandez Garay et al., 2004). Further, greater animal production (gain ha^{-1}) of up to 130 kg has been reported for animals grazing RP compared to N-fertilized (120 kg N ha^{-1} yr^{-1}) bahiagrass (*Paspalum notatum* Flügge) pastures (Sollenberger et al., 1989). The mechanism by which greater animal production occurred was sustained high nutritive value (i.e., crude protein and in vitro organic matter digestibility) of RP compared to bahiagrass, especially in the latter half of the growing season.

In addition to its impact on forage nutritive value and increased animal response, the capacity of RP and other legumes to fix atmospheric N_2 make them an alternative to inorganic fertilizer as a source of N for grasslands (Muir et al., 2011). Thus, use of legumes in general and RP specifically should improve the likelihood of long-term pasture persistence while maintaining and/or improving productivity of low-input forage-livestock systems (Thomas, 1994).

Persistence of legumes in grazed warm-climate grasslands has long been a factor limiting their use (Shelton et al., 2005). Ortega-S et al. (1992) evaluated RP persistence under a wide range of levels of residual forage mass after grazing and length of rest interval between grazing events. They found that it was possible to maintain ≥ 80% RP contribution based on botanical composition by weight (i.e., ≤ 20% from warm-season perennial grasses) across a relatively wide range of levels of rest interval if the residual dry matter after a grazing event was ~ 1700 to 2300 kg ha^{-1} (15- to 20-cm stubble height).

In spite of documented persistence and impact on animal performance in pastures, RP use in the USA Gulf Coast Region has been limited primarily to hay production due to the costs associated with vegetative establishment, management for weeds and water, and taking land out of production for one or more growing seasons to allow adequate establishment (Adjei and Prine, 1976; Prine et al., 1986a,b; Rice et al., 1995). In an effort designed to reduce establishment costs and expand use of RP in low-input grazed grassland systems in the Gulf Coast Region, planting RP in strips into existing bahiagrass pastures was proposed (Castillo, Chapter 3). It was shown that either rotational or simulated continuous stocking during the establishment year greatly reduced RP cover and frequency of occurrence. Defoliation by mowing or no defoliation were superior to grazing. Establishment of RP is thought to require two growing seasons under most conditions (Prine et al., 1986a,b), but there are no data describing the effect of grazing in the year after planting on RP establishment and spread.

The current experiment investigates grazing management strategies in Year 2 (Y2) plots (year after establishment) where different defoliation strategies were imposed in Year 1 (Y1; year of establishment). The specific objectives were to evaluate: 1) the effect of year-after-establishment grazing management of bahiagrass swards strip-planted to 'Florigraze' RP on peanut cover, frequency, spread, and botanical composition, and 2) the interaction effects of defoliation strategies during the establishment-year with year-after-establishment grazing management of bahiagrass swards strip-planted to RP.

Materials and Methods

Experimental Site

The experiment was conducted for 1 yr (2011) at the University of Florida Beef Research Unit (29°43' N; 82°21'W) near Gainesville, FL. A second year is being conducted in 2012, but data are not yet available for inclusion in the dissertation. The experiment was imposed on plots that were subjected to different defoliation management options during the year of establishment. Establishment-year responses were described in Chapter 3.

The soils at the experimental site were classified as Sparr fine sand (loamy, siliceous, subactive, hyperthermic Grossarenic Paleudults) and Pomona sand (sandy, siliceous, hyperthermic Ultic Alaquods). Initial characterization of the surface soil (0 to 15 cm) indicated soil pH of 6.2 and Mehlich-1 extractable P, K, Ca, and Mg of 43, 46, 468, and 63 mg kg^{-1}, respectively. Based on the recommendations for growth of RP, the area was fertilized at the beginning of the growing season with 30 kg ha^{-1} of K, using muriate of potash (KCl, 600 g K_2O kg^{-1}, and 500 g Cl kg^{-1}). Rainfall and temperature data from the experimental period are presented in Chapter 3. Total rainfall in 2011 was 1029 mm compared to the 30-yr average of 1238 mm. Last freeze event before planting occurred on 14 March. First freeze event at the end of the growing season occurred on

10 Nov. 2011. These dates are typical for this location and do not differ to a large extent from long-term averages.

Treatments and Experimental Design

The treatments for this study were imposed in 2011 on the plots used for the first year (2010) of the study described in Chapter 3. Each original 9-m wide × 15-m long plot from the earlier study was divided into three sub-plots of 9-m width and 5-m length. The 9-m width of the sub-plot consisted of a 4 m-wide strip planted to Florigraze in 2010 bounded on both sides by 2.5-m wide strips of bahiagrass sod. Treatments were the factorial combinations of four Year 1 (Y1) defoliation strategies and three Year 2 (Y2) grazing management treatments, for a total of 12 treatments. Treatments were replicated three times in a randomized complete block design and were arranged as a split-plot experiment with Y1 treatment as the main plot and Y2 treatment as the sub-plot.

Main-plot defoliation strategies imposed in 2010 were described in detail in Chapter 3. In summary, there were four treatments: 1) control (no defoliation of the planted RP strip with adjacent bahiagrass harvested every 28 d to 10-cm stubble height); 2) hay production (RP strip and adjacent bahiagrass both harvested every 28 d to 10-cm stubble height); 3) simulated continuous stocking (pastures grazed weekly to 15-cm bahiagrass stubble height); and 4) rotational stocking (pastures grazed every 28 d to 15-cm bahiagrass stubble height). Year 2 grazing management treatments applied to subplots were: 1) simulated continuous stocking (SC; same as Treatment 3 from Y1); 2) rotational stocking with 28-d resting period (RS-28; same as treatment 4 from Y1); and 3) rotational stocking with 42-d rest period between grazing events (RS-42). At each grazing event in 2011, all sub-plot treatments were grazed until the bahiagrass stubble height was 15 cm.

The four main-plot treatments were included because they resulted in varying levels of RP contribution and because differences carried over to the year after establishment. The results in Chapter 3 indicate that grazing during the establishment year greatly reduced RP contribution compared to control and hay production treatments. This provided opportunity to investigate grazing management options during Y2 under a wide range of initial levels of RP starting conditions. For the sub-plot treatment, the general guidelines to determine treatments were based on a study by Ortega-S. et al. (1992). They evaluated the effects of grazing frequency and intensity on persistence and herbage accumulation of a well-established (5-yr-old) Florigraze RP stand that contained 10 to 20% perennial grasses at the start of the trial. The authors indicated that to maintain ≥ 80% RP contribution in the pasture during the 2 yr of the experiment (based on botanical composition by weight), the residual dry matter after a rotational stocking event should be approximately 1700 to 2300 kg ha^{-1} (15- to 20-cm stubble height).

The methodology used to impose the treatments was mob stocking, meaning that a high stocking density (3 animals per plot) was used for a short grazing period (~ 0.5 to 1 h). While the animals were grazing, height of the bahigrass sod growing at the edges of the RP strip was monitored frequently using a ruler and animals were removed from the plots when the average height of 10 measures per experimental unit reached 15 cm. Grazing started on 28 June when average sward height was 20 cm based on RP and bahiagrass and continued according to the treatment schedule throughout the growing season. After the 28 June grazing (first grazing event), there were three and two grazing events for the RS-28 and RS-42 treatments, respectively.

Response Variables

Measurements of RP contribution were canopy cover, frequency, spread, and botanical composition by weight. Longer-term as opposed to monthly changes in RP contribution were considered of importance. Initial measurements (taken before Y2 treatments were applied), that served as point of comparison for data collected later in the year, included canopy cover and frequency on 28 June and spread which was measured before the last clipping/grazing event at the end of the 2010 growing season (Chapter 3).

Canopy Cover and Frequency

Rhizoma peanut canopy cover in the planted strip was estimated visually near mid-season (August) and at the end of the season (October). A 1-m^2 quadrat (0.5 × 2 m) was placed in the center of the RP strip at a permanently marked location in each experimental unit, so that canopy cover was estimated on the same area over time. The 0.5-m side of the quadrat was oriented parallel to the RP rows. Thus, the area enclosed by the quadrat included four rows of RP with the ends of the quadrat positioned so that they rested midway between the outermost RP row that was included in the quadrat and the RP row that was located just outside the quadrat. The quadrat was divided into 100, 10- by 10-cm squares (five rows of 20), and canopy cover was estimated visually by the same observer in 20 stratified 10- by 10-cm squares (four squares in each row of 20) per quadrat and averaged to obtain an overall cover per quadrat location (Appendix A).

Frequency of occurrence is a measurement of the relative distribution of RP in the strip. It was determined on the same dates at the same quadrat locations that were used to estimate canopy cover. Presence or absence of RP was determined in 20 stratified 10- by 10-cm squares per quadrat location. Frequency was calculated as the percentage of the total number of cells assessed where RP was present.

Spread

Rhizoma peanut spread was measured once on the day before the last grazing event of the season (17 Sept. 2011). A transect was positioned through the center of the RP strip running the length of the plot. At the 1.5- and 3.5-m points along the 5-m transect, a line, perpendicular to the transect, was extended on each side. Spread was defined as the distance from the center of the planted RP strip to the farthest point where identifiable above-ground RP plant parts were found. The average of the four measurements provided the estimate of RP spread for each experimental unit.

Botanical Composition

Botanical composition by weight in the middle of each strip was estimated two times (near mid-season in August and toward the end of the growing season in September) by clipping two 0.25-m^2 quadrats per plot to a 10-cm stubble height in the middle of each RP strip. Regrowth was at least 3-wk old when sampling occurred. Fresh herbage was collected and separated into grass and RP components and dried at 60°C until constant weight. Botanical composition was calculated by dividing weight of the RP component by the sum of all other herbage plus RP. There were no botanical composition data collected from the SC treatment because RP plants did not reach the 10-cm sampling height.

Bahiagrass Herbage Harvested

Herbage harvested was measured prior to each grazing event for the two rotational stocking treatments. One 0.25-m^2 quadrat was clipped to 15-cm stubble in the bahiagrass portion of the experimental unit. The collected herbage was weighed fresh, and dried at 60°C until constant weight to determine dry matter concentration and to calculate herbage harvested. In the simulated continuous stocking treatment, sampling occurred biweekly before every second grazing event. This treatment was sampled more frequently because a cage technique was used to restrict grazing from sampling units and because cages should not remain in one area for an extended period lest forage mass or sward structure become very different than the surrounding pasture. Thus, on SC pastures, one 0.5-m^2 circular exclusion cage per plot was positioned at a representative location in the bahiagrass strip. A 0.25-m^2 area from the center of the caged area was harvested biweekly before grazing. The cages were moved to a new location for the next 2-wk period as soon as grazing was completed on that plot. Herbage harvested was not measured in the RP strip because RP plants generally did not reach the target stubble height (15 cm) during Y2.

Statistical Analysis

Data were analyzed using PROC GLIMMIX of SAS (SAS Institute, 1996). Sampling date was considered a repeated measurement with an autoregressive covariance structure. Block was considered a random effect. The Y1 defoliation treatment and its interactions were included in the model to look at the cumulative effects of Y1 and Y2 treatments. In the analysis, Y1 defoliation treatment, Y2 grazing treatment, and their interactions were considered fixed effects.

Interaction effects were analyzed with the SLICE procedure, and mean separation was based on the PDIFF and SLICEDIFF procedure of LSMEANS using SAS. Plots of model residuals were used to check normality, and in the case of non-normal distributions, data transformations were used. Square root transformation was used for canopy cover, frequency, and botanical composition data. Treatments were considered different when $P \leq 0.05$. Interactions were assessed whenever $P \leq 0.10$.

Results and Discussion

To ensure clarity of data interpretation, it should be noted that although Y1 (2010) treatment effects are tested in this chapter, all measurements reported were taken in 2011, with the exception of the "initial measure" of spread which was taken in fall 2010.

Canopy Cover and Frequency

For RP canopy cover, there were effects of Y1 defoliation strategy, sampling date, and Y2 grazing management treatment × sampling date interaction. For RP frequency, treatment effects were similar to those for canopy cover, except for a trend toward Y2 grazing management treatment × sampling date interaction ($P = 0.08$).

Averaged across sampling dates in 2011, canopy cover and frequency for Y1 control and hay production treatments were not different (Table 4-1; 13 and 66%, respectively for control; 15 and 59%, respectively, for hay production). Canopy cover of Y1 hay production treatment was greater than Y1 simulated continuous (5%) and rotational stocking (4%). Canopy cover in the two grazing treatments was not different. Frequency was greatest for Y1 control and hay production treatments compared to simulated continuous and rotational stocking (28 and 22%, respectively; Table 4-1).

There was sampling date × Y2 grazing management treatment interaction. Canopy cover in mid-season was greatest for RS-42 (12%) compared to 6% for both SC and RS-28 (Fig. 4-1). By late-season, canopy cover was not different among treatments and was 6, 6, and 4% for SC, RS-28, and RS-42, respectively. Frequency followed the same pattern as cover. There was a trend ($P = 0.08$) for greater decrease (-12 percentage points) in RP frequency for RS-42 compared with RS-28 (-10) and SC (-7) from the initial measurement to late-season, respectively. The results indicate that regardless of the grazing management treatment used in Y2, observed cattle preference for herbage in the strip and associated heavy defoliation of RP at every grazing event overrode the potential benefit of longer resting periods between grazing events for the RS-42 treatment.

Previous research reported canopy cover and frequency of 30 and 67%, respectively, in the establishment year for planted RP strips that were managed for hay production or not defoliated (Chapter 3). These values compared favorably to less than 5% cover and 20% frequency when plots were grazed (either simulated continuous or rotational stocking) (Chapter 3). When RP is planted in a prepared seedbed in pure stand for hay production, it is typical that canopy cover increases over time to provide complete cover by the end of the second or third year (Prine et al., 1986a, b). The decrease in RP cover and frequency in Y2 indicates that both continuous and rotational stocking as practiced in this experiment had a negative impact. The sharp decline in RP cover and frequency from mid- to late-season was unexpected. This may have been due to the cumulative effect of defoliation throughout the growing season and because toward the end of the growing season, prioritization of RP growth shifts to below-ground biomass (Saldivar et al., 1992a). In contrast, SC and RS-28 showed marked declines by mid-season, likely a function of more frequent grazing of those treatments than RS-42.

Lower RP canopy cover and frequency with grazing were attributed previously to observed animal preference for forage in the planted strip during the year of establishment (Chapter 3). Animal preference for the RP strip continued in the current experiment during Y2. The result was that the planted strip was regularly grazed below the 15-cm target for bahiagrass. Thus, in order to achieve establishment of a RP-bahiagrass mixture using the strip-planting approach and with grazing in Y2, frequency and intensity of grazing need to be selected to favor RP, with less attention paid to the height of bahiagrass outside the strip. Well-established Florigraze RP has demonstrated persistence under grazing (Ortega-S. et al., 1992); nevertheless, even for established stands grazing intensity (i.e., stubble height, residual dry matter) was a critical factor determining RP contribution. Ortega-S. et al. (1992) reported that very close defoliation of RP (i.e., to 500 kg ha^{-1} residual dry matter) reduced legume contribution, regardless of the length of the resting period between subsequent defoliation events. Although establishing Florigraze does not thrive under close grazing, it may be that other RP cultivars with different growth habit and morphology (i.e., more prostrate vs. upright), are more tolerant of close grazing when planted in strips; however, that information is not available.

Botanical Composition

For botanical composition there were effects of Y1 defoliation strategy, Y2 grazing management, sampling date, sampling date × Y2 defoliation management interaction, and a trend (*P* = 0.07) toward Y1 × Y2 defoliation treatment interaction. In general, the RP component was ≤ 20% of the herbage harvested.

Botanical composition data were analyzed by Y1 defoliation strategy to explore the trend (P = 0.07) toward Y1 defoliation strategy × Y2 grazing management interaction. The RP percentage was greater for Y2 treatment RS-42 than RS-28 for plots that in Y1 had been managed for hay production or stocked rotationally (Table 4-2). There was only a trend (P = 0.16) toward an increase in RP percentage with longer Y2 rest period in Y1 control plots, and there was no effect of Y2 management on Y1 plots that received the simulated continuous stocking treatment (Table 4-2). Analysis by Y2 grazing strategy indicated that for pastures grazed every 42 d in Y2 (RS-42) botanical composition was greatest for plots that during Y1 had received either the control or hay production treatments (Table 4-2). Within Y2 treatment RS-28, the Y1 control had greater percentage RP than Y1 rotational but was not different than any other Y1 treatment (Table 4-2).

Because of the sampling date × Y2 grazing management strategy interaction, data were analyzed by sampling date and by Y2 grazing management strategy. Rhizoma peanut contribution at mid-season was greater for RS-42 (12%) compared to RS-28 (2%; Table 4-3). At late-season there were no differences among grazing treatments, with RP contribution increasing from mid- to late-season by 9 percentage units for RS-28 compared to a trend toward a decrease for RS-42 (-4 percentage points). It is not completely clear why the contrasting trends for RS-28 and RS-42 treatments occurred from mid- to late-season since botanical composition measurements were taken after ~3 wk of regrowth following the previous grazing event for both treatments.

