RESEARCH

Strategies to Control Competition to Strip-Planted Legume in a Warm-Season Grass Pasture

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ABSTRACT

Planting rhizoma peanut (RP) (*Arachis glabrata* Benth.) in tilled strips in existing bahiagrass (*Paspalum notatum* Flüggé) pastures may be an option for establishing legume–grass mixtures in the U.S. Gulf Coast, but management during establishment is not well defined. The objectives were to determine the effect of weed control strategies and N fertilizer on RP establishment in the strip. Treatments were the factorial combinations of six weed control strategies—(i) control (no herbicide and no mowing), (ii) mowing (every 28 d to 10-cm stubble height), or a single application of herbicides (kg a.i. ha^{-1}) (iii) pendimethalin (0.93), (iv) clethodim (0.10), (v) imazapic (0.07), or (vi) imazapic (0.07) plus 2,4-D amine (0.28)—and two N rates (0 and 50 kg ha^{-1} yr^{-1}). Cover (approximately 31%) and frequency (approximately 70%) of RP were not different in imazapic and imazapic plus 2,4-D treatments, but they were greater than in the other treatments (<10 and 25%, respectively). Light reaching the level of RP in the canopy in imazapic and imazapic plus 2,4-D treatments was ≥96% of incident light until July and was consistently greater than the other treatments. Nitrogen fertilization following herbicide treatment increased RP cover by 10 percentage points for imazapic and imazapic plus 2,4-D. Results indicate that imazapic or imazapic plus 2,4-D offer sufficient control of weed competition to improve establishment of strip-planted RP, and application of 50 kg N ha^{-1} increases RP establishment if grass and weed competition is controlled.

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Abbreviations: PAR, photosynthetically active radiation; RP, rhizoma peanut.

Rhizoma peanut (RP) is a warm-season, vegetatively propagated, perennial legume with unique potential for incorporation into low-input forage-livestock systems in the U.S. Gulf Coast region (French et al., 1994; Castillo et al., 2013). 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.) (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). Furthermore, due to 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 (Sollenberger et al., 1989; Thomas, 1994).

In spite of these advantages, high costs associated with vegetative establishment (approximately US$1000 ha^{-1}), management for weeds, and taking land out of production for one or more growing seasons to allow adequate establishment of RP

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have limited its commercial use primarily to production of high-quality hay for dairy and equine rations (Adjei and Prine, 1976; Prine et al., 1986; Rice et al., 1995). Establishment of RP is generally slow and competition from weeds has affected early growth when RP is planted in pure stand or grown 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 tilled strips in existing bahiagrass pastures was proposed as an alternative strategy to a completely prepared seedbed for RP establishment (Castillo et al., 2013). The goal is to reduce establishment cost to make feasible the use of RP for low-input systems such as beef cow–calf (*Bos* spp.) 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 use the bahiagrass forage during the RP establishment year, thereby avoiding the negative impact to the overall grazing program of removing land from production.

There is little existing information describing the effects of various weed control strategies on establishment of strip-planted RP. Therefore, the objectives were to determine the effect of (i) weed control strategies in the planted strip and (ii) 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 Castillo et al. (2013). In summary, total rainfall was 1103 and 1029 mm in 2010 and 2011, respectively, compared to the 30-yr average of 1238 mm. Last and first freeze events occurred on 8 Mar. and 10 Nov. in 2010 and 14 Mar. and 14 Nov. in 2011, respectively, and these dates did not differ to a large extent from long-term averages.

Land Preparation and Planting

Before strip-planting RP in the existing bahiagrass sod, strips were plowed in February with a moldboard plow and 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 (Fig. 1). The planted strips were bounded on both sides by a 2.5-m strip of bahiagrass. Florigraze RP rhizomes were planted in the prepared strip using a conventional Bermuda King sprig planter during late winter (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 approximately 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. 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.

