# MIXED GRAZING BY CATTLE AND GOATS FOR THE CONTROL OF BLACKBERRY IN RHIZOMA PEANUT-GRASS PASTURES

By

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To Mom and Dad

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Rhizoma peanut (*Arachis glabrata* Benth.)-grass pastures are currently being evaluated as an option to reduce N-fertilizer dependency of grass-based systems and to provide satisfactory nutritive value for low-input beef cattle production in Florida. Broadleaf weeds such as blackberry (*Rubus fruticosas* L.) can become a constraint in established pastures, and biological control of blackberry by grazing animals has not been evaluated in this context. Two studies were conducted during 2011 and 2012. The first investigated the effectiveness of using goats in various mixed-grazing methods with cattle as a means of blackberry control, and the second quantified responses of blackberry to targeted hand clipping and leaf removal in order to more completely describe the regrowth and persistence characteristics of this weed.

Results of the grazing experiment show that cattle do not select for blackberry, but goats consume it readily. The degree of selection for blackberry by goats is affected by method of mixed grazing, and it was greatest when goats followed cattle sequentially onto pasture, and least when cattle followed goats onto pasture or when the cattle and goats grazed concurrently at a moderate stocking rate. Treatments which included goats resulted in a decrease in height of the blackberry component of the sward during

a grazing event, whereas the cattle-alone treatment resulted in an increase in height of blackberry. When cattle grazed alone, pregraze blackberry percentage in the biomass increased by 10 percentage units compared with decreases of 11 units with goats alone or 13 units with cattle plus goats at a high stocking rate. Treatments which included goats resulted in either decreases or smaller increases than for cattle alone in pregraze blackberry biomass over the experimental period. Treatments with goats resulted in greater leaf removal of marked blackberry plants and a greater reduction in blackberry stem density than did cattle alone.

In the second experiment, treatments in which blackberry leaves were not removed below the clipping stubble height  generally had taller blackberry regrowth height, greater subsequent biomass production, less reduction in cover, and smaller decreases in stem density. Blackberry cover increased as clipping stubble height increased, and blackberry stem density decreased to a greater degree with shorter stubble height.

These studies showed that goats were more effective to controlblackberry than cattle, but it was not sufficient for eradication of blackberry from heavily infested rhizoma peanut-grass pastures during the 2-yr experimental period. Results from Experiment 2 suggest that blackberry leaf removal, possibly achieved through grazing by goats, in conjunction with mechanical defoliation to short stubble, will significantly reduce subsequent blackberry mass, cover, and stem number in areas that are heavily infested with this challenging weed. Longer term multi-species grazing might effectively control blackberry over time.

# CHAPTER 1
# INTRODUCTION

Nitrogen-fertilized C4 grasses are the most common form of pasture for cattle (*Bos* sp.) in Florida. With increasing prices for fossil fuels and ensuing increases in N fertilizer cost, more attention has been focused on identifying lower-input, alternative pastoral systems. One possible system for Florida includes incorporating rhizoma peanut (*Arachis glabrata* Benth.), a perennial legume, into C4 grass pastures. Currently there is a significant research emphasis in Florida on strip planting rhizoma peanut into existing bahiagrass (*Paspalum notatum* Flügge) swards (Mullenix et al., 2012; Castillo et al., 2013).

One of the problems associated with rhizoma peanut-grass pastures is the occurrence of broadleaf weeds such as dogfennel [*Eupatorium capillifolium* (Lam.) Small], teaweed (*Chenopodium abrosioides* L.), and blackberry briar (*Rubus* spp.) some years after establishment (Valencia et al., 1999). The most common approach to weed management in these situations has been the use of herbicides. For those managers interested in minimizing herbicide input or in biological weed control alternatives, there is very limited information available for rhizoma peanut-based pastures.

Goats (*Capra hircus*) have been used in many parts of the world in a number of contexts for eradication of undesired vegetation (Davis et al., 1975; Krause et al., 1987; Fajemisin et al., 1995; Hart, 2001). Goats are classified as browsers and eat relatively less grass in their total diet than cattle. They often exhibit preference for woody vegetation or forbs and have a narrow muzzle with adaptable lips, allowing them to browse carefully among even briars (Lu, 1988).

Use of goats in mixed livestock species grazing has proved beneficial for achieving desired changes in botanical composition in previous studies (Abaye et al., 1997; Fraser et al., 2006). Based on differences in ingestive behavior among animal species included in a mixed grazing regime, plant species are selected to a greater or lesser degree. Many times one herbivore species will readily consume plants considered to be weeds, while other animal species will avoid these plants. Use of goats and cows in mixed grazing systems for altering sward botanical composition has not been evaluated extensively in the literature (Sollenberger et al., 2012), and neither has the sequential order of entry of grazing species into the pasture nor their stocking rate. These gaps in the literature, as well as the presence of existing literature touting the effectiveness of the use of goats for brush control in the context of mixed grazing systems (Celaya et al., 2006; Animut and Goetsch, 2008), which lend merit to additional research exploring the use of mixed-grazing approaches for manipulating botanical composition of complex plant species mixtures.

The experiments described in this thesis evaluated use of defoliation as a means of broadleaf weed control in rhizoma peanut-grass pastures. Two studies were conducted. The objective of Experiment 1 was to determine the effect of various systems of mixed grazing on productivity and botanical composition of rhizoma peanut-grass pastures in which blackberry briar had invaded significantly. Grazing systems tested included single animal species controls, simultaneous mixed grazing by goats and cattle at two stocking rates, and two sequences of animal species allocation to pasture (goats followed by cattle, cattle followed by goats). Experiment 2 evaluated the effect of controlled and targeted hand clipping of blackberry in small-plot mixtures with rhizoma peanut and grass. Blackberry regrowth and persistence responses were measured following defoliation to different heights and with or without leaf removal from residual herbage below the various height treatments. It is anticipated that the results of these experiments will provide useful data to assess the potential of mixed grazing systems including goats for control of blackberry in rhizoma peanut pastures (Experiment 1) and will increase understanding of the relative importance of defoliation stubble height and leaf removal on blackberry regrowth and persistence (Experiment 2).

# CHAPTER 2
# LITERATURE REVIEW

## Grass-Based Forage Systems and Sustainability

C4 grasses are the most common pastured forage species for cattle (*Bos* sp.) production in Florida, with primary species in use including bahiagrass (*Paspalum notatum* Flügge), bermudagrass [*Cynodon dactylon* (L.) Pers.], stargrass (*Cynodon nlemfuensis* Vanderyst), and limpograss (*Hemarthria altissima* Stapf et C.E. Hubb.). Bahiagrass pasture for beef production alone comprises over 1 million ha in Florida (Sumner et al., 1992). Reasons for the popularity of bahiagrass include its tolerance of close grazing and relatively low levels of soil nutrients.

Many C4 grass forages require significant annual inputs of fertilizer, particularly N (Sumner et al., 1992), in order to persist and maintain desired levels of productivity. Large price fluctuations in fertilizer cost threaten the sustainability of N-fertilized grass-based cattle production systems. In the case of bahiagrass, insufficient fertilization of pastures due to increasing fertilizer prices has been implicated in weakening of stands, making them more susceptible to pests including mole cricket (*Scapteriscus* sp.) (Adjei et al., 2006).

## The Legume Alternative

Legumes are an option for reducing dependence on costly N fertilizer in pastures. In Florida, rhizoma peanut (*Arachis glabrata* Benth.) is one of few perennial legumes available for incorporation into existing C4 grass pastures. Rhizoma peanut is a warm-season legume adapted to well-drained soils and tolerant of relatively heavy grazing (Rice et al., 1995). It is grown on approximately 15,000 ha in North Florida and South Georgia (Myer et al., 2010). Because of its high forage quality, rhizoma peanut is considered a subtropical equivalent of alfalfa (*Medicago sativa* L.) (Gelaye and Amoah, 1991). Rhizoma peanut is propagated vegetatively using rhizomes, which are expensive to purchase, and stands often take 2 yr to develop complete groundcover (Johnson et al., 1994). As a result, rhizoma peanut is used primarily for hay in Florida because the high cost and slow rate of establishment make it difficult to achieve adequate return on investment in grazing systems, even with its' long stand life.