Spread

There was Y1 defoliation strategy effect on spread, but control and hay production treatments were not different (201 and 197 cm, respectively). They were greater than both Y1 rotational and simulated continuous stocking (160 and 163 cm, respectively).

Given that Y2 grazing management effects were not significant and there was no interaction of Y1 defoliation treatment × Y2 grazing treatment, Y2 grazing treatment means were averaged across sub-plots and the year effect (Y1 vs Y2) of Y1 treatments on spread was compared. Year was included in the model as a fixed effect to allow estimation of RP spread into bahiagrass over time. Results indicated spread was greater in Y2 (~ 30 cm) for areas that were managed using the control and hay production treatments in Y1 compared to either of the Y1 grazing treatments (Fig. 4-2). A similar effect was reported by Castillo (Chapter 3) in plots that were managed for hay production during 2 yr.

Bahiagrass Herbage Harvested

There were no treatment effects on bahiagrass herbage harvested. Herbage harvested averaged 1.7 Mg ha^{-1} yr^{-1}.

Implications of the Research

For establishment-year treatments, Year 2 RP canopy cover was not different for control and hay production (13 and 15%, respectively). The control was not different than simulated continuous (5%), but it was greater than rotational stocking (4%); the grazing treatments were not different. Year 2 RP frequency was not different for Y1 control and hay production treatments (66 and 59%, respectively) with both being greater than simulated continuous (28%) and rotational stocking (22%). For Y2 grazing treatments, canopy cover and frequency were greatest for RS-42 in mid-season (12 and

49%, respectively); nevertheless, by late-season there were no differences among treatments (approx. 5% cover and 40% frequency). In general, the RP component was ≤ 20% of the herbage harvested and was greater toward the end of the season. The results indicate that while defoliation strategy during the year of establishment set the starting point for RP contribution, grazing during the year after establishment can override the potential positive effects of the previous year's management. These data suggest that if RP planted in strips is to be grazed in Year 2, grazing management should be focused on management strategies targeted to the RP, as opposed to the bahiagrass growing along side the strips. Specifically, grazing should be no more frequent that every 42 d, and cattle should be removed when the planted strip is grazed to a height of 15-20 cm.

Table 4-1. Effect of Year 1 (2010) defoliation strategy on Year 2 (2011) canopy cover and frequency of rhizoma peanut planted in 2010. Data are means across three replicates, two sampling dates, and three grazing management treatments (n = 18).

Year 1 defoliation strategy	Canopy cover†	Frequency
	------------------------- % ------------------------	
Control	13 ab	66 a
Hay production	15 a	59 a
Simulated continuous stocking	5 bc	28 b
Rotational stocking 28 d	4 c	22 b
SE	3	6

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

Table 4-2. Year 1 (2010) defoliation strategy × Year 2 (2011) grazing management interaction effect on rhizoma peanut (RP) botanical composition in strips planted to RP in existing bahiagrass in 2010. Data are means across three replicates and two sampling dates (n = 6) from year 2011.

	Year 2 grazing management‡		
Year 1 defoliation strategy	RS-28†	RS-42	*P-value*
	------------------ % -------------------		
Control	10 a	13 a	0.16
Hay production	5 ab	15 a	0.001
Simulated continuous	5 ab	6 b	0.50
Rotational stocking	3 b	7 b	0.04
SE	1	1	

† RS-28 = rotational stocking with a 28-d interval between grazing events; RS-42 = rotational stocking with a 42-d interval between grazing events.
‡ Means within a column not followed by the same letter are different ($P = 0.05$).

Table 4-3. Botanical composition in 2011 strips planted to RP in 2010 into existing bahiagrass. Data are means across three replicates, two 2011 sampling dates, and four defoliation strategies from 2010 (n = 24).

	Sampling date		
Year 2 grazing management	Mid-season†	Late-season	*P-value*
	--------------------- % ---------------------		
Rotational stocking 42 d	12 a	8	0.061
Rotational stocking 28 d	2 b	11	<0.0001
SE	1	2	

†Means not followed by the same letter are different within columns.

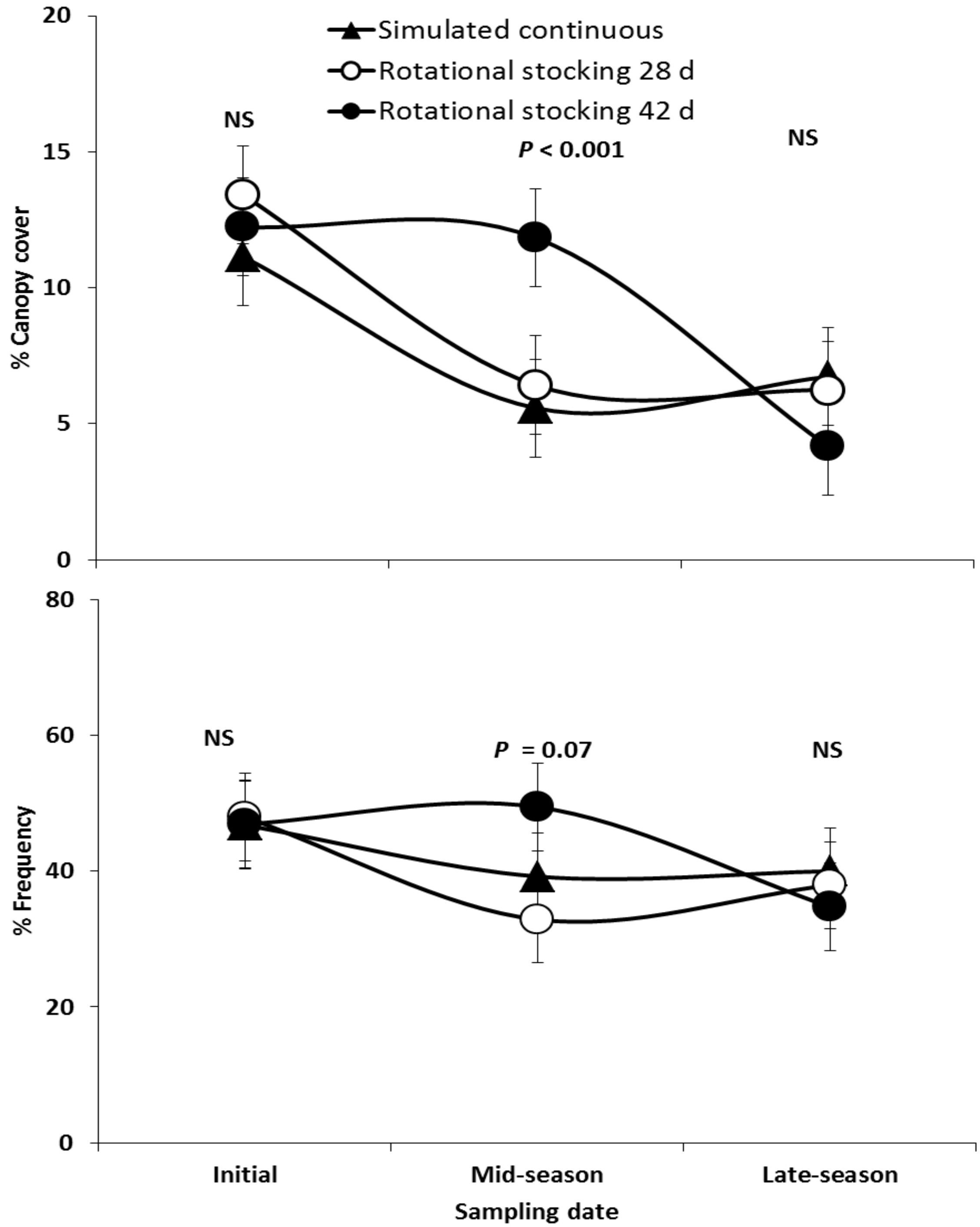

Figure 4-1. Canopy cover and frequency of rhizoma peanut in 2011 as affected by 2011 grazing management treatment following planting in strips in bahiagrass pastures in 2010. Initial, mid- and late-season dates correspond to June, August, and October, respectively, in 2011. Error bars represent treatment means (n = 12) ± one standard error.

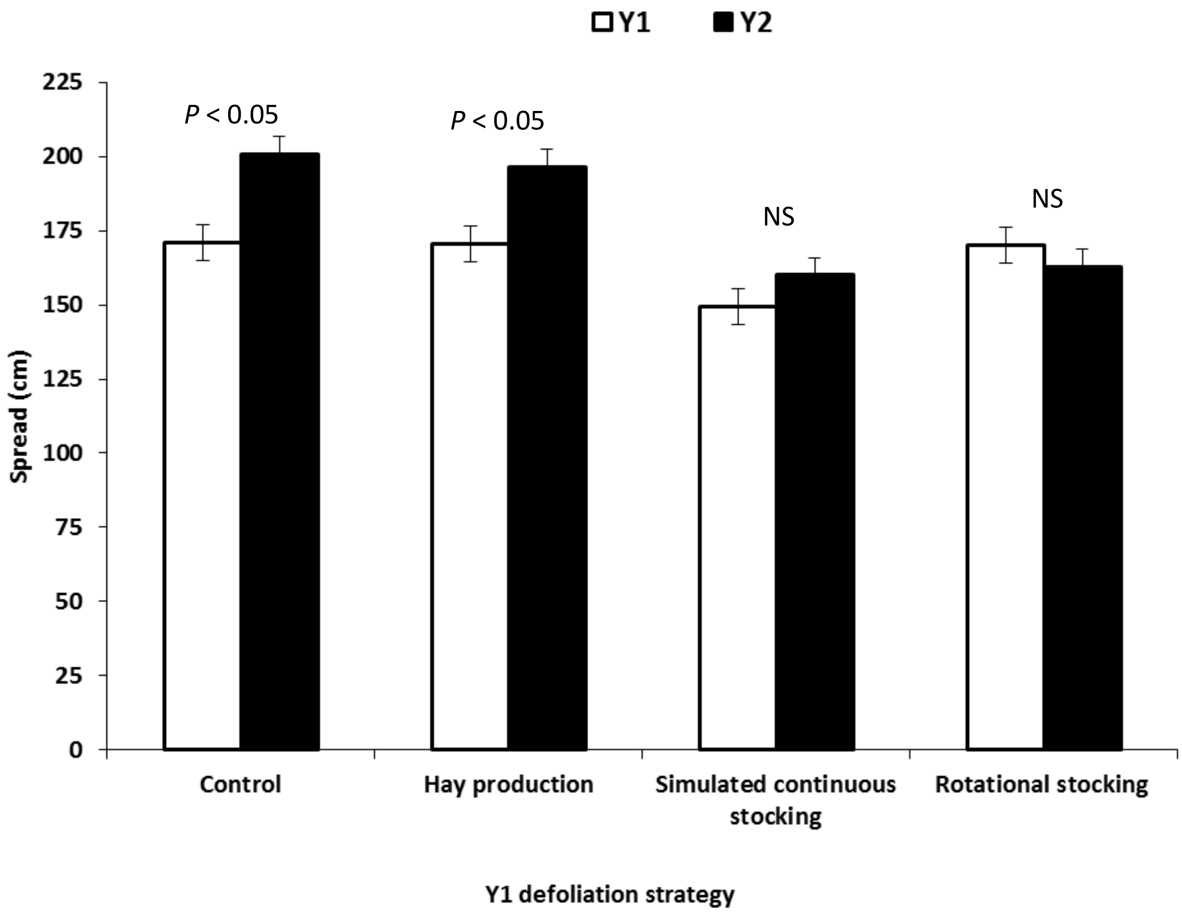

Figure 4-2. Effect of year-of-establishment defoliation management on spread measurements taken at the end of the establishment year of 2010 (Y1) and the year after establishment of 2011 (Y2). Spread is the distance from the center of the planted RP strip to the farthest point where identifiable above-ground RP plant parts were found. Error bars represent treatment means (n = 3) ± 1 standard error.

CHAPTER 5
STRATEGIES TO CONTROL COMPETITION TO STRIP-PLANTED LEGUME IN A WARM-SEASON GRASS PASTURE

Overview of Research Problem

Rhizoma peanut is a warm-season, vegetatively propagated, perennial legume with potential for incorporation into low-input forage-livestock systems in the USA Gulf Coast Region (French et al., 1994). Positive attributes of RP include drought tolerance (French, 1988), dry matter yields up to 10 to 12 Mg ha^{-1} yr^{-1} under natural rainfall conditions (Beltranena et al., 1981; Ocumpaugh, 1990), similar crude protein concentration and digestibility to alfalfa (*Medicago sativa* L.) (Prine et al., 1981; Beltranena et al., 1981), and persistence under a wide range of management systems for hay, silage, grazing, and as an understory forage crop (Prine et al., 1981; Ortega et al., 1992; Johnson et al., 2002). Further, due its capacity to fix N_2 from the atmosphere and higher nutritive value compared to tropical grasses (Muir et al., 2011), RP may also be an alternative source of N for grasslands, improving the likelihood of long-term persistence while maintaining and/or improving productivity of low-input forage-livestock systems (Thomas, 1994).

In spite of these advantages, high costs associated with vegetative establishment, management for weeds, and taking land out of production for one or more growing seasons to allow adequate establishment of RP, have limited its commercial use primarily to production of high-quality hay for dairy and equine rations (Adjei and Prine, 1976; Prine et al., 1986a, b; Rice et al., 1995). Establishment of RP is generally slow and competition from weeds has been reported to affect early growth of RP when planted in pure stand and growing in RP-bahiagrass mixtures (Canudas et al., 1989; Williams, 1994; Valencia et al., 1999). Herbicides have been the most-used and effective practice to control competition from weeds in newly planted RP fields. Ferrell and Sellers (2012) compiled a list of labeled herbicides for use in RP pastures.

Planting RP in strips is currently being evaluated as an alternative strategy for introducing RP into existing bahiagrass pastures. The goal is to reduce establishment cost to make use of RP feasible for low-input systems like beef cow-calf production. If less expensive establishment can be achieved, RP has demonstrated ability to persist and spread in mixtures with bahiagrass (Ortega-S. et al., 1992). Under the strip-planting approach, initial physical separation of the legume and grass provides opportunities for specialized cultural, chemical, and mechanical management practices that may lower inputs (e.g., number of herbicide applications per growing season) required for successful establishment of a RP-bahiagrass mixture. Additionally, there is potential to utilize the bahiagrass forage during the establishment year, thereby minimizing the negative impact to the overall grazing program. There is little existing information describing the effects of various management strategies on establishment of strip-planted RP. Thus, the objectives were to determine the effect of 1) weed management strategies in the planted strip and 2) a starter application of N fertilizer on strip-planted RP establishment and spread.

Materials and Methods

Experimental Site

The experiment was conducted for 2 yr (2010 and 2011) at the University of Florida Beef Research Unit (29°43' N; 82°21'W) near Gainesville, FL, with a new area planted each year. The site was chosen because of available well-established (at least 10 yr) and uniform 'Pensacola' bahiagrass pastures and because RP had persisted in adjacent grazed pastures for at least 30 yr, indicating adaptation of RP to this growing environment. The soil was classified as Sparr fine sand (loamy, siliceous, subactive, hyperthermic Grossarenic Paleudults). Initial characterization of the surface soil (0 to 15 cm) indicated soil pH of 5.5 and Mehlich-1 extractable P, K, Ca, and Mg of 35, 44, 290, and 46 mg kg^{-1}, respectively. Based on a recommended target pH of 6.0 for growth of RP, 1 Mg ha^{-1} of dolomitic lime [$(CaMg)(CO_3)_2$] was applied to the experimental area before planting in 2010. Soil samples taken before planting in 2011 confirmed the increase of soil pH to 6.1. The area was fertilized with 60 kg K ha^{-1} yr^{-1}, using muriate of potash (KCl, 600 g K_2O kg^{-1}, and 500 g Cl kg^{-1}) at the beginning of the growing season. Detailed rainfall and temperature data during the years of the experiment were presented in Figure 3-1 (Chapter 3). To generalize, total rainfall was 1103 and 1029 mm in 2010 and 2011, respectively, compared to the 30-yr average of 1238 mm. First and last freeze events of the growing season occurred on 8 March and 10 Nov. in 2010, and 14 March and 14 Nov. in 2011, respectively, and these dates did not differ to a large extent from long-term averages.

Land Preparation and Planting

Prior to strip-planting RP in the existing bahiagrass sod, strips were plowed in February with a moldboard plow and heavily disked several times to ensure grass- and weed-free planting area. The strips were 4-m wide and accommodated eight rows of RP, with spacing between rows of 0.5 m. The first and last rows of planted rhizomes were 0.25 m from the undisturbed edge of bahiagrass sod. The planted strips were bounded on both sides by a 2.5-m strip of undisturbed bahiagrass sod. Florigraze RP rhizomes were planted in the prepared strip using a conventional Bermuda King sprig planter during late winter (25 Mar. and 5 Apr. 2010 and 2011, respectively). The planting material was obtained from a commercial farmer cooperator. The rhizomes were planted at a rate of 1000 kg ha^{-1} (packed at ~ 79 kg m^{-3}) to approximately a 5-cm depth. After planting, plots were cultipacked to ensure adequate soil-rhizome contact. Irrigation was applied during April and May each year such that weekly rainfall plus irrigation equaled the 30-yr average weekly rainfall (18 and 20 mm per week in April and May, respectively). No irrigation was provided thereafter.