Treatments and Design

Treatments were the factorial combinations of six weed control strategies and two N rates. Mechanical and chemical weed control strategies were evaluated. They were (i) control (no herbicide or mowing in the planted strip), (ii) mowing (entire plot clipped every 28 d to 10-cm stubble height simulating a bahiagrass hay production system), or the application of herbicides: (iii) pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] (Prowl; BASF) (0.93 kg a.i. ha^{-1}) at planting, (iv) clethodim [(E)-2–2[1-[[3-chloro-2-propenyl)oxy]imino]propyl]5-[2(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one] (Select Max; Valent U.S.A. Corporation Agricultural Product) (0.10 kg a.i. ha^{-1}) when grass weeds were 10 to 15 cm tall, (v) imazapic [(± –2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1 *H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylicacid] (Impose; Makhteshim Agan of North America, Inc.) (0.07 kg a.i. ha^{-1}) when grass or broadleaf weeds were 5 to 10 cm tall, or (vi) imazapic (0.07 kg a.i. ha^{-1}) plus 2,4-D amine (dimethlyamine salt of 2,4-dichlorophenoxyacetic acid) (2,4-D amine Weed Killer; Universal Crop Protection Alliance LLC) (0.28 kg a.i. ha^{-1}) when grass or broadleaf weeds were 5 to 10 cm tall. Nitrogen rates were 0 and 50 kg N ha^{-1} yr^{-1} and were applied once in the establishment year to both the strips planted to RP and the adjacent bahiagrass on 18 May 2010 and 29 June 2011. These dates correspond to 2 wk after herbicide treatment application. 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 Florida (Mackowiak et al., 2008). 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 by 9 m wide (Fig. 1), with a 1-m border between the lengths of the plots.

The herbicides and rates of application were based on previous research (Ferrell et al., 2006), 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 preemergence herbicide in plantings of annual peanut (*Arachis hypogaea* L.) to manage competition from annual grasses and certain small-seeded broadleaf weeds (Prostko et al., 2001; Johnson et al., 2010; Mossler 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 approximately 11 wk after planting (9 June 2010 and 28 June 2011), coinciding with the anticipated end of the sprout-emergence period and following the approach described by Castillo et al. (2013). 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 and Frequency

Rhizoma peanut canopy cover and frequency were measured following the methodology described by Castillo et al. (2013). In summary, a 1-m^2 quadrat (0.5 by 2 m) was placed in the center of the RP strip at a fixed location. The area enclosed by the quadrat included four rows of RP with the 0.5-m side of the quadrat oriented parallel to the RP rows. The quadrat was divided into 100 10- by 10-cm squares (five rows of 20), and canopy cover was estimated visually in 20 stratified squares and averaged to obtain an overall cover per experimental unit. Canopy cover in the planted strip was estimated for all treatments starting at the end of the shoot emergence period and every 28 d thereafter, occurring on the day after each defoliation event of the mowing treatment. 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 the 20 stratified 10- by 10-cm squares so that frequency was calculated as the percentage of cells where RP was present divided by the total number of cells.

Light Environment

To assess the importance to RP establishment of shading by weed species, ambient light environment at the top of the RP canopy was measured in the planted strip 2 wk before the end of the shoot-emergence phase and every 28 d thereafter. It was assumed that in some treatments the weeds would be taller than RP, thus potentially affecting RP establishment. 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 mowing treatment. Light environment was characterized using a SunScan Canopy Analysis System (Dynamax Inc.). 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. 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 and multiplying by 100 to express it as a percentage. The average of three observations per experimental unit provided an estimate of light environment.