Lower-cost alternatives for peanut establishment are needed in order for it to be an attractive option for low-input grazing systems. One approach to the incorporation of rhizoma peanut in such systems may be strip-planting the legume into grass swards. Because rhizoma peanut is a long-lived perennial with ability to spread laterally via an extensive rhizome system, it has potential to spread into the surrounding grass areas, and form a mixed pasture over time. This approach to establishment of peanut currently is being evaluated in Florida (Mullenix et al., 2012; Castillo et al., 2013). If these approaches are successful in developing mixed peanut-grass swards, then it is likely that broadleaf weed control issues will arise over time and some producers may consider grazing management strategies instead of herbicides for their control.

## Weed Management in Rhizoma Peanut

One of the major challenges associated with establishment and persistence of rhizoma peanut pastures is weed control (Canudas et al., 1989; Sollenberger et al., 1995; Valencia et al., 1999). For example, it has been reported that 'Florigraze' rhizoma peanut is not as competitive with broadleaf weeds as it is with grasses (Canudas et al., 1989). Further, the competitiveness of rhizoma peanut with desirable grasses, particularly in Florida environments where severe spring drought limits grass growth, can lead to niches for broadleaf weed proliferation in peanut swards (Valencia et al., 2001).

Both broadleaf and grassy weeds reduce rhizoma peanut pasture quality. Weeds commonly found in rhizoma peanut stands include sedges (*Cyperus* sp.), crabgrass [*Digitaria sanguinalis* (L.) Scop.], sandspur (*Cenchrus echinatus* L.), dogfennel [Eupatorium capillifolium (Lam.) Small], Mexican teaweed (*Chenopodium ambrosioides* L.), Virginia pepperweed (*Lepidium virginicum* L.), Florida pusley (*Richardia scabra* L.), pigweed (*Amaranthus retroflexus* L.), cogongrass [*Imperata cylindrica* (L.) Beauv.], passion flower (*Passiflora edulis* Sims) and blackberry (*Rubus fruticosas* L.) briar (Prine et al., 1984; Canudas et al., 1989; Valencia et al., 1999).

Recommended weed management practices in rhizoma peanut stands include higher planting densities (Prine et al., 1984) and herbicide treatments. Higher planting densities are effective for weed control during establishment, but this practice is expensive and weeds can still be an issue in later years (Prine et al., 1984; Valencia et al., 2001). Historically, chemical control of weeds in established rhizoma peanut stands has had drawbacks. Valencia et al. (1999) reported lower occurrences of Mexican teaweed 2 mo after rhizoma peanut swards were treated with glyphosate, yet they noted substantial recovery of Mexican teaweed 4 mo after application for low and moderate herbicide rates. Further, although Mexican teaweed recovery was not substantial for the high glyphosate rate, dry matter yield of rhizoma peanut decreased as rate of glyphosate increased. Recent advances in herbicide technology have shown that the herbicide imazapic is the most effective option to date for controlling some broadleaf weeds in peanut pastures (Ferrell et al., 2006). In spite of this success, there may be a future role for biological weed control, i.e., by grazing, in low-input or organic systems, in part due to the relatively high cost of the applicable form of imazapic, Impose, which has been estimated at $325/gal (Ferrell and Sellers, 2011).

## Characteristics of the Broadleaf Weed Blackberry

One of the more challenging broadleaf weeds to control in rhizoma peanut pastures is blackberry. Ferrell and Sellers (2010) have noted significant presence of blackberry in Florida pastures, the challenges associated with its control, and the adverse effects it has on cattle and grazing. Additionally, it is listed as one of the ten most common weeds in utility rights-of-way in Florida (Webster, 2011) and is a Weed of National Significance in Australia (Thorp and Lynch, 2000). It is prevalent in marginal lands and pastures which receive lax management. Its growth potential in more intentionally managed areas has been suggested to be limited by grazing, herbicides, and land preparation practices such as plowing (Amor, 1974a).

Blackberry forms dense thickets of thorny shrubs from crowns under the soil surface, which are the main energy storage and regrowth centers for blackberry plants. These woody, perennial storage organs of the plant can be quite large (> 20 cm) in diameter (Ainsworth and Mahr, 2005) and are one of the reasons for the superior persistence of blackberry. They make the plants resilient to fire, cutting, and grazing, and allow them to readily sprout new stems after one of these events (Ainsworth and Mahr, 2005). Each new stem generated typically lives for 2 yr (Ainsworth and Mahr, 2005), therefore there is substantial turnover in canes from root crowns in blackberry plants.

Blackberry is also capable of regrowth and dispersion via lateral rhizomes which can form new plants, although this method is not as prevalent in well-established stands

(Amor, 1974a). This process of vegetative growth is significantly more pronounced in areas adjacent to thickets, disrupted stands, or stands or plants treated with herbicides (Amor, 1974b). Distribution and reproduction by seed in blackberry is viewed as not significant due to their poor establishment (Amor, 1974a).

Browsing or grazing of blackberry has been viewed as a potential control option (Amor, 1974a, Ainsworth and Mahr, 2005, Ann Blount, personal communication), but there are gaps in the literature concerning necessary frequency of grazing, stocking rates, or animal species which exhibit preference for the plant. Amor (1974a) reported a decrease in daughter plant formation from rhizomes when blackberry was grazed by horses (*Equus caballus*) or cattle, and Ainsworth and Mahr (2005) reported a preference for blackberry browse by sambar deer (*Cervus unicolor* Kerr.). No studies were found that address mixed grazing or grazing by goats (*Capra hircus*) for control of blackberry.

## Biological Weed Control Using Grazing Livestock

A strategy for weed management that has not yet been implemented in rhizoma peanut pastures is biological control using grazing animals. Goats have been used for weed control in both pastureland and rangeland situations because of their ingestive behavior and diet selection (Lu, 1988; Animut et al., 2005; Animut and Goetsch, 2008). They have also been utilized in mixed-grazing systems, with desirable outcomes in terms of pasture botanical composition (Papachristou, 1996; Animut et al., 2005; Celaya et al., 2006; Fraser et al., 2007; Animut and Goetsch, 2008).

Goats are distinct from sheep (*Ovies aries*) and cows (*Bos* sp.) in terms of their grazing behavior, most prominently in regard to their selectivity and tendency to browse rather than graze (Lu, 1987). In addition, their employment of a bipedal stance enlarges the total amount of forage or browse that they can access in a given area (Lu, 1987). Goats are also more prone to eye-level feeding than cows or sheep (Lu, 1987), suggesting a tendency to feed at a different level of the sward canopy and utilize other forage species or plant parts than cows or sheep. In a study evaluating goat feeding behavior, Askins and Turner (1972) noted that about one-third of goat's grazing time consisted of consumption of low-level grasses, while two-thirds of their time was spent browsing forbs and other plants higher in the canopy. Diet selection in goats varies from that of cows or sheep most notably in terms of their preference for forbs rather than grasses or relatively decumbent legumes such as clovers (*Trifolium* sp.; Lu, 1987; Gurung et al., 1993). Physical characteristics of goats contribute to their selectivity, including their well-developed lips and tongue, which allow them to feed even on thorny brush or shrubs (Lu, 1987; Gordon, 2003).

In a rangeland setting, Warren et al. (1984) found that goats preferred browse over grasses throughout summer, autumn, and winter in South Texas, with 52 to 68% of their diet consisting of shrubs during this time. Additionally, the reoccurrence of sagebrush (*Artemisia tridentate* Nutt.), leafy spurge (*Euphorbia esula* L.), and knapweed (*Centaurea* sp.) proliferation coincided with a regional decline of goat production in the western USA (Provenza, 2003).