Treatments and Design

Treatments were the factorial combinations of two N rates and six weed management strategies. Nitrogen rates were 0 and 50 kg N ha^{-1} yr^{-1}. Mechanical and chemical weed management strategies were evaluated. They were: 1) control (no herbicide or mowing in the planted strip), 2) mowing (entire plot clipped every 28 d to 10-cm stubble height simulating a bahiagrass hay production system), and the application of herbicides: 3) pendimethalin at a rate of 0.93 kg a.i. ha^{-1} at planting, 4) clethodim at a rate of 0.10 kg a.i. ha^{-1} applied when grass weeds were 10- to 15-cm tall, 5) imazapic at a rate of 0.07 kg a.i. ha^{-1} when grass or broadleaf weeds were 5- to 10-cm tall, and 6) imazapic (0.07 29 kg a.i. ha^{-1}) mixed with 2,4-D amine at a rate of 0.28 kg a.i. ha^{-1} when grass or broadleaf weeds were 5- to 10-cm tall. The 12 treatments were assigned to experimental units as a factorial arrangement in a randomized complete block design and were replicated three times. Experimental units were 3-m long × 9-m wide, with a 1-m border between the lengths of the plots.

Nitrogen was applied once per year to the entire plot (i.e., both the strips planted with RP and the adjacent bahiagrass). Application of N occurred 2 wk after completion of herbicide treatments (18 May 2010 and 29 June 2011). The source of N was NH_4NO_3 fertilizer (340 g N kg^{-1}). Addition of 50 kg N ha^{-1} yr^{-1} was chosen because it approximates the average amount of N fertilizer applied per year to grazed bahiagrass pastures in FL (Mackowiak et al., 2008).

The herbicides and rates of application were based on previous research, and these specific herbicides were chosen because they are the only ones labeled for use in RP pastures in Florida (Ferrell and Sellers, 2012). Pendimethalin is an exception to this criterion and is not labeled for use in RP. It was included as a treatment because of its use as a pre-plant incorporated herbicide in plantings of annual peanut (*Arachis hypogea* L.) to manage competition from annual grasses (Prostko et al., 2001; Johnson et al., 2002; Mosler and Aerts, 2010). Herbicide treatments were applied once per growing season and only to the RP strips. The strips were sprayed using a 3.04-m wide boom using a CO_2-pressurized backpack sprayer calibrated to deliver 187 L ha^{-1} at 310 kPa.

The mowing treatment was first applied ~ 11 wk after planting (9 June 2010 and 28 June 2011), coinciding with the anticipated end of the sprout-emergence period, and followed the approach described by Castillo (Chapter 3). Timing was based on data reported by Williams (1993) and Williams et al. (1997), who indicated that sprout emergence continued for 7 wk after first sprouts emerged. In the control and all herbicide treatments, the planted strip was not mowed during the growing season but the bahiagrass bordering the planted strip was mowed to 10-cm stubble every 28 d. This occurred at the same time as the entire plot of the Mowing treatment was clipped.

Response Variables

Canopy Cover

Rhizoma peanut canopy cover in the planted strip was estimated visually for all treatments starting at the end of the shoot emergence period and every 28 d thereafter during the growing season. Cover was measured on the day after each defoliation event of the Mowing treatment. A 1-m^2 quadrat (0.5 × 2 m) was placed in the center of the rhizoma peanut strip at a fixed location so that canopy cover was estimated each time in the same area. The 0.5-m side of the quadrat was oriented parallel to the RP rows. Thus, the area enclosed by the quadrat included four rows of RP with the ends of the quadrat positioned so that they rested midway between the outermost RP row that was included in the quadrat and the RP row that was located just outside the quadrat. The quadrat was divided into 100, 10- by 10-cm squares (five rows of 20), and canopy cover was estimated in 20 stratified 10- by 10-cm squares (four squares in each row of 20 squares) per quadrat and averaged to obtain an overall cover per experimental unit (Appendix A; Interrante et al., 2009).

Frequency

Frequency is a measurement of the distribution of RP in the planted strip. It was determined on the same dates at the same quadrat locations that were used to estimate RP canopy cover. Presence or absence of RP was determined in the 20 stratified 10- by 10-cm squares and was calculated as the percentage of cells where RP was present divided by the total number of cells.

Light Environment

Ambient light environment at the top of the RP canopy was measured 2 wk before the end of the shoot emergence phase and every 28 d thereafter. Measurements on all experimental units were taken between 1200 and 1500 h Eastern Daylight Time on Day 14 of each of the 28-d regrowth periods of mowing treatment. Light environment was characterized using a SunScan Canopy Analysis System (Dynamax Inc., Houston, TX). The system consists of a 1-m-long quantum sensor that was placed at the height of the

RP canopy to measure transmitted photosynthetically active radiation (PAR), and an unshaded beam fraction sensor that was placed outside the plots to measure incident PAR. Thus, the light environment experienced by RP plants was characterized as percent of incident PAR that reached the RP canopy and was calculated by dividing the transmitted PAR by incident PAR and multiplying by 100 to express it as a percentage. The average of three observations per experimental unit provided an estimate of light environment.

Canopy Height and Spread

Rhizoma peanut canopy height and spread were measured on the day before the last clipping event of each year (29 Sept. 2010 and 17 Sept. 2011). Four measurements per plot were averaged to provide the estimate for each experimental unit. Canopy height measurements were intended to describe canopy development and interaction with treatments and to address concerns as to whether the application of 2,4-D herbicide during the year of establishment altered RP growth. Canopy height was estimated using a ruler to measure the distance from the soil surface to the non-extended height of the RP canopy. Spread was defined as the distance from a transect running through the length of the center of the planted strip to the farthest point where above-ground RP plant parts were found. Spread was measured on each side of the transect at 1 and 2 m from the end of the plot for a total of four observations per experimental unit.

Year-after Establishment Measurements

Canopy cover, botanical composition by weight, and spread of RP were measured the year after RP establishment with the purpose of estimating treatment carryover effects. During the year after establishment the entire plot of all treatments was clipped to 10-cm stubble height every 28 d, simulating a bahiagrass hay production system. Canopy cover and botanical composition were measured in the middle of the growing season (28 July 2011 and 31 July 2012). Spread was measured at the end of the growing season in 2011 and will be measured at the end of the growing season in 2012. Canopy cover and spread methodology were the same as described earlier. Botanical composition by weight was estimated by clipping one 0.25-m^2 quadrat to a 10-cm stubble height in the middle of each RP strip. Fresh herbage was collected and separated into grass and RP components. They were dried separately at 60°C until constant weight, and botanical composition was calculated.

Statistical Analysis

Data were analyzed as repeated measures using PROC GLIMMIX of SAS (SAS Institute, 2010). Sampling date was considered the repeated measurement with an autoregressive covariance structure. Year and block were considered random effects. Year was considered random because a new set of plots was established each year. Treatments and their interactions were fixed effects. In the case of second- and third-order interactions, simple effects were analyzed using the SLICE procedure of SAS. Mean separation was based on the PDIFF and SLICEDIFF procedure of LSMEANS. Plots of model residuals were used to check normality, and in the case of non-normal distributions, data transformations were used. Square root transformation was used for canopy cover and botanical composition data. Treatments were considered different when $P \leq 0.05$.

Results and Discussion

Canopy Cover and Frequency

There were effects of weed management strategy and sampling date. Second- and third-order interactions were significant with the exception that there was only a trend toward N application × sampling date interaction (*P* = 0.06). Weed management strategy effects on canopy cover were significant starting from July (2^{nd} sampling date), where imazapic and imazapic + 2,4-D were similar (20 and 19%, respectively) and greater than clethodim (7%), pendimethalin (4%), mowing (2%) and control (4%). Greatest canopy cover was achieved in August and was similar for imazapic and imazapic + 2,4-D (27 and 34%, respectively) and greater than the other treatments. Cover did not change from July through the remainder of the growing season for treatments which did not receive imazapic, while those receiving imazapic increased (Figure 5-1). Toward the end of the growing season, canopy cover in imazapic was 9% lower than Imazapic + 2,4-D; although, both treatments remained greater than the others.

Broadleaf weeds present in the strips planted to RP were mainly Mexican tea (*Chenopodium ambrosioides* L.) and cutleaf ground-cherry (*Physalis angulata* L.), and they were most prevalent in the control, pendimethalin, mowing, and clethodim treatments. Also, there was a pronounced shift in weed population pressure to sedges (*Cyperus spp.*) after application of clethodim as opposed to bahiagrass and broadleaf weeds in the control, pendimethalin and mowing treatments.

Due to the N rate × competition-control strategy interaction (*P* = 0.02), simple effects of N application on weed management were averaged only across sampling dates (Figure 5- 2). Nitrogen fertilization increased RP canopy cover in imazapic (from

13 to 21%; $P = 0.04$) and imazapic + 2,4-D treatments (from 15 to 26%; $P = 0.01$), but there was no effect of N on mowing and a trend ($P = 0.07$) toward reduced canopy cover in control, pendimethalin, and clethodim with N application.

The literature has reported contradictory conclusions when N is applied during establishment of RP. Negative effects on RP ground coverage, dry matter production, and nodulation were reported by Adjei and Prine (1976). Consequently N application was not recommended when planting RP. It is likely, however, that the negative RP response to N was due to the very high N rates used (0, 168, and 336 kg ha^{-1}) and also increased competition from weeds after N fertilization. Valentim (1987) reported little effect on nodule weight in RP after an application of 50 kg N ha^{-1} compared with greater negative effect when 100 kg N ha^{-1} was applied. Thomas (1994) reported similar results to those of Valentim (1987) when working with *Arachis pintoi* Krapov. & W.C. Greg., where levels greater than 100 kg N ha^{-1} inhibited nodulation when measured at 8 wk after planting. It has been suggested that 50 kg N ha^{-1} could be used as a starter dose without unduly affecting *A. glabrata* or *pintoi* infection and nodulation (Valentim et al., 1986; Thomas 1994).

Our results indicate that application of 50 kg N ha^{-1} had positive effects on RP canopy cover and frequency in the treatments where competition from weeds was effectively controlled (imazapic and imazapic + 2,4-D; Figs. 1 and 2). Competition control using these two treatments was achieved by completely suppressing broadleaf weeds (combined action of imazapic and 2,4-D herbicides) and temporarily suppressing bahiagrass growth which allowed time for establishment of RP while preventing emergence of other weeds. Thus, by the end of the season, canopy closure was achieved by RP and the re-growing bahiagrass.

Frequency responses were similar to RP canopy cover (Figure 5-1). Starting from July, the imazapic and imazapic + 2,4-D treatments were similar (46 and 49%, respectively) and greater than clethodim (34%), pendimethalin (24%), mowing (15%), and control (23%). Greatest frequency was achieved toward the end of the growing season. Imazapic and imazapic + 2,4-D were similar (67 and 73%, respectively) and greater than the other treatments which remained below 35%. Nitrogen fertilization increased RP frequency in imazapic (from 43 to 57%; $P = 0.05$) and imazapic + 2,4-D treatments (from 45 to 61%; $P = 0.02$); there was no effect of N in the Mowing treatment, and there was a negative effect in control, pendimethalin, and clethodim treatments ($P = 0.04$; *P value* corresponds to averaged control, pendimethalin and clethodim treatments with 0 vs. 50 kg N ha^{-1} yr^{-1}).

Rhizoma peanut canopy cover and frequency (~30 and 80%, respectively) were similar to the values reported when no defoliation or when production of hay were imposed during the year of establishment on strip-planted RP without N application and treated with imazapic (Chapter 3). When N was applied following a single application of imazapic or imazapic +2,4-D, canopy cover and frequency were ~41 and 80%, respectively. Thus, a single application of imazapic or imazapic + 2,4-D, followed by an application of 50 kg N ha^{-1} yr^{-1} has the potential to improve establishment of RP planted in strips, provide N to the bahiagrass growing along the edges of the strips, and increase RP contribution to the planted strip by the end of the year of establishment.

Light Environment

Nitrogen application, weed management strategy, sampling date, and second-order interactions were significant. Incident PAR at RP canopy height was similar at all sampling dates for imazapic and imazapic + 2,4-D treatments (above 96%) and was consistently greater than the other treatments until July when PAR for control was 77%, 81% for mowing, 75% for pendimethalin, and 82% for clethodim. Light environment decreased from July until September in all treatments except Mowing which remained constant at ~ 81%. In September, imazapic and imazapic + 2,4-D were similar to mowing (81, 84, and 84%, respectively), and these three were greater than control (68%), pendimethalin (57%), and clethodim (70%) (Figure 5-3). Even though there was a decrease in incident PAR at RP canopy height after July for the imazapic and imazapic + 2,4-D treatments, the decline (~10%) did not preclude further increases in RP canopy cover and frequency (Figure 5-1) and appeared to be function of bahiagrass regrowth.

Nitrogen application × weed management strategy interaction was analyzed over collection dates. Application of N decreased the amount of incident PAR reaching the canopy of RP in all treatments except in imazapic and imazapic + 2,4-D (Figure 5- 4). Consequently, effects on light environment appear to be a critical factor affecting RP establishment response to N fertilization. The benefits of N application are apparent when competition from weeds is suppressed for an extended period, as was the case in the imazapic and imazapic + 2,4-D treatments. In contrast, application of N can be deleterious for the establishment of RP planted in strips when other species are actively competing with RP for light.

Canopy Height and Spread

For RP canopy height there was effect of weed management strategy and a trend toward weed management strategy × N application interaction (P = 0.08). The interaction was due to greater (numerically) RP height with N application in control, pendimethalin, and clethodim (+5, +2, and +5 cm, respectively) and equal or lower height for the mowing, imazapic, and imazapic + 2,4-D treatments (0, -2, and -2 cm, respectively). Averaged across N applications, RP canopy height was greatest and similar in the control and pendimethalin treatments (30 and 31 cm, respectively) followed by clethodim (26 cm), and lowest for the mowing, imazapic, and imazapic + 2,4-D treatments (10, 11, and 8 cm, respectively; Figure 5-5). The results indicate that in growing environments where light is limiting, RP has the capacity to show phenotypic plasticity (stem elongation in this case) as a light-capturing strategy. Further, there was no effect of applying 2,4-D amine herbicide on RP canopy height (imazapic vs. imazapic + 2,4-D) during the year of establishment at the rate used in this study.

There were no treatment effects on spread measurements during the year of establishment. Similar results were reported in Chapter 3 for non-defoliated and hay production treatments imposed during the year of establishment.

Year-after Establishment Measurements

Canopy cover and frequency

There were effects of weed management strategy and weed management strategy × N application interaction for canopy cover. The interaction was due to greater (numerically) RP canopy cover with N fertilization in imazapic and imazapic + 2,4-D treatments (+6, and +9%, respectively) and equal or lower canopy cover with N fertilization in control, mowing, pendimethalin, and clethodim (-5, 0, -3,and -5%, respectively). Due to the interaction effect, the data were analyzed by N application rate. The effect of N application, even a year after application, was most apparent in imazapic and imazapic + 2,4-D treatments where competition from weeds was effectively controlled (Table 5-1).

Frequency followed the same trend as canopy cover. There were effects of weed management strategy and its interaction with N application (P = 0.03). When no N was applied, RP frequency in imazapic and imazapic + 2,4-D (57% for both) treatments were similar to clethodim (45%) and greater than the others. Clethodim was similar to control and pendimethalin (37 and 35%, respectively). The lowest frequency occurred in the mowing treatment (13%). When N was applied during the year of establishment, imazapic and imazapic + 2,4-D had the greatest frequency (70 and 73%, respectively) compared to the other treatments which were all similar and lower than 25% (Table 5-1).

Botanical composition

There were plant competition-control strategy effects on botanical composition but no interaction with N rate (P = 0.42). Imazapic and imazapic + 2,4-D treatments (11% for both treatments) had greater RP than control (1%), mowing (1%), and pendimethalin (3%). Clethodim (5%) was intermediate and similar to all treatments (Table 5-1). Imazapic and imazapic + 2,4-D treatments were noteworthy for the presence of RP patches where growth was relatively decumbent and less upright. Thus a significant proportion of the RP that resulted in superior cover and frequency responses in these treatments remained lower than the 10-cm cutting height for the botanical composition measures. This conclusion is supported by the canopy height results from the year-of establishment where RP height was lowest (Figure 5-5) in treatments where canopy cover and frequency were highest (Figure 5-1).

Spread

There were no treatment effects during the year after establishment. Thus, given that there were no treatment effects during either year (year of and year after establishment), spread was analyzed combining the 2-yr data of the corresponding set of plots. Year was included in the statistical model as a fixed effect to estimate RP spread into the bahiagrass over time. Results from 2011 indicated that on average RP spread 36 cm per year (year effect; P = 0.006).