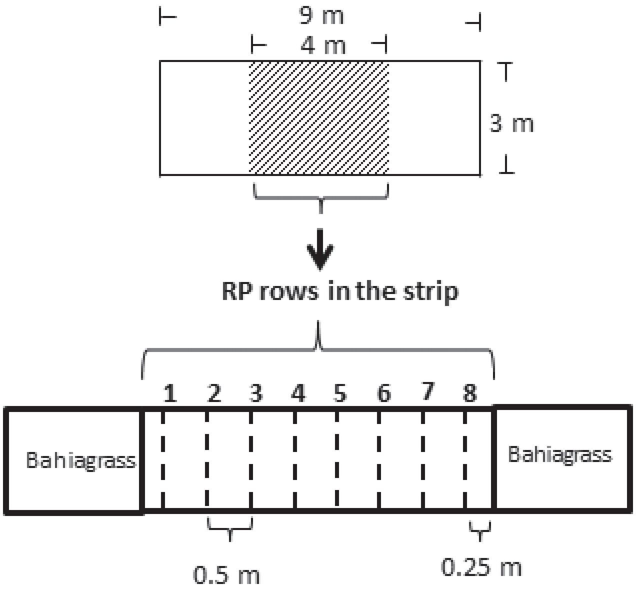

Figure 1. Diagram of an experimental unit. Rhizoma peanut (RP) was planted in seedbed strips prepared into existing bahiagrass pastures.

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 nonextended 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 aboveground RP plant parts were found. Spread was measured on each side of the transect at two points per plot for a total of four observations per experimental unit.

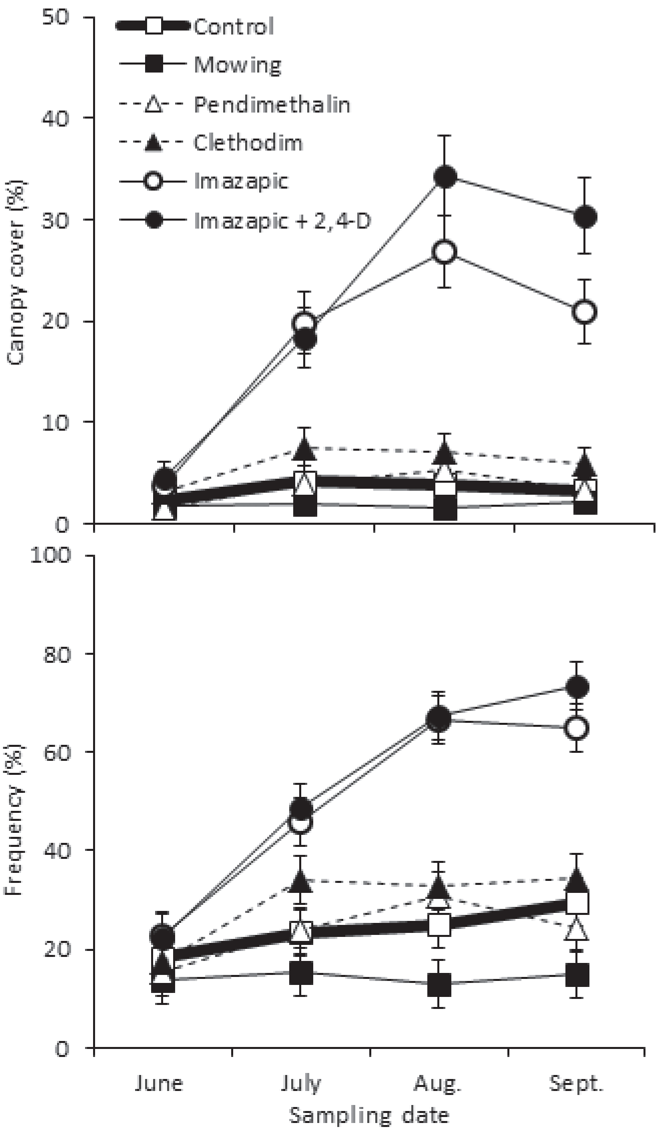

Figure 2. Canopy cover and frequency of occurrence of rhizoma peanut planted in strips in existing bahiagrass pastures as a function of six weed control strategies. Data are means across 2 yr. Error bars represent treatment means averaged across N rates (*n* = 6) ± 1 standard error.

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 study area 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 (23 Sept. 2011 and 10 Oct. 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 and they were dried separately at 60°C until constant weight. Percent RP biomass of the total biomass harvested was calculated by dividing RP biomass by the sum of RP and grass components and multiplying the result by 100 to express it as a percentage.