Goats have controlled undesirable vegetation in a number of situations. Due to their unique grazing habits and selectivity, goats often consume many kinds of forbs or woody vegetation that cows and sheep do not (Taylor, 1985). Goats have been used for biological control of gorse (*Ulex europaeus* L.), an invasive, thorny shrub in New Zealand (Rolston et al., 1981; Radcliffe, 1982). The system included putting goats on gorse-infested grasslands first, as goats preferentially selected gorse to grass, then as gorse density decreased due to goat feeding, gradually replacing goats with sheep which better utilize the newly-cleared grasslands (Krause et al., 1987). Celaya et al. (2006) also found goats to be efficient in controlling gorse species in Western Europe.

Davis et al. (1975) used browsing by goats in combination with mechanical control methods for controlling Gambel oak (*Quercus gambelii* Nutt.) in the western and southwestern USA. Mechanical control was necessary as a primary form of management, as many of the oak trees were taller than the top boundary of grazing area for goats (about 2.2 m). After initial mechanical control, goats were found to successfully control Gambel oak sprouts. In terms of cost and long-term control, this method was superior to chemical, mechanical, or fire control alone (Riggs et al., 1988). Lym (2005) found goats to be helpful in controlling leafy spurge. Grazing was successful and cost effective in reducing topgrowth of leafy spurge when the plant infested large areas of land, yet regrowth of leafy spurge occurred after animals were taken off, necessitating incorporation and combination with other strategies such as fire, chemical, and mechanical control. In this case, grazing by goats proved beneficial as a supplemental biological control strategy, even though grazing by goats alone was not sufficient to adequately control leafy spurge.

Although historically the majority of goat production has occurred in developing countries, an increase in production is evident in developed countries, such as the USA, over the past few years (Boyazoglu et al., 2005). This has been associated with an increased demand for goat meat (Gipson, 1999, Solaiman, 2007), most notably by ethnic populations in these countries (Cosenza et. al., 2003). Additionally, prices of

$100 or more per head for kids, yearlings, does, and bucks in the southeastern USA (Georgia Livestock Review, 2013) warrant producer consideration for expanded use of these animals, especially in situations where their use could be substituted for costly herbicides.

## Multi-Species Grazing

Mixed grazing systems have been used in a number of contexts, and in these systems there exist possibilities for increased productivity or efficiency of forage use (Abaye et al., 1993), and for positive vegetation dynamics (Fraser et al., 2006). Animut and Goetsch (2008) noted that differences in preference for plant species and parts, in ability or willingness to consume plant species present, and in physical capabilities of some animal species to gain access to specific types of vegetation contribute to the greater efficiency observed. Also due to differences in diet among ruminant species, Squires (1982) noted the possibility of a mixed-species grazing system to spread grazing pressure more evenly over vegetation in situations with heterogeneous plant communities. These factors have led to the suggestion that higher stocking rates may be achieved on mixed-grazed pastures, or at least that stocking rate effects from mono-species grazing cannot be directly applied to mixed-grazing systems (Animut et al., 2005). This potential was also noted by Fraser et al. (2006), who found that multi-species grazing provides better utilization of pasture, and by Animut and Goetsch (2008) who reported that it enhanced total income and sustainability of an operation. It was further noted that the potential for utilization of otherwise non-utilized resources in mixed grazing systems is higher for pastures or rangelands with large biological diversity of vegetation (Warren et al., 1984; Animut and Goetsch, 2008).

The two main approaches for mixed grazing are “concurrent” (also termed conjoint), with two or more animal species grazing the same pasture or paddock at the same time, and “sequential”, in which a pasture is first grazed by one species and followed by another, so that only one animal species is present on a given pasture at a time (Fraser et al., 2007). Additionally, sequential strategies can include either one species directly following another, such as the next day, or one species grazing an area for a portion of the season, then the other species grazing that area for the remainder of the season (Fraser et al., 2007). Both concurrent and sequential mixed grazing methods have proven beneficial in some aspects of production, but there is wide variability in how these strategies affect a system.

Fraser et al. (2007) noted that “mixed or conjoint grazing, when two or more animal species are grazed together, can lead to improved performance of one or more species involved, and a higher total output per unit area … [because of] better utilization of pasture. This may be due to [animal species] having different preferences for plants both as regards to species and plant parts, and/or a reduction in sward rejection due to dung contamination.” Forbes and Hodgson (1985) found sheep to graze closer to cattle dung deposits than cattle, implying more forage was available to sheep in the mixed grazing context. Fraser et al. (2007) reported that “sequential grazing systems, when different animal species graze an area in succession, also have the potential to improve productivity, apparently as a result of one animal species creating a sward with a composition or canopy structure beneficial to another species.” This is similar to the findings of Merrill et al. (1968) who noted that larger animal species can physically create a more attractive sward to other animal species due to foraging behavior and diet selection.

Stocking rate in mixed grazing systems is a factor that affects vegetation dynamics and forage selectivity among animal species (Animut et al., 2005). One instance of this phenomenon was reported by Animut et al. (2005) in a conjoint mixed grazing trial of sheep and goats on mixed grass-forb pastures. They noted that at higher mixed stocking rates, the percentage of grasses in swards increased.

Marley et al. (2006), in a study of concurrent and sequential grazing of cattle and sheep on sown ryegrass-clover pastures, found the lowest fecal egg counts from lambs occurred from sequentially grazing cattle then sheep. In addition, concurrent grazing resulted in higher growth rates of lambs than did sequential or single-species grazing.

There are a number of studies in which animal response to mixed grazing has been reported. Conjoint mixed grazing of sheep and cows was compared to individual species grazing of bluegrass (*Poa pratensis* L.) and white clover (*Trifolium repens* L.) pastures (Abaye et al., 1993). Mixed grazing increased daily gain, total gain, and weaning weights of lambs, as well as resulting in a shorter time needed for lambs to reach target weaning weight. They also found that mixed grazing provided a better season-long balance of forage growth and quality and better met the nutritional needs of the animals than individual species grazing.

Similarly, Radcliffe et al. (1991), reporting on concurrent mixed grazing of goats and sheep on perennial ryegrass (*Lolium perenne* L.) and white clover pastures, found lambs to have a faster growth rate on mixed-grazed pastures than on sheep-only pastures. Mixed-grazed pastures also resulted in a higher white clover percentage in the sward than sheep-only pastures.

Fraser et al. (2005) compared concurrent and sequential grazing by cattle and sheep in terms of growth rate of weaned lambs. Greater growth rates occurred under concurrent conditions, and they also found that concurrent grazing resulted in greater carrying capacity and total liveweight gain per unit area during the post-weaning time period. In contrast, the sequential treatment provided the highest carrying capacity for the pre-weaning time period. It was reported that lambs exhibited lower growth rates and liveweight gain for the sheep-alone treatments during the pre-weaning period. Sehested et al. (2003) found multiple benefits from both concurrent and sequential grazing by cattle and sows (*Sus scrofa*). Both methods improved weight gain for heifers but not for sows. The concurrent and sequential treatments resulted in better herbage quality than for the sow-only treatment. Additionally, both concurrent and sequential grazing increased total animal weight gain and estimated herbage intake per hectare than either sows or heifers grazing alone.

In a situation where multi-species grazing is to be considered, it is important to match the animals to be used with the forage species which are present in order to maximize benefits from both the plants and animals in the system (Shipley, 1999). This selective pairing is also necessary in order to achieve desired results such as weed selection by the animal species present (Olson, 1999).

## Summary

Increasing N fertilizer costs have resulted in greater interest in legumes in pastures for Florida beef cattle. Rhizoma peanut is a persistent legume that could make a long-term contribution to sustainable pasture systems if less expensive and protracted options for establishing this legume in grass swards can be developed. Strip planting is being evaluated as an alternative to conventional planting practices and shows potential for being effective while reducing establishment costs. In the past, rhizoma peanut-grass pastures have been invaded by broadleaf weeds, and although options for chemical control now exist, some growers may prefer alternatives that reduce input costs or are based on biological-control principles. Integrating goats into a mixed grazing system may provide significant control of broadleaf weeds. The proposed research will attempt to define grazing strategies using goats and mixed grazing of goats and cattle for achieving blackberry control in rhizoma peanut-grass swards.