Implications of the Research

Competition-control strategy effects on canopy cover were significant starting from July. Greatest canopy cover was achieved in August and was similar for imazapic and imazapic + 2,4-D (27 and 34%, respectively) and greater than clethodim (7%), pendimethalin (4%), control (4%), and mowing (2%) treatments. Application of 50 kg N ha^{-1} yr^{-1} increased RP canopy cover in imazapic (from 13 to 21%; P = 0.04) and imazapic + 2,4-D treatments (from 15 to 26%; P = 0.01); there was no effect of N application on mowing, and a trend (P = 0.07) toward reduced canopy cover in control, pendimethalin, and clethodim treatments when N was applied.

Frequency values followed the same trend as canopy cover. Greatest frequency was observed toward the end of the growing season. Imazapic and imazapic + 2,4-D were similar (67 and 73%, respectively) and greater than the other treatments which remained below 35%. Nitrogen fertilization increased RP frequency in imazapic (from 43 to 57%; P = 0.05) and imazapic + 2,4-D treatment (from 45 to 61%; P = 0.02); there was no effect of N application for mowing and a negative effect of N for control, pendimethalin, and clethodim treatments (P = 0.04). Incident PAR at RP canopy height was similar in all sampling dates for imazapic and imazapic + 2,4-D treatments (above 96%) and was consistently greater than the other treatments until July (control, 77%; mowing, 81%; pendimethalin, 75%; and clethodim, 82%).

Year-after-establishment measurements indicate that treatment effects in the establishment year carried over. Canopy cover, frequency and botanical composition measurements were consistently greatest in the imazapic and imazapic + 2,4-D treatments. Spread measurements indicate that RP grew into bahiagrass sod at a rate of 36 cm yr^{-1}.

In conclusion, the benefits of N application accrue when weed competition is suppressed, as in the case of imazapic and imazapic + 2,4-D treatments. In contrast, N application can be deleterious if competition is not controlled. Single application of imazapic and imazapic + 2,D-4 herbicides followed by application of 50 kg N ha^{-1} yr^{-1} has the potential to improve establishment of RP planted in strips, increase bahiagrass dry matter harvested in the unplanted areas cut for hay, and aid in achieving a RP-bahiagrass mixture in the planted strip by the end of the establishment year.

Table 5-1. Rhizoma peanut (RP) canopy cover, frequency, and botanical composition in July of the year after establishment for RP strips planted in bahiagrass pastures and subjected to various weed management strategies with and without N fertilizer. Data are means across three replicates and 2 yr (n = 6).

Treatment description†	Canopy cover kg N ha^{-1} yr^{-1} 0	Canopy cover kg N ha^{-1} yr^{-1} 50	Frequency kg N ha^{-1} yr^{-1} 0	Frequency kg N ha^{-1} yr^{-1} 50	Botanical composition
	------------------------------------- % --				
Mowing	2 c‡	2 b	13 c	15 b	1 b
Pendimethalin	6 bc	3 b	35 b	23 b	3 b
Control	8 ab	3 b	37 b	19 b	1 b
Clethodim	10 ab	5 b	45 ab	25 b	5 ab
Imazapic	12 ab	18 a	57 a	69 a	11 a
Imazapic + 2,4-D	16 a	25 a	58 a	73 a	11 a
SE	2	2	9	9	2

†Mowing: every 28 d to 10 cm stubble height simulating bahiagrass hay production; control: untreated, un-defoliated strip planted to RP with only adjacent bahiagrass defoliated; and the application of herbicides; pendimethalin (Prowl) at a rate of 0.93 kg a.i. ha^{-1} at planting; clethodim (Select Max) at a rate of 0.10 kg a.i. ha^{-1} applied when grass weeds were 10 to 15 cm tall); imazapic (Impose) at a rate of 0.07 kg a.i. ha^{-1} when grass or broadleaf weeds were 5 to 10 cm tall; and imazapic (0.07 kg a.i. ha^{-1}) mixed with 2,4-D amine at a rate of 0.28 kg a.i. ha^{-1} when grass or broadleaves were 5 to 10 cm tall.

‡Numbers within columns not followed by the same letter are different ($P < 0.05$).

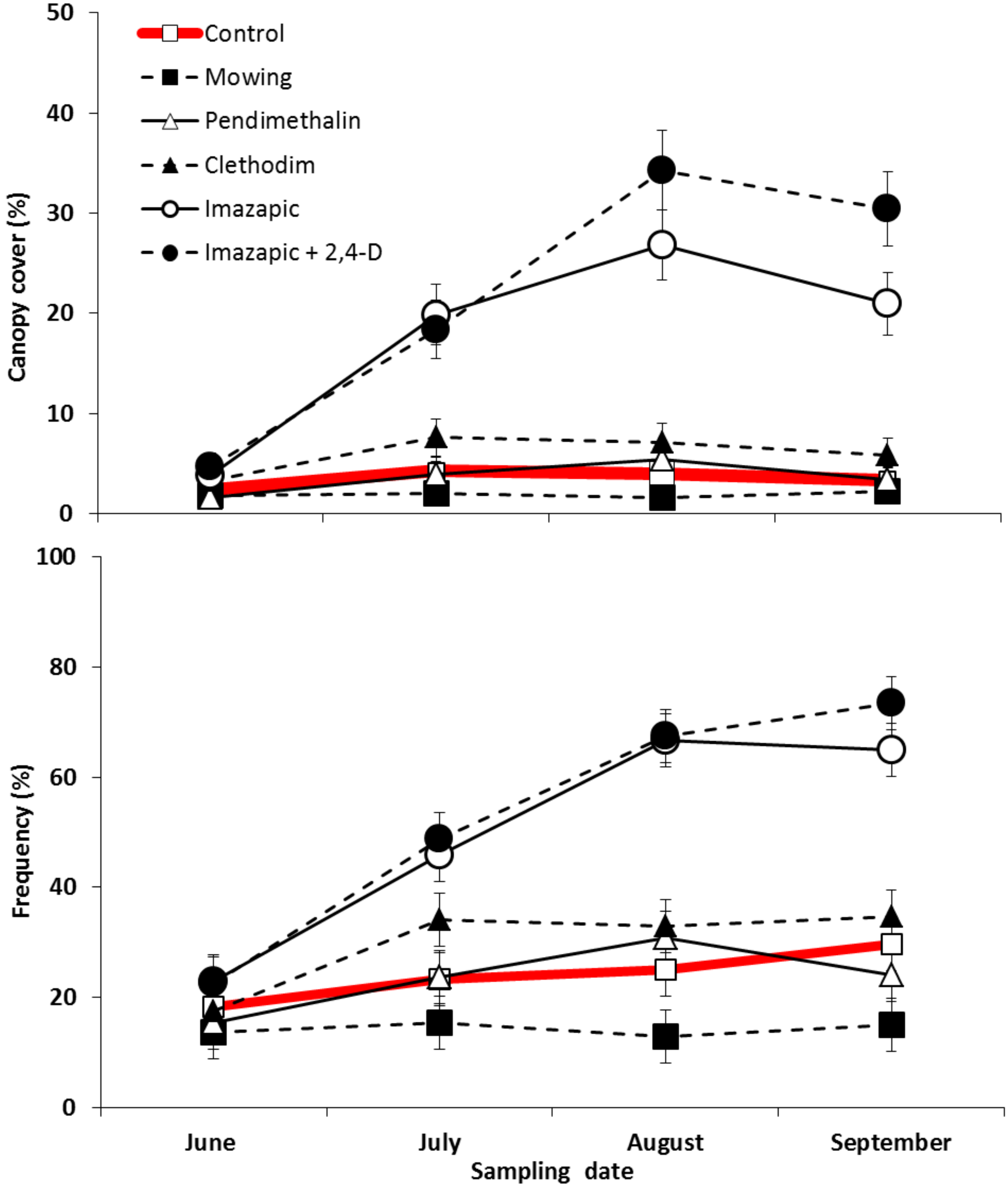

Figure 5-1. Canopy cover and frequency of occurrence of rhizoma peanut planted in strips in existing bahiagrass pastures. Data are means across 2 yr. Error bars represent treatment means averaged across nitrogen rates (n = 6) ± 1 standard error.

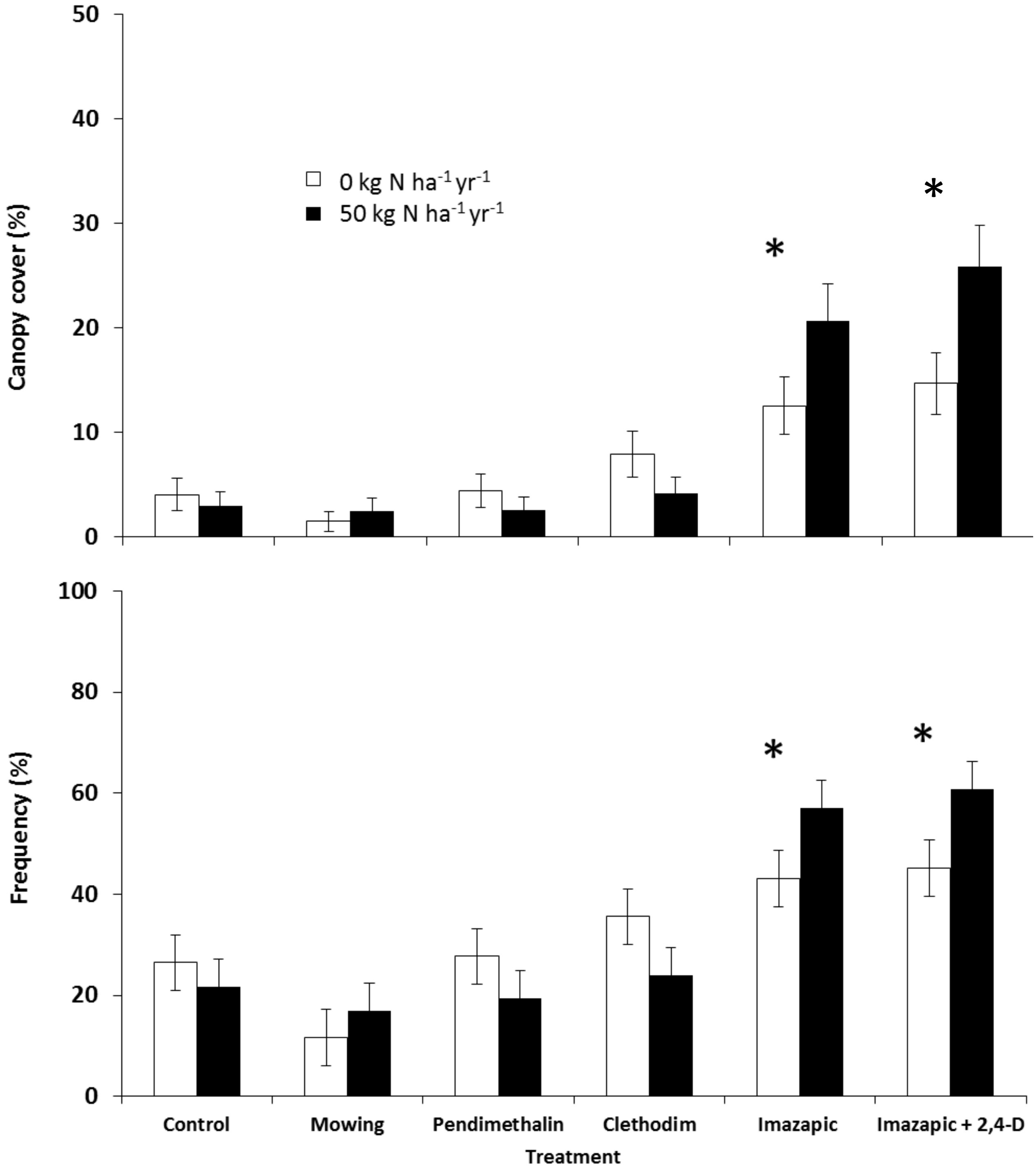

Figure 5-2. Canopy cover and frequency of occurrence of rhizoma peanut planted in strips in existing bahiagrass pastures. Data are means across 2 yr. Error bars represent treatment means averaged across sampling dates and years (n=24) ± 1 standard error. * = significant N effect ($P \leq 0.05$).

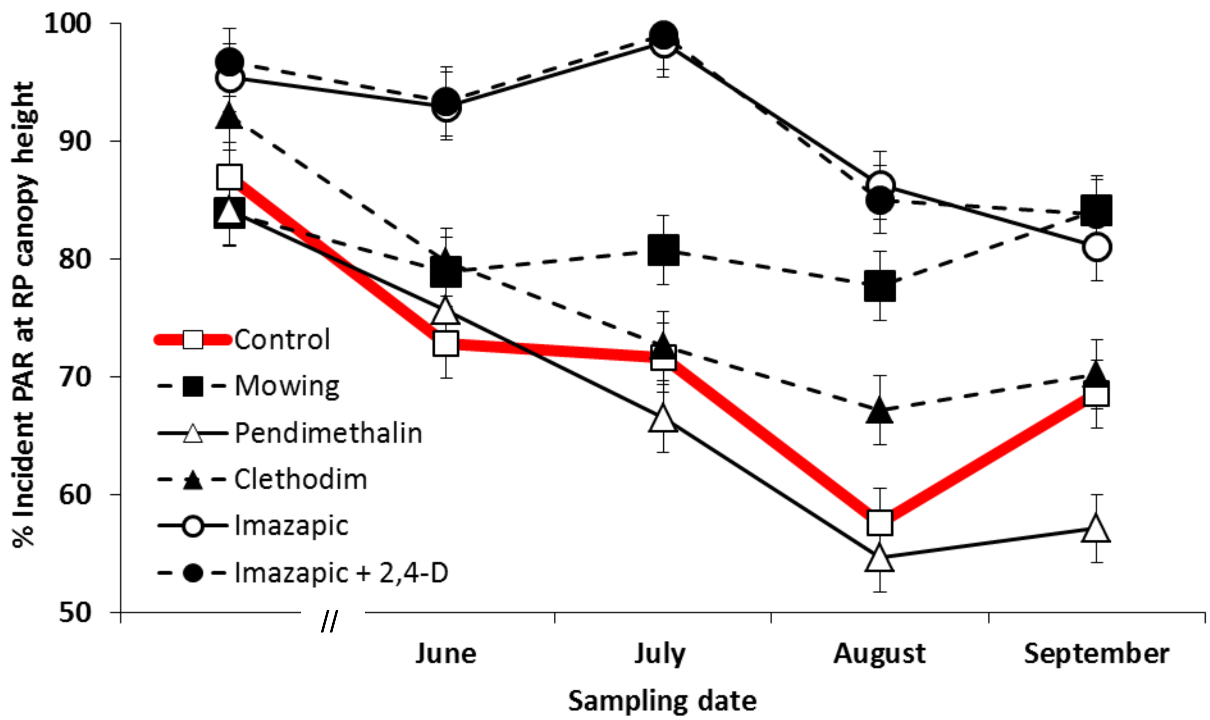

Figure 5-3. Incident photosynthetically active radiation (PAR) at rhizoma peanut canopy height. Data are means across 2 yr. Error bars represent treatment means averaged across N rates (n = 6) ± 1 standard error.

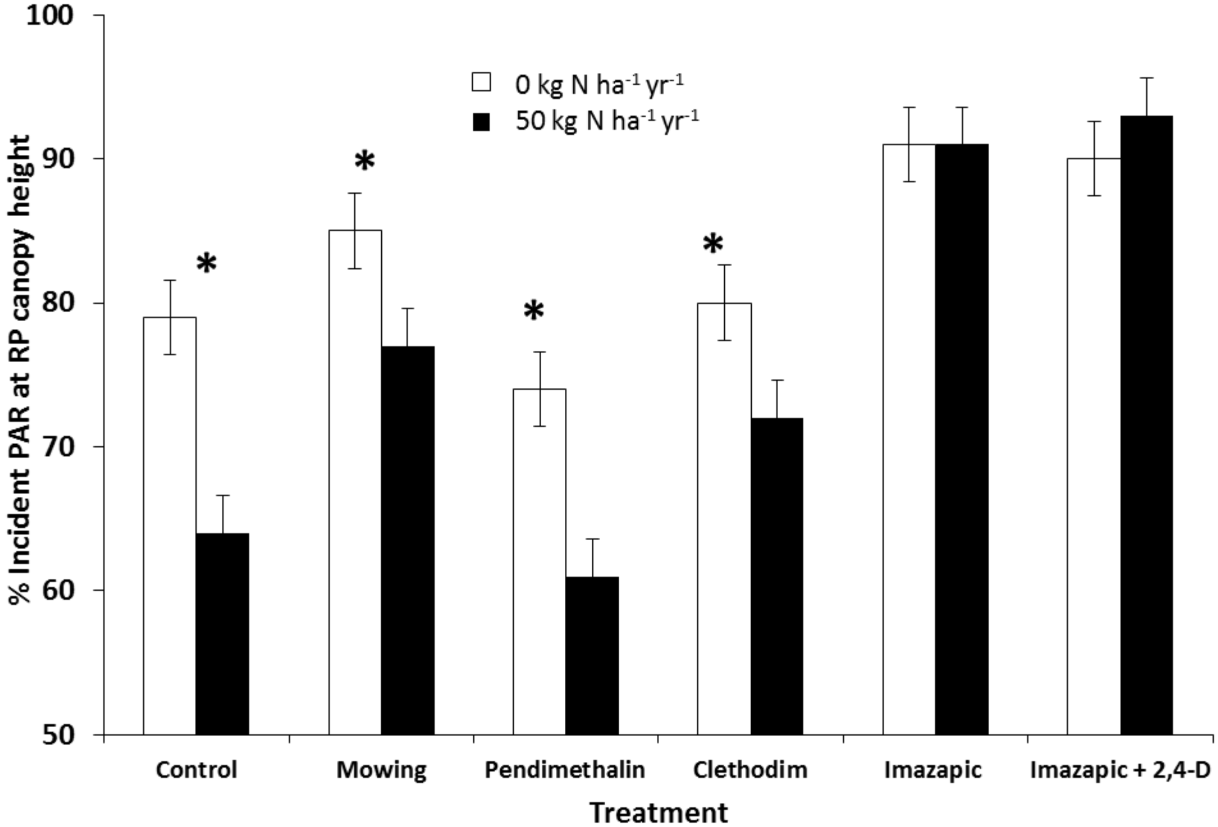

Figure 5-4. Incident photosynthetically active radiation (PAR) reaching the rhizoma peanut (RP) canopy. Data are means across 2 yr. Error bars represent treatment means averaged across sampling dates and years (n = 30) ± 1 standard error. * = significant N effect ($P \leq 0.05$).