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 two- and three-factor 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 nonnormal distributions, data transformations were used. Square root transformation was used for canopy cover and botanical composition data. Treatments were considered different at $P \leq 0.05$. A trend was discussed when $P > 0.05$ and ≤ 0.10.

RESULTS AND DISCUSSION

Rhizoma Peanut Canopy Cover

There was a three-factor interaction of N application × weed control strategy × sampling date for RP canopy cover in the planted strip ($P < 0.01$). Assessment of the three-factor interaction showed it occurred because the N application × weed control strategy interaction was significant ($P \leq 0.03$) from July through September but not in June ($P = 0.82$). There also was no main effect of either N application or weed management in June ($P \geq 0.08$). Lack of treatment effect in June was expected because the treatments had been imposed only a short time before that sampling event. As a result, the three-factor interaction was considered to be of little biological importance, and the focus of the RP canopy cover data presentation will be the significant two-factor interactions weed control strategy × sampling date ($P < 0.01$) and N application × weed control strategy ($P = 0.02$).

There were weed control strategy effects on RP canopy cover starting in July (second sampling date) and continuing through the end of the season (Fig. 2). In July, cover was not different for imazapic and imazapic plus 2,4-D, and it was greater for both treatments than for clethodim, pendimethalin, mowing, or the control. At the end of the growing season, RP canopy cover in imazapic was nine percentage points lower ($P = 0.02$) than imazapic plus 2,4-D, but cover in both treatments remained greater than the others (Fig. 2).

Broadleaf weeds present in the strips planted to RP were mainly Mexican tea [*Dysphania ambrosioides* (L.) Mosyakin & Clemants (syn. *Chenopodium ambrosioides* L.)] and cutleaf ground cherry (*Physalis angulata* L.), and they were most prevalent in the control, pendimethalin, mowing, and clethodim treatments. There was a shift in weed population pressure to sedges (*Cyperus* spp.) after application of clethodim whereas bahiagrass and broadleaf weeds were much more pronounced in the control, pendimethalin, and mowing treatments. A timely application of pendimethalin (preemergent) followed by clethodim (postemergent) combined with the relatively faster canopy closure of annual peanut has proven an effective method to control competition from annual grasses, certain small-seeded broadleaf weeds, and perennial grasses (Ferrell et al., 2012). Under the circumstances of this experiment, a single application of either herbicide did not provide adequate vegetation control for successful RP establishment.

The N application × weed control strategy interaction occurred because N fertilization increased RP canopy cover in only two of six weed control treatments. Average RP cover across sampling dates in imazapic-treated plots increased from 13% for no N fertilizer up to 21% when N was applied ($P = 0.04$), and in imazapic plus 2,4-D plots, cover increased from 15% for no N up to 26% when N was applied ($P = 0.01$) (Fig. 3). In contrast, there was no effect of N on the mowing treatment ($P = 0.459$) while a decrease in RP cover with N fertilization approached significance ($P = 0.07$) in the control, pendimethalin, and clethodim treatments (Fig. 3).

The literature contains varying results regarding the effect of N application during establishment of RP. Negative effects of N on RP ground cover, 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 to increased competition from weeds after N fertilization. Valentim (1987) reported little effect on RP nodule weight 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 pinto peanut (*Arachis pintoi* Krapov. & W. C. Greg.), where levels greater than 100 kg N ha^{-1} inhibited nodulation when measured 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 *A. 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 plus 2,4-D) (Fig. 3). Competition control from 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.

Rhizoma Peanut Frequency

There was a three-factor interaction of N application × weed control strategy × sampling date for RP frequency in the planted strip ($P < 0.01$). For the same reason as described earlier for RP canopy cover, the focus of the RP frequency data presentation will be the significant two-way interactions weed control strategy × sampling date ($P < 0.01$) and N application × weed control strategy ($P = 0.03$).