# CHAPTER 3
# MIXED GRAZING BY CATTLE AND GOATS FOR CONTROL OF BLACKBERRY IN RHIZOMA PEANUT-GRASS PASTURES

## Overview of Research Problem

The C4 grasses, most notably bahiagrass (*Paspalum notatum* Flügge), are the primary pasture species for beef cattle in Florida (Sumner et al., 1992). One of the limitations associated with use of perennial grasses is their reliance on N fertilizer for sufficient production and persistence. Due to recent volatility in N fertilizer prices (Huang et al., 2009), alternative methods of incorporating N into low-input systems, such as those used in beef production, have received significant attention.

One of the methods being evaluated is integrating a legume into the grass-based system (Castillo et al., 2013). Legumes have received this attention due to their ability to fix atmospheric N, thus making it available to the forage-livestock ecosystem via senescence of plant parts, legume root and nodule sloughing, and cycling through livestock excreta (Ledgard and Steele, 1992). In Florida, rhizoma peanut (*Arachis glabrata* Benth.) is one of a limited number of legumes that fits the criteria for incorporation into grazed C4 grass pastures due to its relatively decumbent growth habit, ability to spread in grass pastures, and tolerance to heavy grazing (Rice et al., 1995).

An issue that arises in established rhizoma peanut-grass pastures is the encroachment of broadleaf weeds (Canudas et al., 1989; Sollenberger et al., 1995; Valencia et al., 1999). Of these weeds, blackberry (*Rubus fruticosas* L.) is one of the more challenging plants to control. Two methods to control broadleaf weed encroachment include greater planting densities of rhizoma peanut and the use of herbicides such as imazapic (Prine et al., 1984, Ferrell et al., 2006). However, greater planting densities are expensive due to the high cost of vegetative planting material. Use of herbicides may be too costly for some producers or unattractive to others who are targeting niche markets including organic food products.

One alternative method which has not been previously investigated in this context is the use of biological control of broadleaf weeds, especially by grazing. The use of grazing animals to achieve desired changes in botanical composition of swards has been successful in a number of contexts (Papachristou, 1996; Animut et al., 2005; Celaya et al., 2006; Fraser et al., 2007; Animut and Goetsch, 2008).

Goats (*Capra hircus*) have been a major species used for this purpose due to their diet selection and grazing behavior patterns that are distinctively different than those of cattle (*Bos* sp.) or sheep (*Ovis aries*) (Lu, 1988; Animut et al., 2005; Animut and Goetsch, 2008). Goats readily eat plants which cattle and sheep do not (Taylor, 1985) and often exhibit preference for woody forbs or browse over other types of forage (Warren et al., 1984; Lu, 1987; Gurung et al., 1993). This includes even plants with thorns, which goats are better able to feed on due to their narrow muzzle and well-developed lips and tongue (Lu, 1987; Gordon, 1983). For these reasons, goats were considered to be a possible control option for blackberry in rhizoma peanut-grass pastures.

Mixed grazing by two or more animal species has been utilized in a number of contexts to achieve greater utilization of otherwise unused resources present in a sward (Animut and Goetsch, 2008), increase productivity and efficiency of forage use (Abaye et al., 1993), and positively impact vegetation dynamics (Fraser et al., 2006). These results are often due to heterogeneous plant communities in the grazed area (Squires, 1982), differences among animal species in preference for different plants or plant parts, and physical capabilities of the animals to consume different types of vegetation (Animut and Goetsch, 2008).

Due to a relatively small amount of dietary overlap between goats and cattle (Taylor, 1985) and the heterogeneous sward conditions of rhizoma peanut-grass pastures infested with blackberry, multi-species grazing of goats and cattle for the control of blackberry was investigated. The hypotheses of this research were 1) method of mixed grazing affects diet selection in cattle and goats, 2) grazing by cattle or goats results in different proportion and mass of plant species in the sward, 3) method of mixed grazing affects plant species proportion and mass, and 4) greater stocking rates under mixed grazing result in different pasture characteristics. The specific objectives of this experiment were to compare 1) diet preferences of goats and cattle, 2) changes in plant species proportion and mass in pastures grazed by goats alone vs. cattle alone, 3) effects of mixed grazing methods on plant species proportion and mass, and 4) pasture characteristics at different stocking rates of mixed grazing in rhizoma peanut-grass pastures infested with blackberry.

## Materials and Methods

### Experimental Site

The experiment was conducted at the University of Florida Forage Evaluation Field Laboratory of the Beef Research Unit, northeast of Gainesville, FL (29° 38’ N, 82° 22’ W). The pasture was an established ‘Florigraze’ rhizoma peanut-bahiagrass sward with significant broadleaf weed infestation. Broadleaf weeds included blackberry, Mexican teaweed (*Chenopodium ambrosioides* L.), and dogfennel [*Eupatorium capillifolium* (Lam.) Small], but blackberry was the dominant broadleaf species. The rhizoma peanut pastures were planted in 1983 and they have been used for a variety of grazing experiments since then. Management was generally extensive, with fertilization applied only during the years when the pasture was part of ongoing research trials (< 10 yr).

Soils at the site are in the Smyrna fine sand series (sandy, siliceous, hyperthermic, Aeric Alaquods). The Smyrna series consists of very deep, poorly to very poorly drained soils formed in thick deposits of sandy marine materials. Permeability is rapid in the A, E, and C horizons and moderate or moderately rapid in the Bh horizons. Slopes range from 0 to 2 percent. These soils are sufficiently well drained for rhizoma peanut as indicated by the long stand life at this location. Soil test results prior to initiation of the experiment showed pH to be 6.9 and Mehlich I extractable P, K, Mg, and Ca to be 13, 35, 168 and 880 ppm, respectively.

**Treatments and Design**

The experiment included six grazing treatments arranged in a randomized complete block design, with each treatment replicated three times, for a total of eighteen 8- x 8-m experimental units. Treatments were imposed and responses measured from June through October 2011 and 2012. Each experimental unit was separately fenced for grazing. Rotational stocking was used, and the interval between grazing events was 35 d. Grazing animals were two crossbred yearling beef heifers (*Bos sp.*), of approximately 350-kg liveweight, and mature buck and doe goats of Boer/Nubian/Spanish cross-bred background and weighing an average of 40 kg. The same two heifers and group of 10 (2011) or 12 (2012) goats were used to graze all experimental units within a grazing season to avoid the potential for within animal species differences in grazing behavior.

The six grazing treatments included 1) cattle only, 2) goats only, 3) mixed concurrent grazing by cattle and goats at the same stocking rate as Treatments 1, 2, 5, and 6, 4) mixed concurrent grazing by cattle and goats at a high stocking rate (1.33 times that of all other treatments), 5) mixed sequential grazing with cattle followed by goats, and 6) mixed sequential grazing with goats followed by cattle. The target base stocking rate expressed in terms of cattle was 2.6 animal units (AU; 1 AU = 450 kg liveweight) $ha^{-1}$, so the stocking rate for the 1.33 x was 3.5 AU $ha^{-1}$. All experimental units except Treatment 4 were exposed to the same grazing intensity, and intensity was expressed in animal unit hours of residence time on the pasture per grazing event (calculation described below). The mixed grazing treatments were assigned the same number of animal unit hours as the single species treatments, however for the mixed treatments one-half of the animal unit hours were contributed by cattle and one-half by goats.

Treatments were selected such that effects of mixed vs. single species grazing could be determined and that sequential (in either order with one animal species immediately following the other) vs. concurrent mixed grazing could be compared. The high stocking rate mixed concurrent grazing treatment was included in the expectation that mixed concurrent grazing would result in greater residual herbage mass of the peanut-grass fraction than in the cattle-only treatment because part of the goat diet on the mixed pasture was likely to be plants that cows would not consume. Thus, it was hypothesized that peanut-grass herbage mass at the end of a grazing period would be greater on mixed grazing treatments than on pastures grazed by cows alone, and including the higher stocking rate would apply additional pressure on both the forage and weed components.