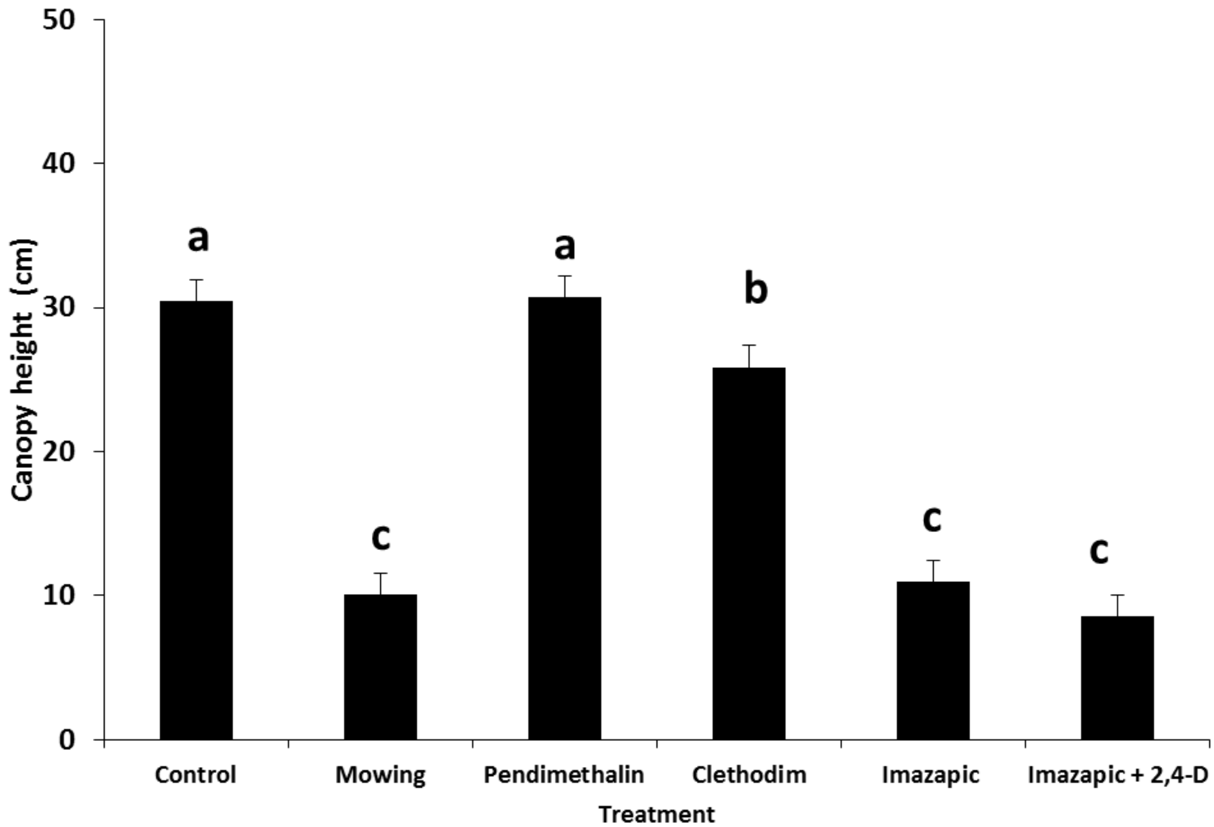

Figure 5-5. Rhizoma peanut canopy height measured at the end of the growing season in 2010 and 2011. Data are means of 2 yr. Error bars represent treatment means averaged across years (n = 6) ± 1 standard error.

CHAPTER 6
SEEDBED PREPARATION TECHNIQUES AND WEED MANAGEMENT STRATEGIES FOR STRIP-PLANTING A LEGUME INTO WARM-SEASON GRASS PASTURES

Overview of Research Problem

Rhizoma peanut is a warm-season, vegetatively propagated, perennial legume with potential for incorporation into low-input, pasture-based livestock systems in the USA Gulf Coast Region (French et al., 1994; Castillo, Chapter 3). Drought tolerance (French, 1998), dry matter yields up to 12 Mg ha^{-1} under natural rainfall conditions (Beltranena et al., 1981; Ocumpaugh, 1990), similar crude protein concentration and digestibility to alfalfa (*Medicago sativa* L.) (Prine et al., 1981; Beltranena et al., 1981), and persistence under a wide range of management systems for hay, silage, grazing, and as a understory forage crop (Prine et al., 1981; Ortega-S. et al., 1992; Johnson et al., 2002) are among RP's positive attributes. No other perennial legume adapted to the USA Gulf Coast region has demonstrated the versatility of RP.

Currently RP is used primarily as a high value hay crop for horses (*Equus caballus*) and dairy cattle (*Bos taurus*) in the Southeast USA. Factors limiting use of RP in grazed pasture systems include high cost and slow rate of establishment and the need to remove the planted area from the grazing rotation during the establishment period. If RP is to become more widely used in low-input pasture systems, lower cost establishment methods will be needed. A technology that may have potential to address this need is strip planting RP into existing perennial grass pastures.

Previous research evaluated and demonstrated potential of strip planting RP in existing bahiagrass pastures (Chapters 3 and 5). This work showed that grazing during the establishment year negatively affects RP cover, frequency, and spread compared to hay production which is similar to no defoliation of the planted strip (Chapter 3). It also indicated that imazapic or imazapic + 2,4-D can be used effectively to control post-emergence weed competition during the establishment year and that application of 50 kg N ha^{-1} after herbicide treatment increases RP cover and frequency in those herbicide treatments that are effective in controlling broadleaf weeds and sedges (*Cyperus* sp.) and stunting bahiagrass (Chapter 5).

Currently, there is little information available regarding seedbed preparation prior to planting RP and its effect on establishment response. Williams et al. (2002) found that planter type (no-till vs. conventional sprig planter) had no effect on rhizoma peanut establishment. They also investigated the factorial combination of seedbed preparation (undisturbed sod vs. rotovated), planting date (winter vs. summer), and use of the herbicide glyphosate vs. none. The authors analyzed the data by year and attributed a large portion of the variation in responses to environmental conditions (rainfall and temperature). In general, they reported a trend toward greater sprout emergence when soil was disturbed (i.e., rotovated, tilled) compared to sod-seeding.

Williams (1993) evaluated pre-plant tillage (plowed = bottom plowed and disked; disked = disked only; and sod = planted directly into grass sod). She reported a general ranking for RP sprout emergence of plowed > disked = sod and recommended planting RP in well-prepared fields during winter. While these studies provide some information on the effects of seedbed preparation prior to planting RP, there was significant variability in treatment responses depending on weather and none of the experiments studied what is now the most likely approach to be used by producers, the combination of herbicides and tillage.

Herbicides, types of implements, and number of passes with equipment over the strips required to achieve an adequate seedbed for RP establishment are critical determinants of establishment cost. These requirements will affect whether a low-cost option can be realized that may result in adoption of this technology by farmers, especially by those using RP in grazed pastures, e.g., pasture managers in the cow-calf industry.

The current experiment was designed to investigate what combinations of pre-plant seedbed preparation and post-plant competition-control strategies are most effective for ‘Florigraze’ RP establishment in strips in bahiagrass sod. The specific objectives were to quantify the effect of seedbed preparation techniques on establishment of RP planted in strips in bahiagrass sod and to determine the effect of post-plant, competition-control strategies and their interaction with seedbed preparation.

Materials and Methods

Experimental Site

The experiment was conducted during 2011 and 2012 at the University of Florida Beef Research Unit (29°43’ N; 82°21’W) near Gainesville, FL. With the exception of sprout emergence, only data from 2011 will be presented in this chapter. The site was chosen because of available well-established (at least 10 yr) and uniform ‘Pensacola’ bahiagrass pastures and because nearby RP pastures at this site have persisted for 30 yr, indicative of adaptation of RP to the area. The soils at the experimental site were classified as Pomona (sandy, siliceous, hyperthermic Ultic Alaquods) and Myakka sands (sandy, siliceous, hyperthermic Aeric Haplaquods). Initial characterization of the surface soil (0 to 15 cm) indicated soil pH of 6.0 and Mehlich-1 extractable P, K, Ca, and Mg of 8, 16, 161, and 25 mg kg^{-1}, respectively. Based on the recommendation for growing RP, the area was fertilized at the beginning of the growing season with 16 kg ha^{-1} of P from triple super phosphate (440 g P_2O_5 kg^{-1}), and 60 kg ha^{-1} of K from muriate of potash (KCl, 600 g K_2O kg^{-1}, and 500 g Cl kg^{-1}). Rainfall data from the experimental period and the 30-yr average are presented in Figure 6-1. Total rainfall during 2011 was 1029 mm. Last freeze event before planting in spring occurred on 8 March 2011. First freeze event at the end of the growing season occurred on 10 Nov. 2011. The dates of freeze events were typical for this location.

Planting Methodology

The strips into which RP was planted were 4-m wide bounded on each side by a 1-m wide strip of undisturbed bahiagrass sod. Strips were planted using a conventional three-row Bermuda King sprig planter (Williams et al., 2002) with a spacing of 0.5 m between rows. Each strip accommodated a total of nine rows of RP. The first and last rows of planted rhizomes were 0.25 m away from the undisturbed edge of bahiagrass sod, and the three external rows on each side of the strip were planted first. The center three rows were planted last such that spacing was 0.25 m between the second and third rows on either side of the center row.

Florigraze RP rhizomes were planted at a rate of 1000 kg ha^{-1} (packed at ~ 79 kg m^{-3}) to approximately 5-cm depth on 5 April 2011. After planting, the plots were cultipacked to firm the seedbed and ensure adequate soil-rhizome contact. Irrigation was applied during April and May such that weekly rainfall plus irrigation equaled the 30-yr average weekly rainfall (18 and 20 mm per week in April and May, respectively). Once the Mowing treatment was initiated in June no further irrigation was provided.

Treatments and Experimental Design

Treatments were the factorial combinations of four seedbed preparation techniques and four weed competition-control strategies, for a total of 16. Treatments were allocated in a split-plot arrangement of a randomized complete block design and were replicated three times. The main-plot factor was seedbed preparation technique, and the sub-plot factor was competition-control strategy. The area of an experimental unit was 3-m long and 6-m wide, with a 1-m border between the lengths of the plots.

Seedbed preparation techniques were: 1) glyphosate (6.2 kg a.i. ha^{-1}) followed by conventional tillage {G-CT; bahiagrass sod sprayed with glyphosate [N-(phosphonomethyl) glycine, in the form of its potassium salt] in October 2010 followed by deep tillage with a moldboard plow and heavy disking during February 2011}; 2) conventional tillage (CT; bahiagrass sod tilled as in G-CT treatment but no glyphosate applied to kill the bahiagrass); 3) no-till (NT, bahiagrass sod sprayed with glyphosate in October 2010, followed by mowing remaining above-ground biomass to 5-cm stubble height before planting RP); 4) sod lifted (SL; bahiagrass sod was lifted with a sod-cutter to a depth of 8 cm below soil level and removed from the strip before planting RP). Seedbed preparation treatments were chosen because they represent available and commercially practical options for addressing bahiagrass competition to establishing RP and because they have potential to create a wide range in disturbance of the bahiagrass sod.

Weed competition-control strategies applied to the strips planted to RP were: 1) single application of imazapic {imazapic; (+/- -2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1 *H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylicacid; Impose} at a rate of 0.07 kg a.i. ha^{-1} when grass or broadleaf weeds were 5- to 10-cm tall, 2) imazapic (0.07 kg a.i.

ha^{-1}) mixed with 2,4-D amine (dimethylamine salt of 2,4-dichlorophenoxyacetic acid; 2,4-D amine Weed Killer) (imazapic + 2,4-D) at a rate of 0.28 kg a.i. ha^{-1} when grass or broadleaf weeds were 5- to 10-cm tall, 3) mowing (Mow; every 28 d to 10-cm stubble height simulating a bahiagrass hay production treatment), and 4) control (Control; no herbicide application, non-defoliated). Herbicides were applied on 14 June 2011 using a CO_2-pressurized backpack sprayer calibrated to deliver 187 L ha^{-1}. The strips were sprayed using a 3.04-m wide boom so that the bahiagrass at the edges of the strips was not sprayed. Weed management strategies were based on the results of studies conducted first in 2010 (Chapters 3 and 5).

The Mow treatment was applied starting ~ 11 wk after planting (28 June 2011), coinciding with the anticipated end of the sprout-emergence period, and every 28 d thereafter throughout the growing season. Timing of initiation was based on data reported by Williams (1993) and Williams et al. (1997), who indicated that sprout emergence continued for 7 wk after first sprouts emerged. In G-CT, CT, and SL treatments, the planted strip was not defoliated during the growing season, but the bahiagrass bordering the planted strip was mowed to 10-cm stubble every 28 d. This occurred at the same time the entire plot of the Mow treatment was clipped. Herbicide Clethodim ((E)-2-2[1-[[3-chloro-2-propenyl)oxy]imino]propyl]5-[2(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one; Select Max) was spot-sprayed to control common bermudagrass [*Cynodon dactylon* (L.) Pers.] growing in the strips planted to RP.

Response Variables

Sprout Emergence

Sprout counts were measured with the objective of determining the effect of seedbed preparation techniques. Sub-plot treatments had not yet been imposed during the sprout emergence period, thus only main plot effects were quantified. Sprout counts began at sprout emergence and occurred every 2 wk through 6 wk after emergence. First sprout emergence occurred 4 wk after planting on 28 April and May 17 in 2011 and 2012, respectively. Sprout emergence was determined by counting the number of sprouts within three randomly located, permanently marked 20- by 50-cm quadrats per main plot, so that evaluations were done in the same places over time. The 50-cm side of the quadrat was always placed parallel to the RP rows with the 20-cm side centered perpendicular to a row of RP. Total sprout emergence in a plot was calculated as the average of the three quadrats per plot and is expressed as sprouts m^{-2}.

Canopy Cover and Frequency

Rhizoma peanut canopy cover in the planted strip was measured visually every 28 d for all treatments on the day after each defoliation event of the Mow treatment. A 1-m^2 quadrat (0.5 × 2 m) was placed in the center of the RP strip at a permanently marked location in each experimental unit, so that canopy cover was estimated on the same area over time. The 0.5-m side of the quadrat was oriented parallel to the RP rows and was placed 1 m away from the edge of the bahiagrass sod. Thus, the area enclosed by the quadrat included a total of six rows of RP. The quadrat was divided into 100, 10- by 10-cm squares (five rows of 20), and canopy cover was estimated visually by the same observer in 20 stratified 10- by 10-cm squares (four squares in each row of 20) per quadrat and averaged to obtain an overall cover per experimental unit (Appendix A; Interrante et al., 2009).

Frequency of occurrence is a measurement of the relative distribution of RP in the strip. It was determined on the same dates and at the same quadrat locations that were used to estimate RP canopy cover. Presence or absence of RP was determined in 20 stratified 10- by 10-cm squares. Frequency was expressed as a percentage and was calculated as the number of cells where RP was present divided by the total number of cells assessed with the quotient multiplied by 100.

Light Environment

Ambient light environment at the top of the RP canopy was measured 2 wk before the projected end of the shoot emergence phase (Williams, 1993; Williams et al., 1997) and every 28 d thereafter. Measurements on all experimental units were taken between 1200 and 1500 h Eastern Daylight Time on Day 14 of each of the 28-d regrowth periods of the Mow treatment. Light environment was characterized using a SunScan Canopy Analysis System (Dynamax Inc., Houston, TX) at three randomly selected locations per plot. The SunScan consists of a 1-m-long quantum sensor that was placed at the height of the RP canopy to measure transmitted photosynthetically active radiation (PAR), and an unshaded beam fraction sensor that was placed outside the plots to measure incident PAR. Thus, the light environment experienced by RP plants was characterized as percent of incident PAR that reached the RP canopy and was calculated by dividing the transmitted PAR by incident PAR and multiplying by 100 to express it as a percentage. The average of four observations per experimental unit provided an estimate of light environment.