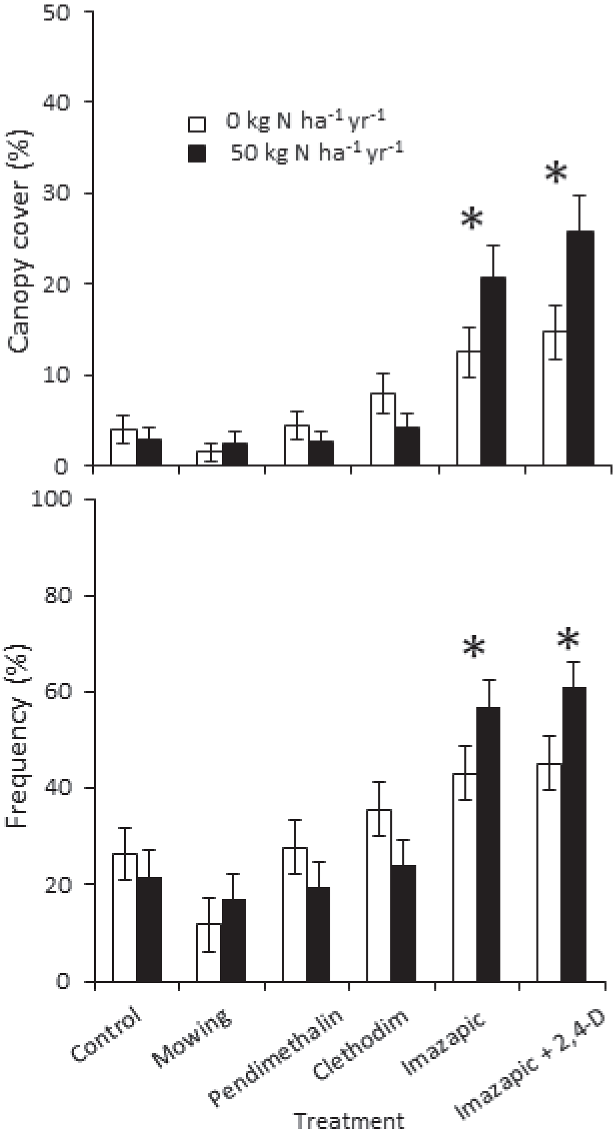

Figure 3. Canopy cover and frequency of occurrence of rhizoma peanut planted in strips in existing bahiagrass pastures as a function of six weed control strategies and application of N. Data are means across 2 yr. Error bars represent treatment means averaged across sampling dates and years ($n = 24$) ± 1 standard error. *Significant N effect ($P \leq 0.05$).

By the second sampling date in July, RP frequency was similar in the imazapic and imazapic plus 2,4-D treatments and greater than clethodim, pendimethalin, mowing, and control (Fig. 2). This pattern of response continued through the end of the growing season, at which time imazapic and imazapic plus 2,4-D were not different (67 and 73%, respectively) but were greater than the other treatments, which remained below 35% RP frequency.