The initial concept for developing stocking guidelines for these pastures was to select a grazing intensity that approximates what has been used successfully in the past on rhizoma peanut pastures. Because there were a range of plant species and different combinations of animal species on the pastures, it did not seem appropriate to choose a target plant height as the indicator for the end of a grazing event. It was assumed, for example, that a target height for blackberry may be reached much sooner during a grazing period on pastures to which goats were assigned than for treatments with cattle only, or likewise a particular height of peanut and grass may be achieved sooner in pastures grazed only by cattle as opposed to mixed grazing or goat-alone treatments.

Thus, it was decided that grazing intensity should be expressed based on animal unit hours of residence time. An estimate of the carrying capacity of peanut pastures was needed as a starting point. The only study found that measured carrying capacity of rhizoma peanut pastures (i.e., used a variable stocking rate) was conducted with yearling beef animals and reported a carrying capacity of 1150 kg liveweight $ha^{-1}$ $d^{-1}$ (Sollenberger et al., 1989). Thus, that number was used as the starting point for the calculation of animal unit hours of residence time.

The first step was to scale down from a 1-ha model system to our treatment area. The 8- x 8-m experimental unit in this study can be considered to be one paddock of a rotationally stocked pasture. The rest period between grazing events was 35 d, and with a grazing period of 1 d, this translates into a pasture of 0.2304 ha (36 paddocks x 64 $m^2$ $paddock^{-1}$ = 2304 $m^2$ = 0.2304 ha). The 1150 kg liveweight $ha^{-1}$ $d^{-1}$ carrying capacity target needed to be scaled by multiplying by 0.2304 ha (1150 kg liveweight $ha^{-1}$ $d^{-1}$ * 0.2304 ha = 265 kg liveweight $d^{-1}$). Based on data for cattle from Macoon (1999) and goats from Lu (1988) in this or similar environments, livestock graze approximately 7 h per day. Thus 7 h of grazing by one 265-kg liveweight heifer on an 8- x 8-m paddock during each grazing event would achieve the target grazing intensity. In order to achieve 7 h of grazing, it is necessary to determine what percentage of hours of residence time during daylight that animals are actually grazing. Data of this type are limited, but Bakare and Chimonyo (2011) reported that goats spent approximately 70% of two, 4-h residence periods grazing or browsing. We applied these data to both goat and cattle stocking calculations. Thus to achieve seven, 265-kg liveweight hour equivalents of grazing would require a residence time of 10 h (7 h/0.7 = 10 h). To calculate the number of kg liveweight hours of residence time needed, the product of 10 h * 265 kg liveweight resulted in 2650 kg liveweight hours residence time (10 hours * 265 kg liveweight = 2650 kg liveweight hours). The next step was to determine how long animals of specific liveweight should be stocked on the pasture. If two heifers were used and if each averaged 350 kg, for each hour present they contributed 700 kg liveweight hours of residence time. Dividing the 2650 kg liveweight hours by 700 indicates that 3.8 h of residence time of these two animals would be needed to reach the target. If more or heavier animals were put on the pasture, then the amount of time animals were present on each pasture would be reduced. Calculations for goats were done using a similar procedure and on a metabolic weight basis to establish stocking equivalencies with cattle (Sollenberger and Vanzant, 2011).

Grazing occurred during the period from 0700 to 1100 h to avoid periods of excessive heat when animals would most likely be resting. During the night before grazing events, heifers and goats were non-fasted so that intake while on treatment pastures the next day was as near to normal as possible. Heifers occupied reserve pastures of rhizoma peanut-bahiagrass-blackberry whenever not on treatment. Goats were on the same reserve pasture during daylight hours, but at night they were confined in a corral to protect them from predators. They received bermudagrass [*Cynodon dactylon* (L.) Pers.] hay, which was readily consumed, while in the corral.

Pastures were grazed at 35-d intervals during each grazing season. Grazing started in early June and concluded in October, which provided four grazing events per year for each treatment. To balance the workload and have a sufficient number of goats to impose the grazing treatments, one block (contained one replicate of each of the six treatments) was grazed each week, with one to no more than two treatments grazed per day on Monday through Friday. Thus, Block 1 was grazed in Week 1, and Blocks 2 and 3 in Weeks 2 and 3, respectively. In Week 6, Block 1 was grazed for the second time, and this pattern was followed throughout the grazing season. Blocking was used to account for the fact that only one block was grazed in a given week. The experimental units were selected for homogenous stands of blackberry, and analysis of pre-treatment observations showed that there were no differences in blackberry proportion present among experimental units.

## Measurements

### Grazing behavior

For the single-species animal treatments, two animals were selected for observation every grazing event, and bite counts (defined as severing vegetation) were recorded for 30 min per animal per grazing event. The 30-min period occurred during the middle 50% of the time animals spent on that pasture during that grazing event. Chews were not counted as bites and were not measured as a response. For mixed-species treatments, two animals of each species were selected for monitoring and bite counts recorded. Counted bites were allocated to various categories of vegetation. The categories were forage (peanut or grass), blackberry, and other broadleaf weeds. This measure provided data on diet selection of the two animal species.

The data from grazing behavior were evaluated in two ways. The first approach included pooling all bite count data across the animal species present within an experimental unit and calculating the proportion of total animal bites that were allocated to each of the different plant components. The second approach involved calculation within an animal species of the proportion of total bites taken by that species that were allocated to each of the different plant components.

**Extent of defoliation**

Response variables to characterize extent of defoliation for the various components within the swards included average pre- and post-graze height of sward components, blackberry plant leaf count, and plant mass. Pre- and post-graze height of sward components was measured in an effort to determine the effect of treatment on the extent of removal by defoliation and the regrowth of different species/categories of vegetation between grazing events. Before and after every grazing event, 20 height measurements were taken for forage (peanut-grass), blackberry, and other broadleaf weeds. Average decrease in height during the grazing period indicated the degree to which animals in a particular treatment grazed that plant category. Average increase in height during the regrowth period was indicative of the vigor of that plant category in response to previous grazing events. The latter response was considered an early indicator of weakening of that plant category due to defoliation.

Blackberry leaf counts were taken to assess the effect of treatment on removal of photosynthesizing area. Ten blackberry plants per experimental unit were marked by applying spray paint close to the ground, and leaf counts were recorded pre- and post-graze for every grazing event. The criterion used for what was considered a 'leaf' was surface area larger than 4 $cm^2$ so that small emerging leaves would not affect counts. If partial removal was recognized, an attempt was made to account for the fraction of a leaf removed.

Mass of sward components pre- and post-graze was measured to assess the amount of biomass removed from an experimental unit during a grazing event. To minimize the amount of plot area affected by this destructive sampling technique, measurements were taken only before and after the first and last grazing event each year. Three, 0.25-$m^2$ quadrats were sampled before and after grazing in representative locations in each experimental unit. Vegetation within the quadrats was cut to an 8-cm stubble height (always was below the grazing height), and samples were separated into forage (peanut and grass), blackberry, maidencane (*Panicum hemitomon* Schult.), and other broadleaf weed components, dried, and weighed.

**Botanical composition**

Percentage of sward component composition by weight before and after a grazing event was measured to determine the effect of treatment on preponderance of different plant species within the sward. Using the same samples from the plant mass characterization described above, components of forage, blackberry, and broadleaf weeds were expressed as a percentage of total plant mass collected within a quadrat.

### Blackberry stem dynamics

Blackberry stems were counted in an effort to understand more fully the effect of treatment on persistence. Four 20- x 50-cm quadrats were placed at fixed locations along a transect that ran through the middle of each experimental unit. Blackberry stem counts were made before the first and after the last grazing event for each experimental unit each year.

### Statistical Analysis

The data were analyzed using PROC MIXED of SAS (SAS, 1982). Grazing treatment, year, and their interaction were considered fixed effects and block random. Year was considered fixed because of the potential for cumulative effects of Year 1 grazing on Year 2 responses. When the effect of grazing event within a year is of interest, grazing event was considered a repeated measure. When treatment F tests were significant, treatments means were compared using pdiff and considered different if $P \leq 0.05$.