Spread and Canopy Height

Rhizoma peanut spread and canopy height were measured on all plots the day before the last clipping event of the season (17 September) for the Mow treatment. To measure spread, a transect was positioned through the center of the RP strip running the length of the each plot. At the 1- and 2-m points along the 3-m transect, a line, perpendicular to the transect, was extended on each side. Spread was defined as the distance from the center of the planted RP strip to the farthest point where identifiable RP plant parts (above ground) were found. Canopy height was intended to describe canopy development and interaction with treatments. It was measured using a ruler to quantify the distance from the soil surface to the non-extended height of the RP canopy. Four measurements per plot were averaged to provide estimates of spread and canopy height for each experimental unit.

Statistical Analysis

Data were analyzed as repeated measures using PROC GLIMMIX of SAS (SAS Institute, 2010). Sampling date was considered a repeated measurement with a first order autoregressive covariance structure. Block was considered a random effect. Treatments were fixed effects. Mean separations were based on the SLICE and SLICEDIFF procedures of LSMEANS. Plots of model residuals were used to check normality, and in the case of non-normal distributions, data transformations were used. Square root transformation was used for canopy cover, and log based 10 was used for sprout counts. Treatments were considered different when $P \leq 0.05$.

Results and Discussion

Sprout Emergence

There were seedbed preparation and collection date effects. Number of sprouts m^{-2}, averaged across collection dates, was greatest and not different for G-CT (119) and CT (90), while CT was not different than NT (58) but greater than SL (54), and NT was not different than SL (Figure 6-2). Sprout emergence averaged 80 m^{-2} at Week 4 after emergence and did not increase significantly through Week 6 (88 sprouts m^{-2}). Our results agree with previous reports in the literature indicating that the majority of RP sprouts emerged within 6 to 7 wk of initial emergence regardless of pre-plant tillage and planting date (Williams, 1993; Williams et al., 1997). Those authors also reported a trend toward greater sprout emergence when soil was disturbed (i.e., rotovated, tilled) compared to sod-seeding.

Fewer sprouts emerging when RP was planted in existing sod was attributed to factors including desiccation of rhizomes when appropriate soil-rhizome contact was not achieved and to inadequate soil moisture (Williams, 1993). That study was conducted under non-irrigated conditions and treatment responses varied depending on rainfall. Under the conditions of the current experiment, lack of water may not have been a limiting factor because irrigation was provided during the sprout emergence period. Further, there was no active bahiagrass growth in the NT treatment strips because of glyphosate application the previous fall.

It is not completely clear how the presence of decaying plant material (above- and below-ground) affected sprout emergence in the NT treatment. Also, it is not totally clear why there was low sprout emergence in the SL treatment where there was virtually no competition from above- or below-ground plant parts. However, the similarity of the SL and NT responses and the superior performance of G-CT and trend toward superior performance of CT suggest that tilled soil allows for more favorable rhizome placement during planting, perhaps achieving greater depth or better soil-rhizome contact. Nevertheless, differences in number of emerged sprouts did not result in differences in RP canopy cover and frequency of occurrence at 9 mo after planting.

Canopy Cover and Frequency

There were weed management strategy, sampling date, and weed management strategy × sampling date interaction effects. Seedbed preparation did not have an effect (P = 0.67) on RP canopy cover nor did it interact with competition-control strategy (P =

0.31). Averaged across subplot treatments, RP canopy cover and frequency were greatest toward the latter half of the growing season with canopy cover values of 25, 25, 19, and 21% and frequency of occurrence of 59, 58, 52, and 41% for G-CT, NT, CT, and SL treatments, respectively. These canopy cover and frequency data are similar to those reported for strip-planted RP when seedbed preparation was the same as that used for CT in this experiment (Chapter 3). The results further suggest that a single application of glyphosate herbicide in the autumn followed by mowing to remove some of the above-ground biomass before planting (NT) is a viable seedbed preparation option for strip-planting RP in existing bahiagrass pastures.

Differences in RP cover due to post-plant competition-control strategy occurred early in the growing season (July) and cover generally peaked in August (Figure 6-3). Treatment responses were consistent across the season and segregated in treatment pairs with imazapic (33%) and imazapic + 2,4-D (35%) being not different from each other and greater than Control (16%) and Mow (9%). The superior performance of these herbicide treatments has been consistent in several studies evaluating RP strip planting (Chapters 3 and 5).

Frequency followed the same trend as canopy cover. There were weed management strategy, sampling date, and weed management strategy × sampling date interaction effects. Weed management strategy effect was significant starting from August (Figure 6-3), and the treatments segregated in pairs and remained consistent until the end of the growing season. Imazapic (66%) and imazapic + 2,4-D (70%) were not different from each other and greater than Mow (35%) and Control (40%). Similar results were reported by Castillo (Chapter 5).

It is important to note that the cover and frequency data reported in this chapter are from 2011 only, with data from 2012 not yet included in the analysis. It is apparent that regardless of the seedbed preparation strategy used, post-emergence application of imazapic or imazapic + 2,4-D are needed to control competition from weeds or bahiagrass and allow successful establishment of RP planted in strips.

Light Environment

There was trend toward a seedbed preparation effect ($P = 0.07$) and there were effects of weed competition-control strategy, sampling date, and all second order interactions. Seedbed preparation effect on light environment of RP canopy was significant starting in September with PAR in NT and SL being above 90% and not different but greater than CT and G-CT (83 and 76%, respectively) (Figure 6-4). Differences followed the same trend until the end of the growing season in October. There were competition-control strategy effects starting in August with PAR in Mow (96%), imazapic, and imazapic + 2,4-D (100% for both) being not different from each other and all of them greater than Control (86%). The response remained the same through the end of the growing season in October. The decrease in PAR at RP canopy height for the imazapic, and imazapic + 2,4-D treatments during the latter part of the growing season (~ 12%; $P < 0.05$) was also reported by Castillo (Chapter 5), and it was attributed to regrowth of bahiagrass.

Due to seedbed preparation and competition-control strategy interaction, data were analyzed by seedbed preparation (Figure 6-5). There were no differences in light environment due to weed competition-control strategy in NT and SL treatments. In G-CT, light environment was similar and greatest for the imazapic and imazapic + 2,4-D treatments (94 and 90%, respectively), followed by Mow (82%), and lowest for the

Control (74%). In the CT treatment, PAR at RP canopy height for Mow, imazapic, and imazapic + 2,4-D was not different (88, 92, and 91%, respectively) and greater than the Control (73%). Results indicate that a single application of glyphosate in fall followed by no tillage (Treatment NT) provides adequate light environment for establishment of RP (≥ 88%), and further application of herbicides (i.e., imazapic and imazapic + 2,4-D) does not increase PAR to the RP canopy.

Spread and Canopy Height

There was seedbed preparation effect on RP spread (Figure 6-6). Spread was not different for G-CT and CT (189 cm) and NT (178 cm), while SL (169 cm) was not different than NT but lower than G-CT and CT. Given that the outer row of RP was planted 175 cm from the center of the strip, spread was minimal in the first year in all treatments. Similar results were reported by Castillo (Chapters 3 and 5). The SL treatment actually resulted in loss of plants in the outer row of the strip closest to bahiagrass resulting in a reduction in spread. A possible explanation for this response is that the difference in the level of the planted strip and the adjacent bahiagrass sod, due to removal of sod and associated topsoil, may have prevented uniform cultipacking and therefore reduced soil-rhizome contact of the outer-most rows.

There were seedbed preparation technique, competition-control strategy, and interaction effects on RP canopy height. Interaction occurred because there were no competition-control strategy effects for NT and SL seedbed preparation, while for G-CT and CT there were differences. Canopy height of RP averaged across competition-control strategies in the NT and SL treatments was 5 and 6 cm, respectively. For G-CT, canopy height was greatest in the Control (17 cm), followed by Mow (8 cm), which was not different than imazapic + 2,4-D (7 cm), but was greater than imazapic (4 cm). Height of RP was not different in imazapic and imazapic + 2,4-D. For CT, RP height was greatest for the Control (16 cm), followed by Mow (8 cm), which was greater than imazapic (4 cm) and imazapic + 2,4-D (4 cm) (Figure 6-7). Canopy height of RP in this study followed a similar pattern as that described in Chapter 5. When RP grows in light-limited environments (Control treatment in G-CT and CT treatments), RP has the capacity to elongate stems (phenotypic plasticity) as a light-capturing strategy.

Implications of the Research

Number of sprouts m^{-2}, averaged across collection dates, was greatest and not different for G-CT (119) and CT (90), while CT was not different than NT (58) but greater than SL (54), and NT was not different than SL (Figure 6-1). Apparent advantage of prepared seedbeds may be due to superior rhizome placement or soil-rhizome contact. In spite of differences in sprout emergence, seedbed preparation technique had no effect on RP canopy cover (avg. of 23%) and frequency (avg. of 53%) and there was no interaction with competition-control strategy. There were plant competition-control strategy effects on RP canopy cover and frequency, with imazapic (33 and 66%) and imazapic + 2,4-D (35 and 70%) being not different from each other and greater than Control (16 and 40%) and Mow (9 and 35%) for canopy cover and frequency, respectively.

There was seedbed preparation × competition-control strategy interaction effect on light environment of RP canopy. Differences in light environment due to weed competition-control strategy occurred only in G-CT and CT treatments where the Control had the lowest PAR. Treatment effects on RP canopy height followed the same trend and RP was tallest in the Control treatment for G-CT and CT. Spread in the establishment year was minimal for all treatments but least for SL which actually experienced loss of plants on the edge of the planted strip.

One-year data indicate that a single application of glyphosate to control bahiagrass in the fall followed by winter mowing to break up residue before planting RP may be a viable seedbed preparation option for successful establishment of RP and may reduce establishment costs over strategies that include a completely prepared seedbed. Regardless of seedbed preparation strategy, application of imazapic or imazapic + 2,4-D should be used to control post-plant competition from weeds or bahiagrass.

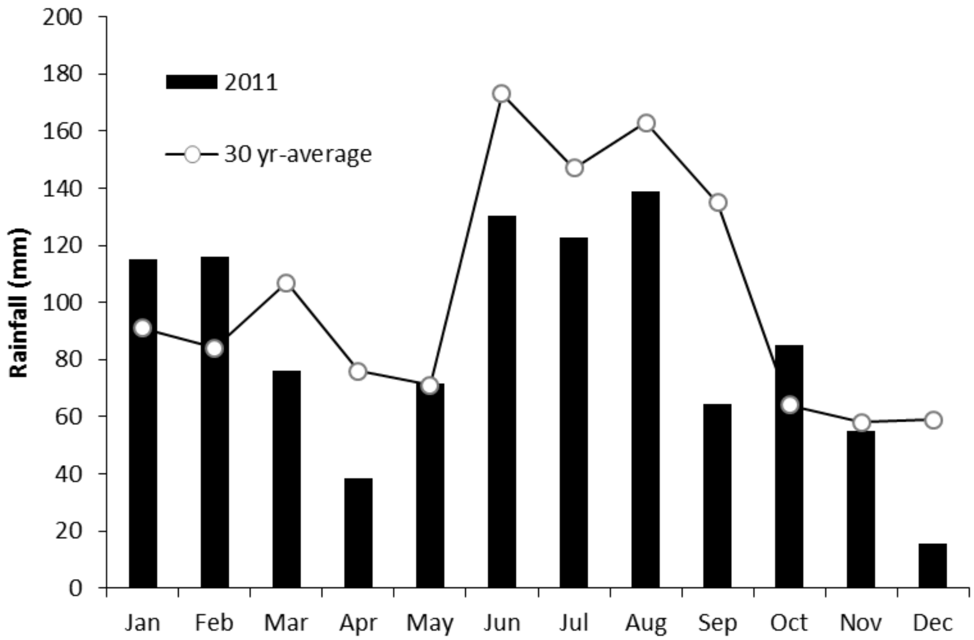

Figure 6-1. Monthly rainfall at the University of Florida Beef Research Unit, Gainesville, FL for 2011 and the 30-yr average.

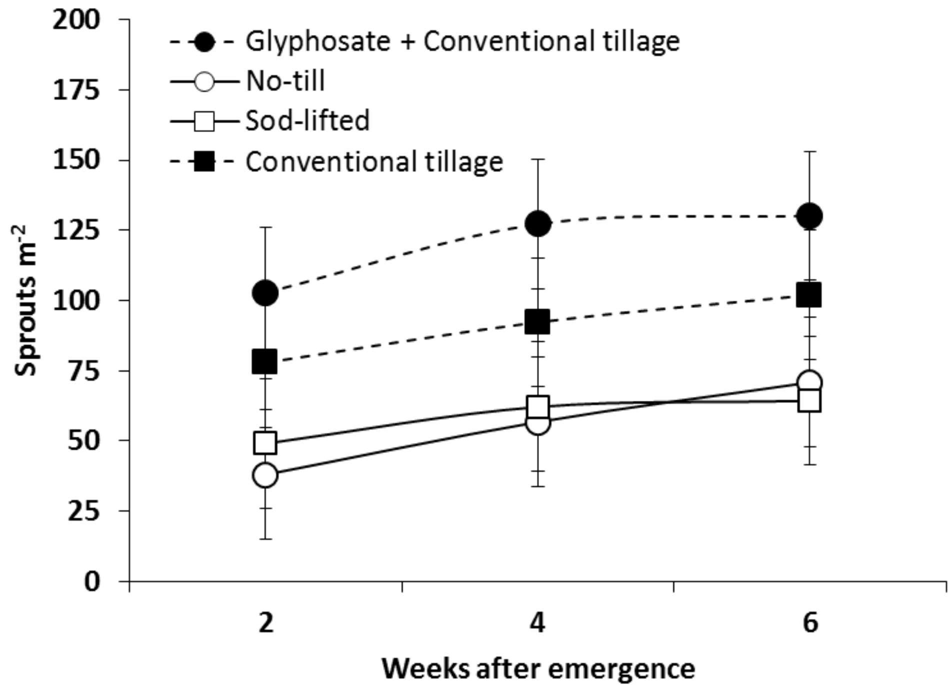

Figure 6-2. Sprout emergence of rhizoma peanut planted in strips in existing bahiagrass plots. Data are means across 2 yr (2011 and 2012). Error bars represent treatment means (n = 6) ± one standard error.

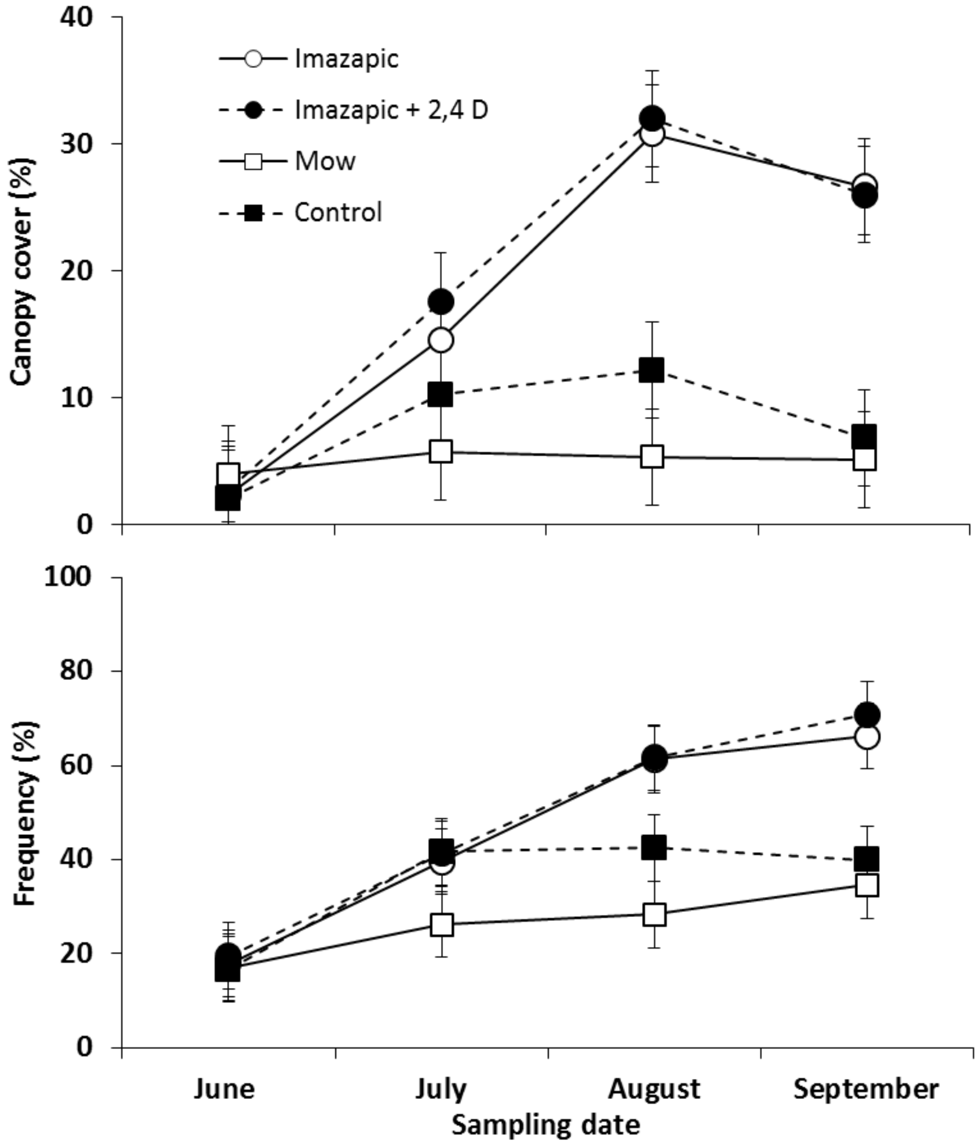

Figure 6-3. Canopy cover and frequency of occurrence of rhizoma peanut planted in strips in existing bahiagrass pastures in 2011. Errors bars represent treatment means (n = 3) ± one standard error.