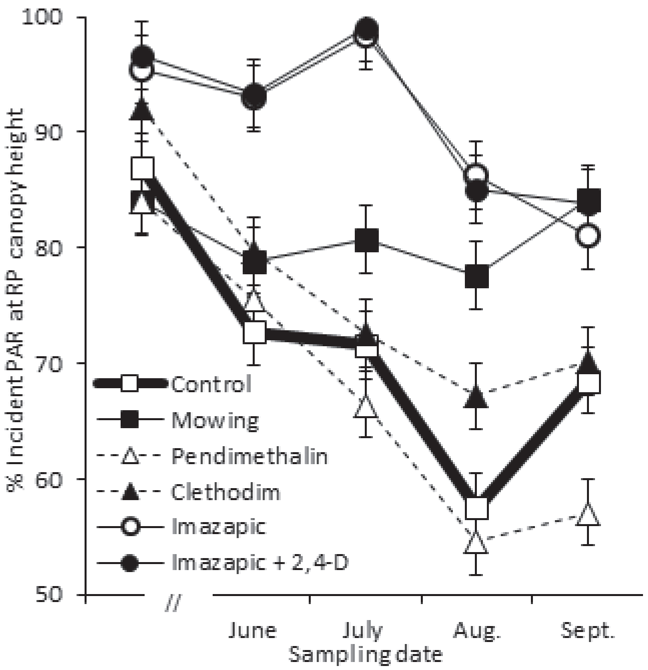

Figure 4. Incident photosynthetically active radiation (PAR) at rhizoma peanut canopy height as a function of six weed control strategies. Data are means across 2 yr. Error bars represent treatment means averaged across N rates ($n = 6$) ± 1 standard error.

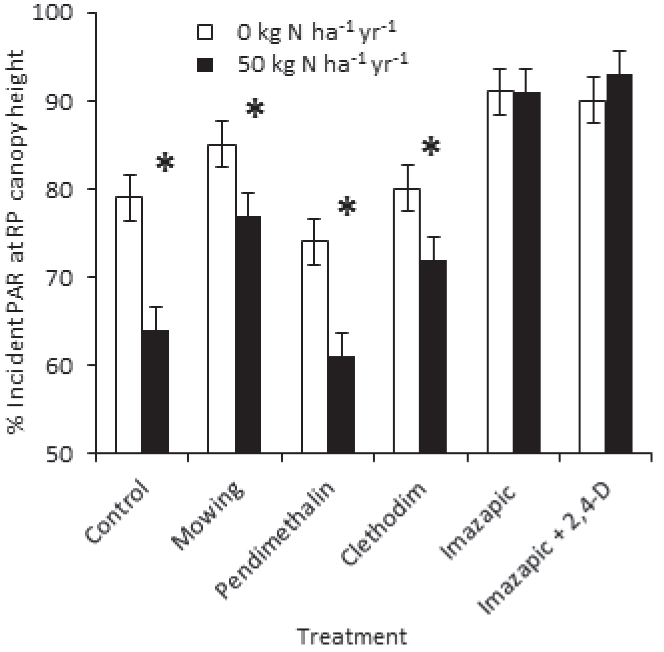

Figure 5. Incident photosynthetically active radiation (PAR) reaching the rhizoma peanut (RP) canopy as a function of six weed control strategies and two N rates. Data are means across 2 yr. Error bars represent treatment means averaged across sampling dates and years ($n = 30$) ± 1 standard error. *Significant N effect ($P \leq 0.05$).

Nitrogen fertilization increased RP frequency in the imazapic treatment from 43 to 57% ($P = 0.05$) and in imazapic plus 2,4-D from 45 to 61% ($P = 0.02$) (Fig. 3). Similar to the response observed for RP cover, there was no effect of N on RP frequency in the mowing treatment and there was a negative effect of N fertilizer in control, pendimethalin, and clethodim treatments ($P = 0.04$; P value is for comparison of the average of control, pendimethalin, and clethodim treatments receiving 0 vs. 50 kg N ha^{-1} yr^{-1}).

Rhizoma peanut canopy cover and frequency (approximately 30 and 80%, respectively) were similar to the values reported when no defoliation was imposed or when hay was produced during the year of establishment on strip-planted RP without N application and treated with imazapic (Castillo et al., 2013). When N was applied following a single application of imazapic or imazapic plus 2,4-D, RP canopy cover and frequency were approximately 41 and 80%, respectively. Therefore, a single application of imazapic or imazapic plus 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

All of the two-factor interactions involving N application, weed control strategy, and sampling date were significant ($P \leq 0.04$). To link light environment responses most directly with RP cover and frequency data, we chose to focus the presentation of results on the interactions of weed control strategy × sampling date ($P < 0.01$) and N application × weed control strategy ($P < 0.01$), the same interactions discussed for cover and frequency.