## Results and Discussion

### Grazing Behavior

When the bite count data were pooled across all animal species on a pasture, percentage of bites that were forage was affected by treatment and year ($P < 0.001$ for both), as was percentage of bites that were blackberry ($P < 0.001$ for both) (Table 3-1). Neither was affected by an interaction of treatment and year. Percentage of bites that were other broadleaf weeds was not affected by treatment ($P = 0.406$), but it was affected by year ($P < 0.001$) (Table 3-1).

The cattle alone treatment had the greatest proportion of bites that were forage (92), and goats alone resulted in the least (38; Table 3-2). All mixed treatments were intermediate (66-71%). The response was the opposite for blackberry bite percentage, with cattle-alone pastures having the least (5%), goats alone the most (59%), and mixed treatments intermediate (24-30%; Table 3-2). There were no treatment differences for the bite percentage of other broadleaf weeds (Table 3-2).

These results support previous studies of goat and cattle diet selection. Celaya et al. (2006), in marginal heathland areas in Spain consisting of perennial ryegrass (*Lolium perenne* L. cv ‘Phoenix’), heather (*Erica* spp., *Calluna*), and gorse (*Ulex gallii*), reported that goats selected more browse or woody vegetation than cattle, and that cattle selected up to 99% grass as opposed to browse. Askins and Turner (1972), in West Texas rangeland, observed that goats selected 28% grass and herbaceous weeds, while the remainder of the diet consisted of browse species, which is similar to the findings of this study. Because bite counts on the mixed-species treatments consisted of contributions from both cattle and goats, intermediate values between cattle alone and goats alone were expected and did occur.

When comparing treatments in terms of bites taken by cattle, the percentage of bites that were forage was affected only by year ($P < 0.001$), while blackberry bite percentage was affected by treatment, year, and treatment × year interaction ($P = 0.011$, $P = 0.004$, and $P = 0.013$, respectively) (Table 3-1). Weed bite percentage was affected only by year ($P < 0.001$). Cattle bites that were forage varied from 99.9% in Year 1 to 96.0% in Year 2, and bites that were other broadleaf weeds increased from 0% in Year 1 to 2.8% in Year 2. The Year 2 reduction in percentage of cattle bites that were forage and increase in percentage of bites that were other broadleaf weeds was primarily a function of a marked increase in presence of passion flower (*Passiflora* sp.)

in Year 2; it is a broadleaf weed which cattle readily consumed. The treatment × year interaction for percentage of cattle bites that were blackberry occurred because there were no differences among treatments in Year 1 and all means were ≤ 0.5%, while in Year 2 there were treatment differences with the cattle-alone treatment having greatest percentage of cattle bites that were blackberry (2.4%) and the sequential treatment of goats followed by cattle having the least (0.1%; Table 3-3). Although there were differences in blackberry percentage in cattle diets due to treatment in Year 2, the magnitude of these differences was very small (< 2.4 percentage units) and is likely of little biological significance.

These data are in agreement with Celaya et al. (2006), who observed cattle to select for grasses and herbaceous species 75-99% of the time when co-grazed with goats and sheep, and observed selection for woody species by cattle never exceeded 25%. Additionally, they noted cattle to almost totally reject gorse, a spiny, woody legume, similar to the response observed for blackberry in this study. These data also agree with Squires (1982), who observed diet selection in a mixed grazing context of goats, cattle, and sheep in a poplar box (*Eucalyptus populnea*) woodland with an understory of shrubs and grasses in New South Wales. He reported that cattle selected more grasses than goats and goats selected more shrubs than cattle.

When goat selection behavior was compared, there was a tendency for forage bite percentage to be affected by treatment ($P = 0.064$), and it was affected by year ($P < 0.001$) (Table 3-1). Percentage of goat bites that were blackberry was affected by both treatment and year ($P = 0.005$ and $P < 0.001$, respectively), while percentage of bites that were other broadleaf weeds was affected only by year ($P = 0.016$) (Table 3-1).

Across treatments, forage bite percentage in Year 1 averaged 40%, whereas in Year 2 it averaged 26%. This difference was explained by an increase in blackberry percentage from Year 1 to Year 2 (54 and 64%, respectively) and in other broadleaf weed percentage from 5 to 9%, respectively. The year difference was probably due in part to the carryover effect of the presence of the blackberry in Year 1 to Year 2. Plots were mowed to a 5-cm stubble during winter prior to the start of the experiment in Year 1, so Year 1 growth of the forage and blackberry components started from a common point close to soil level. To avoid confounding with the grazing treatments, no mowing occurred during the winter between Year 1 and Year 2. Because no treatment in Year 1 resulted in reduction of blackberry down to ground level, i.e., as would be the case following mowing, the swards in Year 2 had greater residual biomass during winter and initiated spring growth more vigorously and accumulated more biomass for the grazing season.

The two sequential treatments resulted in differences in cattle and goat diets. When goats had first access, i.e., goats were followed by cattle, 40% of goat bites were forage and 51% were blackberry. This compares with goat bites of 27% forage and 66% blackberry when cattle had first access and were followed by goats (Table 3-4). The proportion of forage and blackberry bites by goats was similar for the goat-alone treatment and the sequential treatment when cattle had first access and were followed by goats. Stocking rate of the concurrent treatments had no effect on goat bite percentages.

Data for diet selection of goats is similar to the findings of Akins and Turner (1972) who reported that one-third of plant selection by goats consisted of grasses and weeds, with the remainder of selection being for browse species. The proportion of blackberry plus broadleaf weed bites by goats in the current study ranged from 59 to 71%. Malechek and Provenza (1981) reported similar findings that goat diet selection in a rangeland setting consisted of approximately 60% shrubs, 30% grasses, and 10% forbs. Provenza and Malechek (1984) reported greater levels of browse selection by goats at higher stocking rates, but in the current study there was no difference among stocking rates, perhaps because the range in stocking rate treatments was relatively small. Of particular interest is the difference between sequential treatments, whereby when cattle entered the pasture first the percentage of blackberry bites by goats was greater and forage bites less than when goats entered first. This appeared to be due to cattle selecting forage almost exclusively such that when goats entered the pasture opportunities for forage bites had been reduced significantly.

**Extent of Defoliation**

Height reduction of forage during a grazing event was not affected by treatment, year, or their interaction (Table 3-1). Blackberry height reduction was affected by treatment ($P < 0.001$) and year ($P < 0.001$). Reduction of height of other broadleaf weeds was affected by treatment ($P = 0.030$). All treatments which included goats experienced a significant decrease in blackberry plant height, whereas in the cattle-alone treatment blackberry plant height actually increased during the grazing period (Table 3-5). Similarly, all treatments with goats present exhibited a more pronounced decrease in height of the other broadleaf weed component of the sward than did the cattle alone treatment (Table 3-5). Reduction of blackberry height per grazing event across treatments averaged 5.7 cm in Year 1 and 3.8 cm in Year 2.

Differences in height reduction of blackberry among treatments was due in large part to nearly complete avoidance of blackberry by cattle, which left plants in the cattle alone treatment grow freely. The lesser reduction of blackberry plant height in Year 2 was due in part to the blackberry plants having what appeared to be larger stems higher in the canopy that limited stem removal. Further, these blackberry plants in Year 2 exhibited more branching, enabling goats to browse plants with less effect on plant height. The lesser height reduction of blackberry in Year 2 is supported by existing literature. Davis et al. (1975) noted significant control of gambel oak (*Quercus gambelii*) by goats that were placed on areas where the existing oak had been mechanically treated beforehand (similar to conditions at the start of Year 1 in the current study), whereas much less oak was controlled when goats were placed on areas which had an existing stand of oak (similar to Year 2 in the current study). Further, Warren et al. (1984) reported a high preference for shrubby vegetation by goats in South Texas, yet observed the need for additional methods of control (i.e., mechanical clearing) to be used in combination with grazing in order to adequately control shrubs. Much of the greater reduction in height of the other weed component in treatments which included goats was due to selection by goats for species such as dogfennel and pepperweed (*Lepidium virginicum* L.), which cattle avoided.

