Strip Planting a Legume into Warm-Season Grass Pasture: Defoliation Effects During the Year of Establishment

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ABSTRACT
Novel approaches are needed for overcoming barriers to successful association of herbaceous legumes with grasses in warm-climate pastures and to identify low-cost, long-term solutions to the problem of N limitation in low-input systems. The objective of this experiment was to evaluate defoliation management options during the year of establishment when rhizoma peanut (RP) (Arachis glabrata Benth.) was strip planted into existing bahiagrass (Paspalum notatum Flüggé). Treatments were four defoliation strategies: (i) Control (no defoliation of the planted RP strip and adjacent bahiagrass harvested for hay), (ii) Hay Production (RP strip and adjacent bahiagrass harvested for hay every 28 d), (iii) Simulated Continuous Stocking (pastures grazed weekly), and (iv) Rotational Stocking (pastures grazed every 28 d). Simulated Continuous and Rotational Stocking reduced RP canopy cover and frequency of occurrence. Greatest RP cover during the establishment year was achieved in August with 32 and 29% for the Control and Hay Production treatments compared to 5 and 4% for Simulated Continuous and Rotational Stocking, respectively. Spread of RP was least in Simulated Continuous Stocking. Light penetration to the level of RP in the canopy was not a primary driver of RP response because it was greatest for grazed plots where RP performed poorest. Results show that defoliation management during the establishment year is critical and if pastures are defoliated, hay production is the recommended option.

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 N₂ 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 subtropics than in temperate regions. Often, C₃ legumes are overwhelmed when competing with vigorous C₄ 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 that have potential to spread are planted into surrounding grass areas. It will take a period of time for legumes to establish and compete successfully with grasses, and the role of defoliation management during the establishment year is critical.

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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 U.S. Gulf Coast Region the only legume that has demonstrated sufficient persistence and potential for spread to function in such a system is rhizoma peanut (RP).

Rhizoma peanut is a warm-season, vegetatively propagated, perennial legume that was introduced to Florida 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.) (Beltranena et al., 1981; Prine et al., 1981), and persistence under a wide range of management systems for hay, silage, and grazing and as an understory forage crop (Prine et al., 1981; Ortega-S. 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, 1986, 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 United States, 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 offers the opportunity to use grass forage during the legume establishment phase so that land is not totally removed from grazing while allowing successful establishment of the legume. The specific objectives were to quantify the effect of a range of grazing and haying treatments on (i) RP canopy cover, frequency of occurrence, and spread, (ii) the light environment of establishing RP plants, and (iii) bahiagrass herbage harvested or unused.

### 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 Gossarenic 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(CO₃)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. 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 K₂O kg⁻¹ and 500 g Cl kg⁻¹). Rainfall data are presented for both years (Fig. 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 Mar. 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 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 sprig planter (Bermuda King) on 25 Mar. 2010 and 5 Apr. 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⁻¹) 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 (Valent U.S.A. Corporation Agricultural Product) (a.i. Clethodim) ((E)-2-2-[3-chloro-2-propenyl]oxy]mimino] propyl)]-5-[2(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) and Impose (Makhteshim Agan of North America, Inc.) (a.i. ammonium salt of imazapic) ((±)-2-[4,5-dihydro-4-methyl-4-(1-methylthio)-5-oxo-1 H-imidazol-2-yl]-5-methyl-3-pyridine-carboxylic acid) at a rate of 0.10 and 0.07 kg 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 CO₂–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 (September) in both years, all plots were mowed to 10-cm stubble height to prevent seed dispersion from flowering plants of the weed Mexican tea (Dysphania ambrosioides (L.) Mosyakin & Clemants (basionym Chenopodium ambrosioides L.).
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 spp.). The 9- by 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 a defoliation event. A 1-m² quadrat (0.5 by 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) per quadrat and averaged to obtain an overall cover per quadrat location. The average of two locations provided an estimate for each experimental unit (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.). 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. Therefore, 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 year on the day before the last clipping and grazing events of the season. A transect was positioned through the center of the RP strip running the length of 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 before each grazing or clipping event for each treatment except Simulated Continuous Stocking. In the Hay Production and Control treatments, a 1- by 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-m² 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. Therefore, on Simulated Continuous Stocking pastures, two 0.5 m² circular exclusion cages per plot were positioned at representative locations in the bahiagrass strip. A 0.25-m² 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. Defoliation strategies were fixed effects. Mean separations and preplanned contrasts were done based on the SLICE-DIFF and LSMESTIMATE procedures of LSMEANS in SAS. Plots of model residuals were used to check normality, and in the case of nonnormal 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 strategy, 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 (Fig. 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 1). When measured in late June of the year after establishment, defoliation strategy 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 1; 7 and 8% for Simulated Continuous and Rotational Stocking, respectively). Similar results for RP canopy cover (~25%) were reported by Interrante et al. (2011) in a RP stand free of competition from weeds.