Incident PAR at RP canopy height was not different at all sampling dates for imazapic and imazapic plus 2,4-D treatments (above 96% until July) and was consistently greater than the other treatments through August (Fig. 4). In September, imazapic and imazapic plus 2,4-D were similar to mowing, and these three were greater than the other treatments (Fig. 4). These data suggest that a superior light environment for establishing RP was at least partially responsible for the greater RP cover and frequency achieved in the treatments where imazapic was applied. Light environment in the mowing treatment did not completely explain RP response because the light environment was superior from July through September for mowing vs. the control, pendimethalin, and clethodim treatments, but this did not translate into greater RP cover or frequency in the mowing treatment. This suggests that even though RP was not shaded severely in the mowing treatment, the presence of weed species resulted in competition for other resources such that RP establishment was negatively affected.

A N application × weed control interaction occurred because application of N decreased incident PAR reaching the canopy of RP in all treatments except in imazapic and imazapic plus 2,4-D (Fig. 5). Consequently, light environment appears 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 plus 2,4-D treatments. In contrast, application of N can be deleterious for the establishment of RP planted in strips when other species overtop and are actively competing with RP for light.

Canopy Height and Spread

For RP canopy height, there was an effect of weed control strategy (Fig. 6). Canopy height of RP was greatest and not different in the control and pendimethalin treatments followed by clethodim and lowest for the mowing, imazapic, and imazapic plus 2,4-D treatments (Fig. 6). The results indicate that in growing environments where light is limiting, RP uses etiolation as a light-capturing strategy. Furthermore, there was no effect of applying 2,4-D amine herbicide on RP canopy height (imazapic vs. imazapic plus 2,4-D) during the year of establishment at the rate used in this study.

There were no treatment effects on RP spread during the year of establishment. Although there were differences among treatments in RP canopy cover, frequency, and light environment inside the strip, the results indicate that lateral spread of RP to colonize new areas is limited during the year of establishment, perhaps due to greater emphasis of establishing plants on developing rhizome mass than on lateral spread. Similar results were reported by Castillo et al. (2013) for nondefoliated and hay production treatments imposed during the year of establishment.

Year-after-Establishment Measurements

Canopy Cover and Frequency

There was a weed control strategy × N application interaction for RP canopy cover ($P = 0.05$) in the year after establishment. The interaction occurred because RP canopy cover tended ($P = 0.09$) to be greater with N application for the imazapic plus 2,4-D treatment but tended ($P = 0.08$) to be greater with no N application for the control (Table 1). Rhizoma peanut frequency was also affected by the interaction of weed control strategy with N application ($P = 0.03$). The frequency response was similar to cover, and RP frequency tended to be greater with N application ($P = 0.09$) for the imazapic plus 2,4-D treatment while it was favored ($P = 0.04$) or tended ($P = 0.09$) to be favored by no N application when weed control strategy was clethodim or the control, respectively (Table 1). These responses generally correspond with those from the establishment year where N application increased RP cover and frequency only in the most successful weed control treatments.