Leaf retention of marked blackberry plants was affected by treatment ($P < 0.001$) and by year ($P < 0.001$) (Table 3-1). In Year 1, blackberry plants retained 55% of their leaves on average whereas in Year 2 they retained 69%. This can be attributed again to the greater amount of blackberry and thus blackberry leaves in the sward in Year 2. Similar to observations for height reduction, every treatment which included goats displayed a greater removal of leaves from the marked blackberry plants (Table 3-6). There were differences among mixed grazing treatments with the high stocking rate concurrent treatment resulting in lesser leaf retention (49%) than concurrent at the lower stocking rate (64%). Concurrent (64%) and sequential cattle followed by goats (59%) treatments resulted in greater leaf retention than sequential goats followed by cattle (50%) (Table 3-6). Treatments with greatest leaf removal (goats alone, concurrent high stocking rate, and goats followed by cattle) all had approximately 50% removal suggesting that the stocking rates utilized did not put extreme pressure on the blackberry plants present.

Change in biomass of different plant components over time was assessed by subtracting the pre-graze mass of the last grazing event from the pre-graze mass of the first grazing event in both years. Blackberry mass was affected only by treatment ($P <$ 0.001) (Table 3-1). Blackberry mass increased 116 g $m^{-2}$ for the cattle alone treatment. This change was greater than for all treatments that included goats (Table 3-7), which were not different and averaged a decrease in blackberry mass of 6 g $m^{-2}$ with a range from a decrease of 24 g $m^{-2}$ to an increase of 8 g $m^{-2}$. The large difference for the cattle-alone treatment was again due to their near total avoidance of blackberry. This is similar to the findings of Dennis et al. (2012) who noted a substantially higher presence of weeds in cattle only pastures than mixed cattle and goat pastures after being grazed for 2 yr.

Changes in forage, other broadleaf weed, and maidencane pregraze mass were not affected by treatment, but they were affected by year ($P < 0.001$, $P = 0.017$, and $P =$ 0.009, respectively) (Table 3-1). Pregraze forage mass increased by 88 g $m^{-2}$ over the grazing season in Year 1 and 12 g $m^{-2}$ in Year 2. Season-long change in pregraze weed herbage mass decreased 8 g $m^{-2}$ in Year 1 and 32 g $m^{-2}$ in Year 2. The greater decrease in Year 2 was due in part to greater presence of passion flower early in Year 2, a plant that both cattle and goats readily consumed. Maidencane season-long herbage mass increased 32 g $m^{-2}$ in Year 1 and 76 g $m^{-2}$ in Year 2. Greater mass of maidencane in Year 2 was likely due to a marked increase in rainfall relative to Year 1 (Table 3-8), resulting in considerably more maidencane within swards. From May to October in Year 1 total rainfall was 503 mm, whereas in the same period of Year 2 rainfall totaled 1095 mm. Neither cattle nor goats readily selected maidencane.

**Botanical Composition**

Over the course of the grazing season in both years, the proportion of forage, other broadleaf weeds, and maidencane components of the sward were not affected by treatment (Table 3-1). There was a trend for treatment effect ($P = 0.098$) on change in percent blackberry in total plant mass. Pastures grazed by cattle alone had an increase in blackberry of 10% compared with a decrease of 12 and 11% for the concurrent high stocking rate and goats-alone treatments, respectively (Table 3-9). Change in forage percentage in the sward was affected by year ($P < 0.001$) with a decrease of 14% in Year 1 and an increase of 6% in Year 2. Change in maidencane percentage was affected by year ($P < 0.001$), with a 3% increase in Year 1 and a 23% increase in Year 2, with the year affect associated with much greater rainfall in Year 2 as described earlier.

**Stem Dynamics**

Change in number of blackberry stems was quantified to assess impact of treatments on persistence. The response was affected by treatment ($P = 0.005$), with cattle alone distinctly different from all other treatments. Grazing by cattle alone resulted in a decrease of 2 stems $m^{-2}$, whereas for all other treatments number of stems decreased from 7 (concurrent) to 11 stems $m^{-2}$ (goats followed by cattle), with other mixed treatments intermediate to these (Table 3-10). These data agree with Amor (1974a) who observed a decrease in formation of daughter plants of blackberry when cattle were present, which was due to cattle consuming cane apices, arresting the formation of new plants. This is further supported by observations within the current study that the majority of selection for blackberry by cattle was for the top apical growth regions of the plants. In terms of the greater decrease in stem density for treatments which included goats, Amor (1974b) also noted a greater occurrence of daughter plant formation from lateral rhizomes in blackberry in response to mechanical cutting, similar to the effect of heavier grazing. These sucker plants, with younger, more tender leaves, could be easily consumed by goats, leaving their immature stems to die. It appears from the results of this study that cattle prevented an increase in stem density but did not prevent blackberry plant growth, which was then concentrated into existing stems. Whereas goats, in selecting for more blackberry, possibly caused more sucker plant formation, which caused damage to the main plant, and goats subsequently reduced stem density by consuming these younger sucker plants.

**Implications of the Research**

Treatments which included goats showed a greater percentage of total bites for blackberry and a lower proportion for forage. Cattle took almost no bites of blackberry. Within mixed treatments, goats selected the greatest amount of blackberry and the lowest amount of forage in pastures where cows grazed first and were followed by goats. Concurrent mixed grazing and sequential grazing with goats grazing first followed by cattle resulted in the lowest selection of blackberry by goats.

Treatments which included goats resulted in an overall decrease in height of blackberry within the sward during a grazing event, whereas an increase in blackberry height was observed for the cattle-alone treatment. Additionally, treatments including goats exhibited greater removal of leaves from blackberry plants than did cattle alone. Concurrent mixed grazing with a high stocking rate had greater blackberry leaf removal than did concurrent mixed grazing at the lower stocking rate, and goats followed by cattle resulted in greater leaf removal than cows followed by goats.

Cattle grazing alone resulted in a greater increase in pregraze blackberry biomass over the season compared to treatments with goats. The latter displayed either small increases or decreases in blackberry biomass. Similarly, there was a strong trend for percent blackberry in the pregraze biomass to increase throughout the grazing season in cattle alone pastures (10 percentage units), whereas concurrent high stocking rate and goats alone treatments resulted in 12 and 11 percentage unit decreases in blackberry. No differences were found among treatments for change in pregraze forage mass or percent of forage in sward biomass over the course of a grazing season; however treatments with goats resulted in significantly greater decreases in blackberry stem density within grazed pastures.

In conclusion, grazing goats alone or in a mixed context with cattle controlled blackberry to a greater degree than did grazing cattle alone, yet no treatment resulted in total eradication of the weed. Further investigation of using grazing as a means of control of blackberry is warranted, in particular when this method is coupled with another control strategy (i.e., mechanical). In addition, biological control of weeds such as blackberry with grazing will almost certainly require a number of years for success, so longer-term studies would be beneficial**.**

Table 3-1. *P* values for different sources of variation for response variables reported in Chapter 3.

| Response Variable | Source of Variation | | |
|---|---|---|---|
| | Treatment | Year | Treatment × Year |
| Across Species Forage Bite % | <0.001 | <0.001 | 0.374 |
| Across Species Blackberry Bite % | <0.001 | <0.001 | 0.222 |
| Across Species Other Weed Bite % | 0.406 | <0.001 | 0.324 |
| Cattle Forage Bite % | 0.213 | <0.001 | 0.487 |
| Cattle Blackberry Bite % | 0.011 | 0.004 | 0.013 |
| Cattle Other Weed Bite % | 0.799 | <0.001 | 0.942 |
| Goat Forage Bite % | 0.064 | <0.001 | 0.941 |
| Goat Blackberry Bite % | 0.005 | <0.001 | 0.479 |
| Goat Other Weed Bite % | 0.148 | 0.016 | 0.221 |
| Forage Height | 0.172 | 0.645 | 0.952 |
| Blackberry Height | <0.001 | <0.001 | 0.507 |
| Other Weed Height | 0.029 | 0.220 | 0.721 |
| Leaf Retention | <0.001 | <0.001 | 0.124 |
| Pre-graze Forage Mass | 0.215 | <0.001 | 0.035 |
| Pre-graze Blackberry Mass | <0.001 | 0.115 | 0.720 |
| Pre-graze Other Weed Mass | 0.628 | 0.017 | 0.414 |
| Forage Percentage in Biomass | 0.249 | <0.001 | 0.061 |
| Blackberry Percentage in Biomass | 0.098 | 0.283 | 0.194 |
| Other Weed Percentage in Biomass | 0.805 | 0.109 | 0.455 |
| Stem Density | 0.005 | 0.925 | 0.610 |