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 spp. has been reported previously for mixtures where the grass and legume components grew intermingled (Bennett et al., 1999; Lascano, 2000; Valencia et al., 2001). Therefore, while physical separation of the legume and grass components of a mixture provides advantages...
for managing plant competition (Cook et al., 1993), animal selection behavior can offset these advantages and negatively affect legume establishment.

**Frequency**
There were defoliation strategy, sampling date, and defoliation strategy × sampling date interaction effects. Rhizoma peanut frequency of occurrence in the planted strip followed the same pattern of response as canopy cover (Fig. 3). 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 (Table 1). Measurements taken in late June of the year after establishment also followed the same trend as canopy cover. Control and Hay Production treatments were not different (82 and 76%, respectively) and both were greater than either Simulated Continuous or Rotational Stocking treatments (26 and 32%, respectively). Thus, by 14 mo after planting, RP was present in approximately 80% of quadrats assessed in the planted strip if grazing did not occur compared to only approximately 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 ($P = 0.06$) toward an effect of defoliation strategy on light environment.

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**Table 1. Rhizoma peanut (RP) percentage canopy cover and frequency of occurrence in August of the establishment year and 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 ($n = 6$).**

<table>
<thead>
<tr>
<th>Defoliation treatment†</th>
<th>Cover</th>
<th>Frequency</th>
<th>Spread‡</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Establishment year</td>
<td>Year after establishment</td>
<td>Establishment year</td>
</tr>
<tr>
<td>Control (C)</td>
<td>32</td>
<td>32</td>
<td>67</td>
</tr>
<tr>
<td>Hay Production (H)</td>
<td>29</td>
<td>35</td>
<td>67</td>
</tr>
<tr>
<td>Simulated Continuous (SC)</td>
<td>5</td>
<td>7</td>
<td>21</td>
</tr>
<tr>
<td>Rotational (R)</td>
<td>4</td>
<td>8</td>
<td>21</td>
</tr>
</tbody>
</table>

Contrast $P$-values§

<table>
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<th></th>
<th>Establishment year</th>
<th>Year after establishment</th>
<th>Establishment year</th>
<th>Year after establishment</th>
<th>Establishment year</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C + H$ vs. SC</td>
<td>$&lt;0.0001$</td>
<td>$&lt;0.0001$</td>
<td>$&lt;0.0001$</td>
<td>$&lt;0.0001$</td>
<td>0.0274</td>
</tr>
<tr>
<td>$C + H$ vs. R</td>
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<td>$&lt;0.0001$</td>
<td>$&lt;0.0001$</td>
<td>$&lt;0.0001$</td>
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</tr>
<tr>
<td>SC vs. R</td>
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<td>0.5628</td>
<td>0.9632</td>
<td>0.2730</td>
<td>0.1932</td>
</tr>
</tbody>
</table>

SE¶

|     | 3.3 | 5.0 | 4.7 | 5.2 | 7.9 |

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†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; Hay Production: RP strip and adjacent bahiagrass both harvested for hay production every 28 d to a 10-cm stubble height; Simulated Continuous Stocking: pastures grazed weekly throughout the entire growing season to a 15-cm bahiagrass stubble height; 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 aboveground RP plant parts were found.

§Linear combinations of LSMEANS developed using the LSMEANS procedure of LSMEANS in SAS (SAS Institute, 2010).

¶Standard error of a defoliation treatment mean.
Greatest numerical differences among defoliation strategies occurred in August and September (Fig. 4) so defoliation strategies were compared within those dates.

In August Control and Hay Production treatments were not different (87 and 90%, respectively; \( P = 0.38 \)). Rotational Stocking (95%) was greater than Control (\( P = 0.03 \)), there was a trend (\( P = 0.08 \)) toward Rotational Stocking being greater than Hay Production, and Simulated Continuous Stocking (96%) was not different than 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 strategy. 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 aboveground 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 1). Single degree of freedom comparisons were made using the LSMESTIMATE procedure of LSMEANS in SAS (SAS Institute, 2010) to test the average of mowed (Control and Hay Production) vs. Simulated Continuous and Rotational Stocking defoliation strategies. The average of the mowed treatments was similar to Rotational Stocking and 14 cm greater than Simulated Continuous Stocking. 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. Data reported by Butler et al. (2006) and Interrante et al. (2011) indicated much greater spread for Florigraze RP during the year of establishment (≥70 cm). In those studies, however, RP plants were initially grown in the greenhouse and transplanted to the field, they were not defoliated after planting, and the plots were maintained completely free of weeds (RP monoculture) to allow RP spread. Our results indicate that defoliation management under the strip–planting scheme used in the current study is critical 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. It is of significance to note that under the conditions of this experiment a producer who chooses not to use any type of 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.

SUMMARY AND CONCLUSIONS
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 using the grass forage during the year of establishment. It may be possible to decrease the negative impact of grazing by using 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.

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