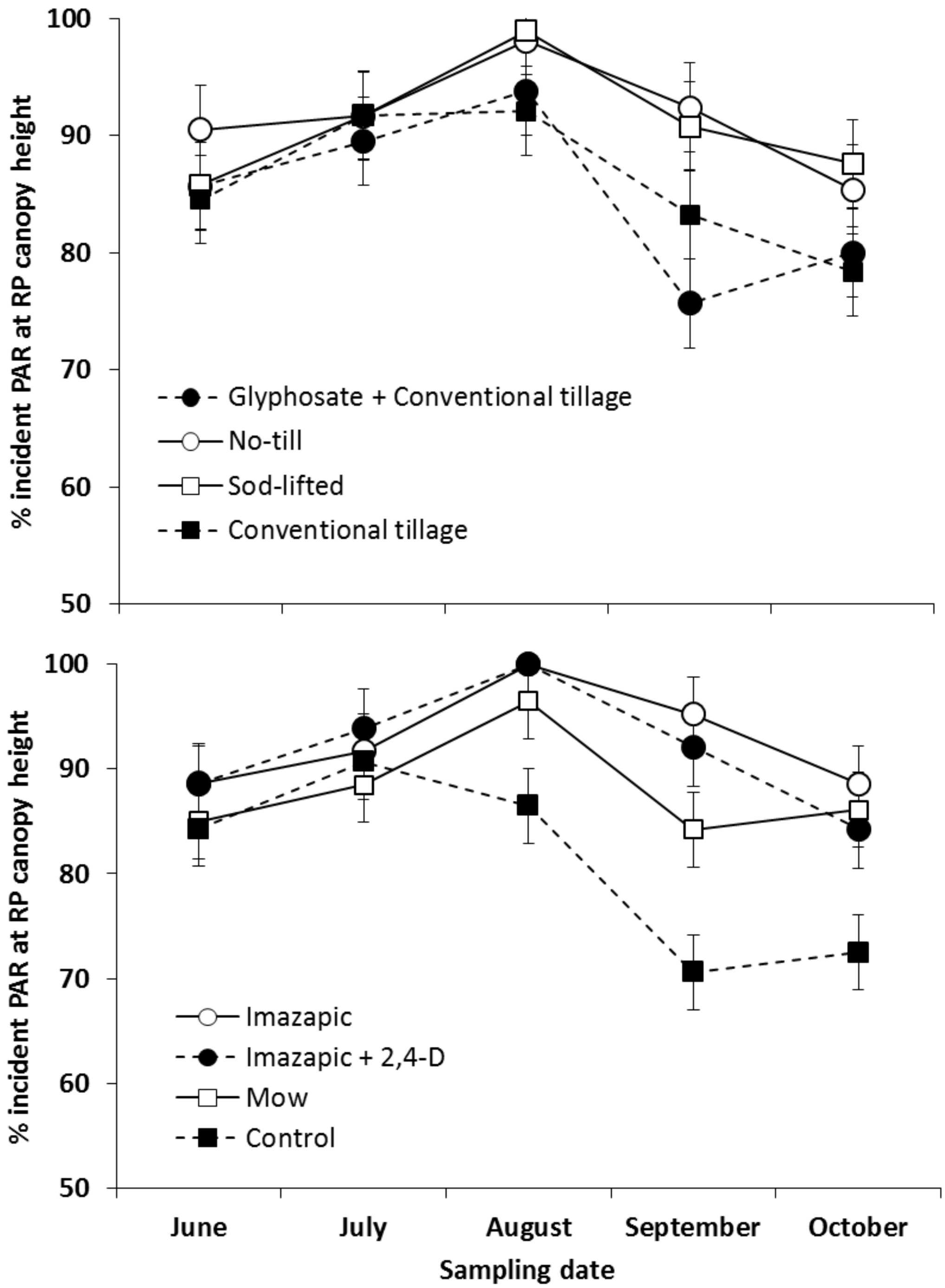

Figure 6-4. Light environment at the top of the rhizoma peanut canopy for strip-planted rhizoma peanut in existing bahiagrass pastures in 2011. Effects of seedbed preparation (above) and competition-control strategy (below) and their interaction with sampling date are shown. Error bars represent treatment means (n = 3) ± one standard error. PAR = Photosynthetically active radiation. * = significant interaction effect ($P \leq 0.05$), NS = no significant interaction effect.

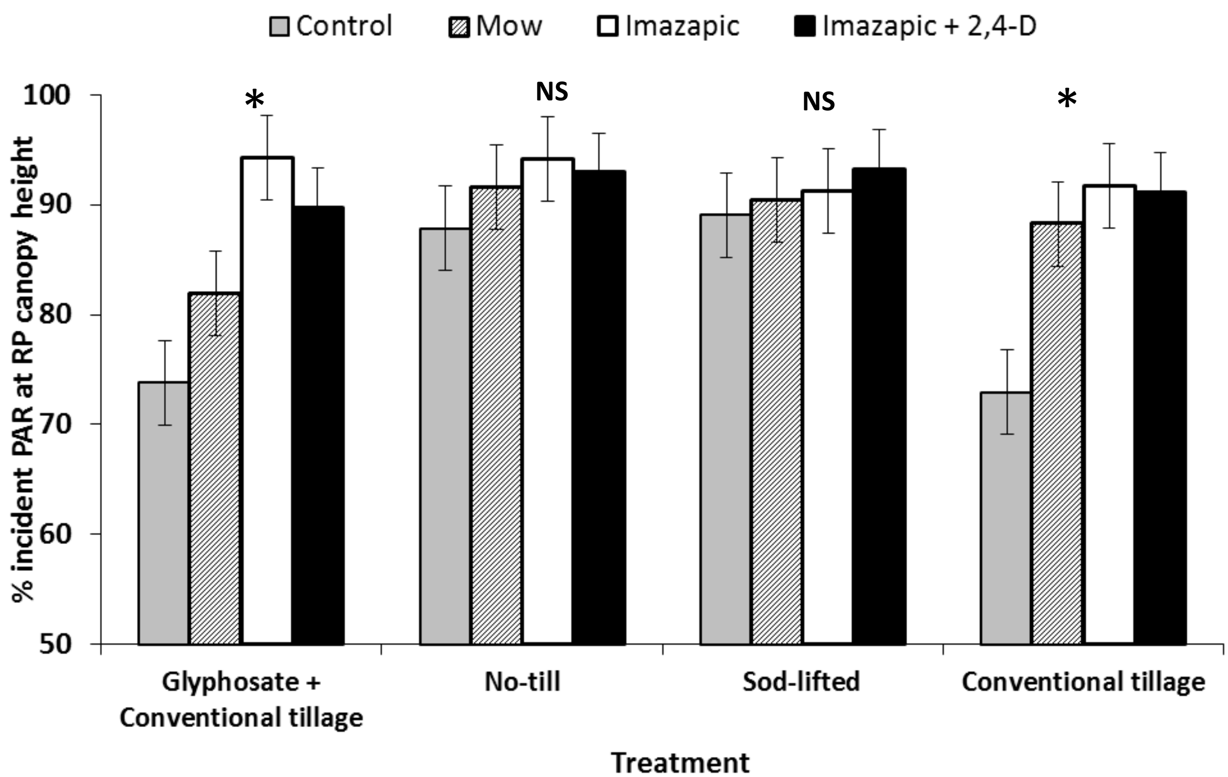

Figure 6-5. Light environment at the top of the rhizoma peanut canopy for strip-planted rhizoma peanut in existing bahiagrass pastures in 2011. Effects of seedbed preparation and competition-control strategy interaction are shown. Error bars represent treatment means (n = 3) ± one standard error. PAR = Photosynthetically active radiation.

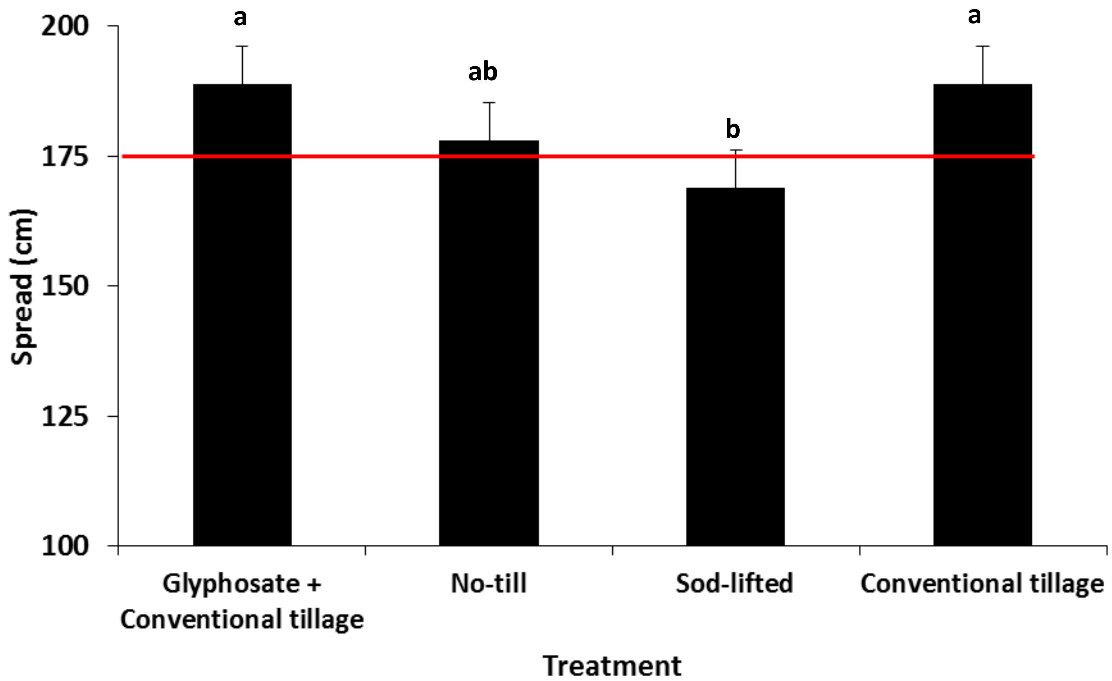

Figure 6-6. Spread of rhizoma peanut (RP) into existing bahiagrass sod following planting in 2011. Spread is the distance from the center of the planted RP strip to the farthest point where identifiable RP plant parts (above ground) were found. Closest RP row was planted at 175 cm from the center of the strip. Error bars represent treatment means (n = 3) ± one standard error.

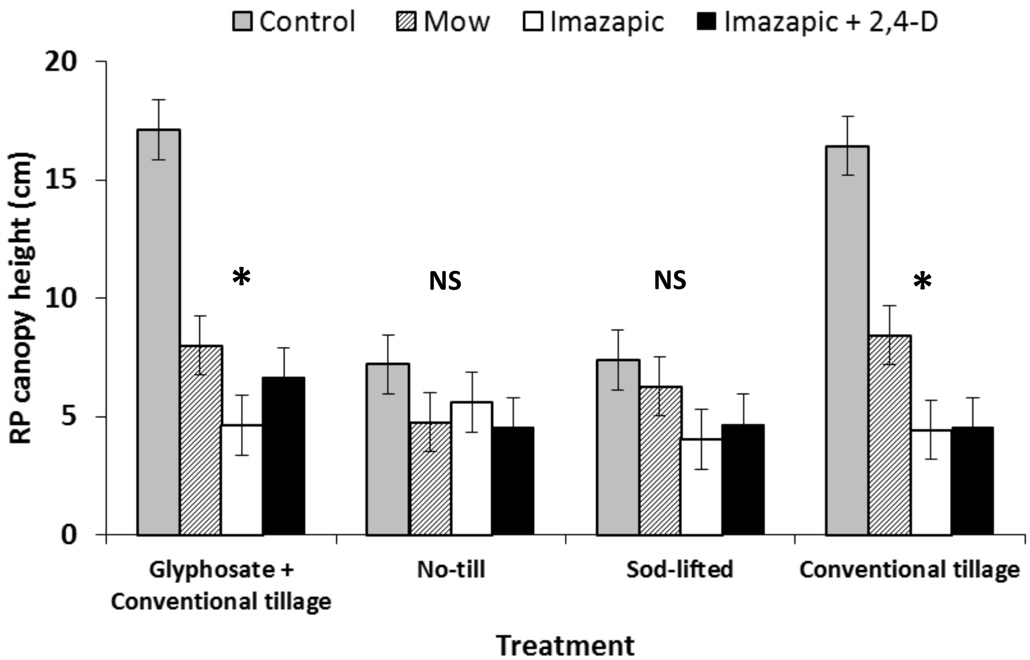

Figure 6-7. Rhizoma peanut canopy height measured once at the end of the growing season in 2011. Effects of seedbed preparation and competition-control strategy interaction are shown. Error bars represent treatment means (n = 3) ± 1 standard error. * = significant interaction effect ($P \leq 0.05$), NS = no significant interaction effect.

CHAPTER 7
SUMMARY AND CONCLUSIONS

Rhizoma peanut (*Arachis glabrata* Benth.; RP) is a tropical/subtropical, vegetatively propagated, perennial legume with demonstrated persistence and potential to provide high quality forage for livestock across the Gulf Coast, USA. It has nutritive value comparable to alfalfa (*Medicago sativa* L.), and is persistent under a wide range of management systems including production of hay, grazing, and as an understory forage crop. Thus, RP is a top candidate among forage legumes to develop grass-legume mixtures that will increase/maintain production and sustainability of the typically low-input monoculture bahiagrass (*Paspalum notatum* Flüggé) pastures used in the forage-livestock systems of the lower southeastern USA.

Up to this time, however, the main use of RP has been for the production of hay due to the high costs associated with establishment, management of weeds, and taking land out of production for ~2 yr to allow establishment of RP. Rhizoma peanut has rarely been planted with grasses; grass-RP mixtures exist due to inadequate control of grass weeds growing in the swards that initially were intended for the production of high quality hay. If RP is to contribute to forage-livestock systems under grazing, it is critical to develop management strategies that minimize costs associated with establishment and allow for utilization of the forage produced during the establishment period of RP.

An alternative approach to RP establishment is to plant RP in strips in existing bahiagrass pastures. This approach may minimize inputs compared to intensive preparation of a seedbed prior to planting a mixed pasture. Using this approach, RP is physically separated from the actively growing grass component of the pasture. Physical separation provides opportunities to investigate seedbed preparation techniques and weed management strategies that may be successfully used for RP but would not be appropriate for an associated grass. It will take a period of time for RP to spread from the planted strip to surrounding areas, but if this can be achieved, it may provide a relatively low-cost option for the establishment and maintenance of mixed grass-legume pastures.

Experiments were conducted to assess the merits of strip planting of RP in existing bahiagrass pasture. Rhizoma peanut canopy cover, frequency of occurrence, light environment, botanical composition, canopy height, and spread were measured to determine relative success of RP establishment in four studies designed to: 1) evaluate the effect of defoliation management strategies during the year of establishment (Chapter 3); 2) investigate grazing management strategies during the year after establishment on plots that started with varying levels of RP contribution (Chapter 4); 3) determine the effect of chemical and mechanical weed management strategies and N fertilizer during the establishment year (Chapter 5); and 4) quantify the effects of seedbed preparation and post-plant weed management strategies (Chapter 6).

The studies were conducted at the Beef Research Unit (BRU) of the University of Florida (29°43’ N; 82°21’W) near Gainesville, FL during 2010, 2011, and 2012. Data from some measurements taken in 2012 are not yet available, so Chapters 4 and 6 contain 1 yr of data while Chapters 3 and 5 contain 2 yr. All the experiments utilized a different area, i.e., a different planting of RP, for each year of study. The experiment reported in Chapter 4 (grazing management effects in the year after establishment) used the plots that had been planted and evaluated the previous year for the work reported in Chapter 3.

The strips planted with RP were 4-m wide and accommodated eight or nine rows of RP, with spacing between rows of 0.5 m. The first and last rows of planted rhizomes were 0.25 m from the undisturbed edge of bahiagrass sod. The planted strips were bounded on both sides by a 2.5-m (studies in Chapters 3, 4, and 5) or a 1-m (Chapter 6) strip of undisturbed bahiagrass sod. ‘Florigraze’ RP rhizomes were planted in the prepared strip using a conventional Bermuda King sprig planter in March or April each year. The planting material was obtained from a commercial farmer cooperator. The rhizomes were planted at a rate of 1000 kg ha^{-1} (packed at ~ 79 kg m^{-3}) to approximately a 5-cm depth. After planting, the plots were cultipacked to ensure adequate soil-rhizome contact.