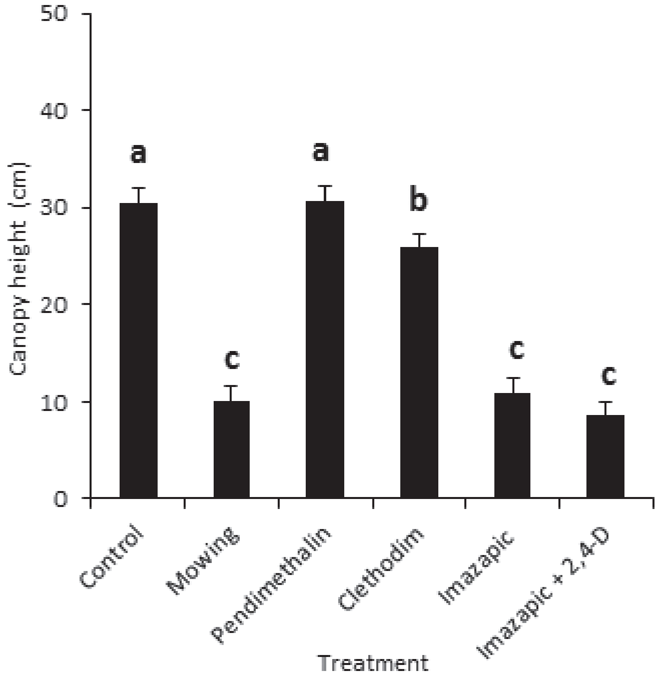

Figure 6. Rhizoma peanut canopy height measured at the end of the growing season in 2010 and 2011 as a function of six weed control strategies. Bars with different letters denote statistical difference ($P < 0.05$). Error bars represent treatment means averaged across years ($n = 6$) ± 1 standard error.

Botanical Composition

Weed control strategy affected botanical composition, but the N application × weed control strategy interaction was not significant ($P = 0.42$). Imazapic and imazapic plus 2,4-D treatments had greater percentage RP than control, mowing, and pendimethalin. Clethodim was intermediate and similar to all treatments (Table 1). Imazapic and imazapic plus 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 used for the botanical composition measures. This observation is supported by the canopy height results from the year of establishment where RP height was lowest (Fig. 6) in treatments where canopy cover and frequency were highest (Fig. 2).

Spread

There were no treatment effects on RP spread during the year after establishment. Because there were no treatment effects during either year (year of or year after establishment), spread was analyzed by including year in the statistical model as a fixed effect to estimate RP spread into the bahiagrass over time. Results indicated that on average, RP spread 31 cm per year (year effect) ($P < 0.01$). Butler et al. (2006) and Interrante et al. (2011) reported ≥70 cm spread of Florigraze RP during the year of

Table 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 control strategies with and without N fertilizer. Data are means of three replicates and 2 yr ($n = 6$).

Treatment description	Canopy cover kg N ha^{-1} yr^{-1} 0	 50	 *P*[†]	Frequency kg N ha^{-1} yr^{-1} 0	 50	 *P*	Botanical composition (RP component)
				%			
Mowing	2 c[‡]	2 b	0.81	13 c	15 b	0.85	1 b
Pendimethalin	6 bc	3 b	0.15	35 b	23 b	0.21	3 b
Control	8 ab	3 b	0.08	37 b	19 b	0.06	1 b
Clethodim	10 ab	5 b	0.15	45 ab	25 b	0.04	5 ab
Imazapic	12 ab	18 a	0.20	57 a	69 a	0.18	11 a
Imazapic plus 2,4-D	16 a	25 a	0.09	58 a	73 a	0.09	11 a
SE	2	2		9	9		2

[†] *P* value for comparison of N rate means within a weed control strategy.

[‡] Means within columns not followed by the same letter are different ($P \leq 0.05$).

establishment. However, in those studies RP plants were initially grown in the greenhouse, transplanted to the field, and the plots were maintained as an RP monoculture and completely free of weeds.

SUMMARY AND CONCLUSIONS

Rhizoma peanut canopy cover and frequency were greatest for imazapic and imazapic plus 2,4-D treatments (27 and 67% for imazapic and 34 and 73% for imazapic plus 2,4-D, respectively) compared with <7 and 35%, respectively, for the others (clethodim, pendimethalin, control, and mowing). Application of 50 kg N ha^{-1} increased RP canopy cover and frequency (approximately 10 and 15 percentage points, respectively) for both imazapic and imazapic plus 2,4-D treatments where weed competition was low. There was either no effect or a negative effect of added N for the other treatments that did not control competition to RP successfully. Incident PAR at RP canopy height was consistently greater for imazapic and imazapic plus 2,4-D treatments than other treatments until August contributing to superior RP establishment. Spread of RP into bahiagrass sod averaged 31 cm yr^{-1} during the establishment year and year after establishment. In conclusion, a single application of imazapic and imazapic plus 2,4-D herbicides followed by application of 50 kg N ha^{-1} has the potential to improve establishment of RP planted in strips and aid in achieving a RP–bahiagrass mixture in the planted strip by the end of the establishment year.

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