Effects of Defoliation in the Establishment Year

The study in Chapter 3 was designed to evaluate options for utilization of the RP-bahiagrass pasture during the year of establishment. The treatments were: 1) control (no defoliation of the planted RP strip with adjacent bahiagrass harvested for hay production every 28 d during the growing season to a 10-cm stubble height); 2) hay production (RP strip and adjacent bahiagrass both harvested for hay production every 28 d to a 10-cm stubble height); 3) simulated continuous stocking (pastures grazed weekly to a 15-cm bahiagrass stubble height); and 4) rotational stocking (pastures grazed every 28 d to a 15-cm bahiagrass stubble height). A combination of herbicides clethodim and imazapic were applied to control weeds growing in the strip planted to RP. The area of an experimental unit was 9-m wide × 15-m long, and each consisted of one 4-m wide strip of RP running the length of the plot and bounded on each side by strips of bahiagrass. Initiation of defoliation treatments was targeted for the end of the RP sprout emergence period which occurred ~11 wk after planting.

Canopy cover and frequency of RP were greatest during August. Hay production and control treatments were not different with 32 and 29% canopy cover, respectively, and 67% frequency for both, and were greater compared to 5 and 4% canopy cover for simulated continuous and rotational stocking, respectively, and 21% frequency for both. Spread was lowest and there was a trend toward less herbage harvested in the simulated continuous stocking treatment compared to the others. Competition for light was not the driving factor affecting RP establishment using these defoliation treatments and the strip-planting approach. Treatments with greatest light level reaching the RP canopy generally were those with lowest RP cover and frequency, indicating that the effect of defoliation of establishing RP was the principal factor driving cover and frequency responses. Measurements of canopy cover and frequency taken in June during the following growing season (year after establishment) revealed that differences in canopy cover and frequency observed in the establishment year carried over.

The results indicate that grazing, either simulated continuous- or rotational stocking every 28 d, reduced RP contribution during the year of establishment as a function of apparent animal preference for forage in the legume-planted strips and the resultant reduction in stubble height well below that of the adjacent bahiagrass strips. It is not known at this point whether rest periods longer than 28 d between grazing events, or the use of other RP cultivars with different growth habits (i.e., more prostrate) may be able to overcome the negative impact of grazing during the year of establishment. It is clear, however, that RP establishment is negatively affected by grazing during the year of establishment, as practiced in this experiment, and defoliation by clipping seems to be the most feasible option for using the forage produced.

Grazing Management in the Year after Establishment

In 2011, plots that were used in 2010 in the study in Chapter 3 were divided into three sub-plots of 9-m width and 5-m length. The 9-m width of the sub-plot consisted of a 4 m-wide strip planted to RP (in 2010) bounded on both sides by strips of bahiagrass sod. This provided a range of starting conditions of RP contribution to further evaluate grazing management effects on RP establishment in Chapter 4. Treatments in Chapter 4 were the factorial combinations of four Year 1 (Y1) defoliation strategies (Chapter 3) and three Year 2 (Y2) grazing management treatments, for a total of 12 treatments. Longer term as opposed to monthly changes in RP contribution was considered of importance; therefore, measurements were taken once at mid- and late-season. Year 2 grazing management treatments were: 1) simulated continuous stocking (SC; same as Treatment 3 from Y1); 2) rotational stocking 28 d (RS-28; equal to Treatment 4 from Y1); and 3) rotational stocking 42 d (RS-42; pastures stocked rotationally every 42 d). All sub-plot treatments were grazed to 15-cm bahiagrass stubble height.

There was no Y1 defoliation strategy (during the year of establishment) × Y2 grazing management (during the year after establishment) effect on RP contribution. One year-data indicate that defoliation management during Y1 remained a critical factor affecting RP contribution during Y2. Canopy cover and frequency of Y1 control and hay production were not different (13 and 15% for canopy cover, and 66 and 59% for frequency, respectively). Canopy cover was greater for hay production than either simulated continuous (5%) or rotational stocking (4%). Frequency was greatest for control and hay production compared to both of the grazing treatments which had RP frequency of ≤ 28%.

Year 2 RP canopy cover and frequency were greatest for RS-42 with 12%, compared to 6% for both SC and RS-28 at midseason. Nevertheless, by late-season RP canopy cover was not different among treatments 6, 6, and 4% for SC, RS-28, and RS-42. Frequency followed the same pattern. In general, the RP component was ≤ 20% of the herbage harvested at mid- or late-season. Botanical composition of RP was greater in plots that were managed for hay production or rotationally stocked during the year of establishment. The results indicate that defoliation management by graziers should be focused on the strip planted to RP as opposed to the bahiagrass borders. If grazing is to occur during the year after establishment, each grazing event must be terminated sooner than in the current study, likely when RP forage in the strip is ~15 to 20 cm tall.

Weed Management Strategies in the Year of Establishment

In Chapter 5 the objectives were to determine the effect of chemical and mechanical weed management strategies, N fertilizer, and its interaction on establishment of RP planted in strips. Treatments were the factorial combinations of two N rates (0 and 50 kg ha^{-1} yr^{-1}) and six weed management strategies; 1) control (no herbicides, no mowing), 2) mowing (every 28 d to 10-cm stubble height); and a single application of herbicides 3) pendimethalin (0.93 kg a.i. ha^{-2}), 4) clethodim (0.10 kg a.i. ha^{-2}), 5) imazapic (0.07 kg a.i. ha^{-2}), or 6) imazapic (0.07 kg a.i. ha^{-2}) + 2,4-D amine (0.28 kg a.i. ha^{-2}).The herbicides and rates of application were based on previous research, and these specific herbicides were chosen because they are the only ones labeled for use in RP pastures in Florida, with the exception of pendimethalin which was included as a treatment because of its use as a pre-plant incorporated herbicide in plantings of annual peanuts (*Arachis hypogea* L.).

Rhizoma peanut canopy cover and frequency were greatest toward the middle of the growing season in August. Imazapic and imazapic + 2,4-D treatments were not different for canopy cover (27 and 34%, respectively) and frequency (67 and 73%, respectively) and were greater compared to the rest of the treatments which were ≤ 7 and 35% for cover and frequency, respectively. Application of 50 kg N ha^{-1} yr^{-1} following herbicide application, increased RP canopy cover (+10%) and frequency (+15%) in imazapic and imazapic +2,4-D treatments. In contrast, N application had a negative effect on the remaining treatments because it increased competition to RP from grass and broadleaf weeds growing in the strip that were not effectively controlled by those herbicides or by mowing. Treatment effects carried-over to the year after establishment.

The RP canopy in imazapic and imazapic + 2,4-D treatments consistently received above 96% of incident photosynthetically active radiation (PAR) until July, compared to the rest of the treatments which received ≤ 82%. Toward the end of the growing season, incident PAR was not different for imazapic, imazapic + 2,4-D, and mowing treatments (~83%) but it was still greater compared to control (68%), pendimethalin (57%), and clethodim (70%). The decrease in PAR at the level of RP in the canopy for the imazapic, and imazapic + 2,4-D treatments during the latter part of the growing season (~12%; $P < 0.05$) was attributed to regrowth of bahiagrass. Application of N decreased the amount of incident PAR in all treatments except for imazapic and imazapic + 2,4-D.

Canopy height measurements of RP taken toward the end of season were greatest and not different for control and pendimethalin treatments (30 and 31 cm, respectively), followed by clethodim (26 cm), and lowest for the mowing, imazapic, and imazapic + 2,4-D treatments (10, 11, and 8 cm, respectively). The results indicate that in growing environments where light is limiting, RP has the capacity to show phenotypic plasticity (stem elongation in this case) as a light-capturing strategy. There were no treatment effects on RP spread during the year of establishment. Spread measurements taken the year after establishment indicated that on average RP spread 36 cm yr^{-1}. Botanical composition from the year after establishment indicated that RP contribution was greatest and not different for imazapic and imazapic + 2,4-D treatments (11% RP component for both), compared to the rest of treatments where RP contribution was ≤ 5%.

Seedbed Preparation of the Planted Strip

Based on the results from Chapter 5, the treatments in which greatest contribution of RP was measured (imazapic and imazapic + 2,4-D amine) were used in the study in Chapter 6 to investigate what combinations of pre-plant seedbed preparation and post-plant weed management strategies are most effective for RP establishment in strips in existing bahiagrass sod. The treatments were the factorial combinations of four seedbed preparation techniques and four weed management strategies. Seedbed preparation techniques were: 1) glyphosate (6.2 kg a.i. ha^{-2}) followed by conventional tillage (G-CT; bahiagrass sod sprayed with glyphosate in October 2010 followed by deep tillage with a moldboard plow and heavy disking during February 2011); 2) conventional tillage (CT; bahiagrass sod tilled as in G-CT treatment but no glyphosate applied to kill the bahiagrass); 3) no-till (NT, bahiagrass sod sprayed with glyphosate in October 2010, followed by mowing the remaining above-ground biomass to 5-cm stubble height before planting RP); 4) sod-lifted (SL; bahiagrass sod was lifted with a sod-cutter to a depth of 8 cm below soil level and removed from the strip before planting RP). Weed management strategies were: 1) single application of imazapic (as in

Treatment 5, Chapter 5); 2) imazapic mixed with 2,4-D amine (as in Treatment 6, Chapter 5); 3) mowing (every 28 d to 10-cm stubble height simulating bahiagrass hay production); and 4) control (no herbicide application, non-defoliated).

Number of sprouts m^{-2} was greatest and not different for G-CT (119) and CT (90), while CT was not different than NT (58) but greater than SL (54), and NT was not different than SL. Apparent advantage of prepared seedbeds may have been due to superior rhizome placement or soil-rhizome contact. Nevertheless, in spite of differences in sprout emergence, seedbed preparation technique had no effect on RP canopy cover and frequency. One-year data indicate that a single application of glyphosate to control bahiagrass in the fall followed by winter mowing to break up residue before planting RP is a viable seedbed preparation option for successful establishment of RP and may reduce establishment costs over strategies that include a completely prepared seedbed. Regardless of seedbed preparation strategy, application of imazapic or imazapic + 2,4-D should be used to control post-plant competition from weeds or bahiagrass.

Implications of the Research

Our results indicate that when Florigraze RP is strip-planted into existing bahiagrass pastures, utilization should be limited to production of hay during the year of establishment. If producers cannot afford to remove land from the grazing rotation or change to a hay production system during the year of establishment, then grazing management strategies should be developed that allow for resting periods between grazing events of longer than 28 d. In addition, decisions about when cattle should enter/exit the pasture should be based on the height of herbage in the strip planted to

RP as opposed to the height of the grass component. Based on data from Ortega-S. et al. (1992), it is suggested that RP not be grazed closer than a 15-cm stubble.

Data from the seedbed preparation study and the grazing management in the year after establishment study reflect only 1 yr of research. Thus, the second year should be included in the analysis before strong conclusions are reached. The preliminary data from grazing management study does suggest, however, that close grazing of the planted strip in the year after establishment is detrimental, even when grazing is infrequent (i.e., 42-d rest period).

These experiments demonstrate sufficient success to support a conclusion that the technology of strip planting merits continued evaluation. However, they have identified a number of challenges that need to be addressed. Questions that remain to be answered include: 1) Would use of glyphosate to kill the grass sod in the fall before planting reduce the level of bahiagrass competition in the year of and year after establishment?; 2) Is grazing in the year of establishment an option if the rest period between grazing events is longer than the 28 d evaluated in this research and if livestock are removed based on stubble height of the planted strip instead of the companion grass?; 3) Is grazing in the year after establishment an option if the rest period between grazing events is ≥ 42 d and if livestock are removed based on stubble height of the planted strip instead of the companion grass?; 4) How long does it take to achieve full RP cover in the strip when various defoliation treatments are imposed?; and 5) What is the expected rate of lateral spread of RP in subsequent years?

Future Research Needs

Florigraze RP has been referred to as being of “intermediate” growth habit, meaning somewhere between upright (i.e., Arbrook) and low-growing (i.e., germplasm

Ecoturf) types. In recent years, there is an increased list of available RP cultivars and germplasms with different growth habits. These contrasting growth habits and associated morphological characteristics (canopy height, shoot/rhizome + root ratio, leaf area index) have the potential to respond differently under grazing and the strip-planting establishment approach. Future research should incorporate a wider range of the available RP material, including Prine (CPI 93483 in Australia and equivalent to PI 231318 in USA), which was selected for persistence and spread in pure stands and in combination with 'Argentine' bahiagrass. Additionally, the effects of strip-planting as a multi-year system should be evaluated on more nearly farm-scale pastures with refined grazing strategies based on the current research and with additional grass species. These longer-term experiments would allow: 1) the questions posed above to be addressed; 2) measurement of ecosystem services provided (i.e., N fixation, changes is soil structure, C sequestration); and 3) more accurate assessment of economic returns from targeted technologies. Should willing producers be identified, these studies could be conducted on farm with producer participation in deciding which treatment options should be compared.

APPENDIX
METHODOLOGY FOR CANOPY COVER AND FREQUENCY MEASUREMENTS

Description. The quadrat consists of 100, 10- by 10-cm squares (five rows of 20). The total area covered by the quadrat is 1-m^2 (0.5 × 2 m). The quadrat was placed in the center of the RP strip at permanently marked locations in each experimental unit, so that canopy cover and frequency were estimated on the same areas over time. The 0.5-m side (length) of the quadrat was oriented parallel to the rhizoma peanut (RP; *Arachis glabrata* Benth.) planted rows (Figure A-1). Thus, the area enclosed by the quadrat included four rows of RP with the ends of the quadrat positioned so that they rested midway between the outermost RP row that was included in the quadrat and the RP row that was located just outside the quadrat. The squares shaded in black (total of 20) in Figure A-1 correspond to those where RP canopy cover and frequency were determined.

Canopy cover. Canopy cover was estimated visually by the same observer in the 20 stratified marked squares (Figure A-1) and averaged to obtain an overall cover per quadrat location. In the studies where the quadrat was placed in two locations per experimental unit, the average of the two locations provided an estimate for each experimental unit. A similar approach was described by Interrante et al. (2009) to measure canopy cover of bahiagrass (*Paspalum notatum* Flügge).

Frequency. Presence or absence of RP was determined in the same 20 stratified 10- by 10-cm squares used to estimate RP canopy cover. Frequency was calculated as the percentage of the total number of squares (20 were assessed per quadrat), where RP was present.

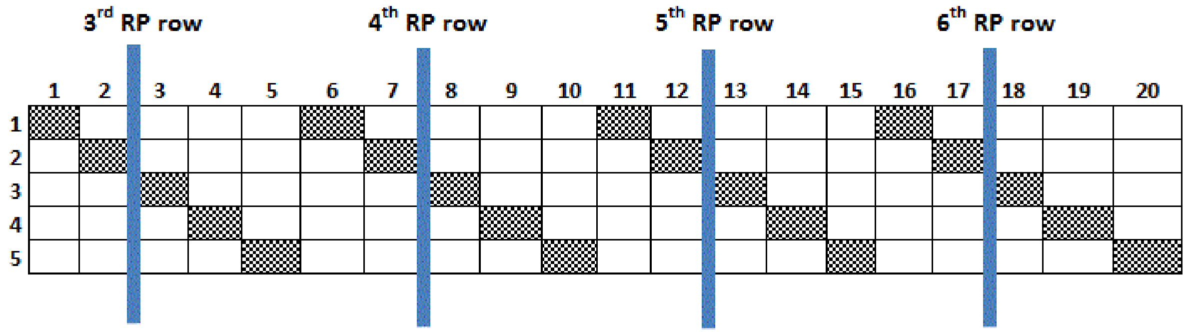

Figure A-1. Quadrat to measure rhizoma peanut (RP) canopy cover and frequency. Each square is 10 by 10 cm. Shaded squares correspond to the squares where measurements were made.

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BIOGRAPHICAL SKETCH

Miguel S. Castillo was born in 1984 in Loja, Ecuador. His interest in agriculture developed at early stages of his life while listening to family conversations and while working on a family farm dedicated to the production of horticultural crops and to a dairy herd. He received a B.S. degree in agricultural science and production (2006) from Zamorano University, Honduras, C.A. In spring 2006 he came to the Everglades Research and Education Center of the University of Florida (UF), as a short-term scholar. Miguel joined the Agronomy Department at UF as Research Assistant in spring 2007. He finished his master's degree in summer 2009, then received the Graduate School Fellowship from UF to continue with the Ph.D. program, and graduated with his Ph.D. in agronomy and a minor in soil and water science in spring 2013. He conducted both graduate degrees (M.S. and Ph.D.) in Dr. Lynn E. Sollenberger's forage management program. Miguel's professional goals are to develop an interdisciplinary research and training program with the long term goal of increasing/maintaining sustainability in agro-ecosystems.