Table 3-2. Percentage of total bites, summed across animal species present on a given treatment, that were forage (rhizoma peanut plus grasses), blackberry, and other broadleaf weeds as affected by grazing treatment. Data are means across three replicates and four grazing cycles per year in each of 2 yr (n = 24).

| Treatment | Forage | Blackberry | Weeds |
|---|---|---|---|
| | ----------------------------------- | -----%----- | ----------------------------------- |
| Cattle Only | 92 a[†] | 5 d | 3 a |
| Goats Only | 38 c | 59 a | 3 a |
| Concurrent | 70 b | 24 c | 5 a |
| Concurrent High Stocking Rate | 71 b | 26 bc | 3 a |
| Cattle Followed by Goats | 66 b | 30 b | 3 a |
| Goats Followed by Cattle | 71 b | 25 bc | 4 a |
| SEM | 3.0 | 2.8 | 1.0 |

[†] Treatment means within a column not followed by the same letter are different ($P \leq 0.05$).

Table 3-3. Percentage of total bites taken by cattle that were forage, blackberry, and other broadleaf weeds as affected by grazing treatment. Data are means across three replicates and four grazing cycles per year in each of 2 yr (n=24).

| Treatment | Forage | Blackberry | | Weeds |
|---|---|---|---|---|
| | | 2011 | 2012 | |
| | --------------------------------%------------------------------ | | | |
| Cattle Only | 97 a[†] | 0.4 a | 2.4 a | 1.8 a |
| Concurrent | 98 a | 0.1 a | 1.1 b | 1.4 a |
| Concurrent High Stocking Rate | 98 a | 0.5 a | 0.6 bc | 0.8 a |
| Cattle Followed by Goats | 98 a | 0.5 a | 0.7 bc | 1.6 a |
| Goats Followed by Cattle | 99 a | 0.2 a | 0.1 c | 0.8 a |
| SEM | 0.79 | 0.003 | | 0.93 |

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

Table 3-4. Percentage of total bites taken by goats that were forage, blackberry, and other broadleaf weeds as affected by grazing treatment. Data are means across three replicates and four grazing cycles per year in each of 2 yr (n=24).

| Treatment | Forage | Blackberry | Weeds |
|---|---|---|---|
| | --------------------------------%------------------------------------ | | |
| Goats Only | 31 b[†] | 63 ab | 5 b |
| Concurrent | 33 ab | 55 c | 11 a |
| Concurrent High Stocking Rate | 33 ab | 58 bc | 8 ab |
| Cattle Followed by Goats | 27 b | 66 a | 5 b |
| Goats Followed by Cattle | 40 a | 51 c | 8 ab |
| SEM | 4.2 | 3.9 | 2.3 |

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

Table 3-5. Height reduction of various botanical components during a grazing event as affected by grazing treatment. Data are means across three replicates and four grazing cycles per year in each of 2 yr (n=24).

| Treatment | Forage | Blackberry | Weeds |
|---|---|---|---|
| | ---------------------------- | cm | ------------------------------ |
| Cattle Only | 5.2 a[†] | -1.2 b[‡] | 3.7 b |
| Goats Only | 5.1 a | 6.2 a | 9.6 a |
| Concurrent | 5.8 a | 5.6 a | 9.2 a |
| Concurrent High Stocking Rate | 6.2 a | 6.0 a | 9.3 a |
| Cattle Followed by Goats | 5.3 a | 5.7 a | 12.0 a |
| Goats Followed by Cattle | 6.3 a | 6.0 a | 10.6 a |
| SEM | 0.45 | 0.67 | 1.62 |

† Treatment means within a column not followed by the same letter are different ($P \leq 0.05$).
‡ Negative number indicates increase in height during the grazing period.

Table 3-6. Leaf retention of marked blackberry plants during a grazing period as affected by grazing treatment. Data are means across three replicates and four grazing cycles per year in each of 2 yr (n = 24).

| Treatment | Leaf retention |
|---|---|
| | % |
| Cattle Only | 99 a[†] |
| Goats Only | 50 c |
| Concurrent | 64 b |
| Concurrent High Stocking Rate | 49 c |
| Cattle Followed by Goats | 59 b |
| Goats Followed by Cattle | 50 c |
| SEM | 2.7 |

† Treatment means not followed by the same letter are different ($P \leq 0.05$).

Table 3-7. Change in blackberry biomass from before the first grazing event to before the last grazing event. Data are means across three replicates in each of 2 yr (n=6).

| Treatment | Change in Blackberry Biomass |
| --- | --- |
| | $g\ m^{-2}$ |
| Cattle Only | 116 a[†] |
| Goats Only | -4 b |
| Concurrent | 8 b |
| Concurrent High Stocking Rate | -24 b |
| Cattle Followed by Goats | 4 b |
| Goats Followed by Cattle | -12 b |
| SEM | 10.7 |

[†] Treatment means not followed by the same letter are different ($P \leq 0.05$).

Table 3-8. Average monthly rainfall for Gainesville, FL for 2011, 2012, and the past 30 yr.

| Month | 2011 | 2012 | 30-yr average |
| --- | --- | --- | --- |
| | ------------------------------ | mm | ------------------------------ |
| May | 67 | 175 | 63 |
| June | 147 | 415 | 181 |
| July | 89 | 70 | 154 |
| August | 84 | 253 | 162 |
| September | 47 | 159 | 112 |
| October | 69 | 23 | 73 |
| Total | 503 | 1095 | 745 |

Table 3-9. Change in percent blackberry within swards from before the first grazing event to before the last grazing event. Data are means across three replicates in each of 2 yr (n=6).

| Treatment | Change in Percent Blackberry |
|---|---|
| | % |
| Cattle Only | 10 a[†] |
| Goats Only | -11 b |
| Concurrent | -6 ab |
| Concurrent High Stocking Rate | -13 b |
| Cattle Followed by Goats | -3 ab |
| Goats Followed by Cattle | -6 ab |
| SEM | 5.5 |

[†] Treatment means not followed by the same letter are different ($P \leq 0.05$).

Table 3-10. Decrease in number of blackberry stems within marked quadrats as affected by grazing treatment. Differences were calculated as number of stems at the start of the first grazing event of the experiment minus the number of stems at the end of the second grazing season. Data are means across three replicates (n = 3).

| Treatment | Decrease in Stem Density |
|---|---|
| | stems $m^{-2}$ |
| Cattle Only | 2 b† |
| Goats Only | 7 a |
| Concurrent | 7 a |
| Concurrent High Stocking Rate | 9 a |
| Cattle Followed by Goats | 9 a |
| Goats Followed by Cattle | 11 a |
| SEM | 2 |

† Treatment means not followed by the same letter are different ($P \leq 0.05$)

# CHAPTER 4
# BLACKBERRY REGROWTH AND PERSISTENCE RESPONSES TO CLIPPING STUBBLE HEIGHT AND LEAF REMOVAL

## Overview of Research Problem

Blackberry (*Rubus fruticosas* L.) is a major weed in many parts of the world, as well as one of the more challenging-to-control broadleaf weeds that occur in rhizoma peanut (*Arachis glabrata* Benth.) pastures. It is listed as one of the ten most common weeds in utility rights-of-way in Florida (Webster, 2011), is a Weed of National Significance in Australia (Thorp and Lynch, 2000), and is viewed as a substantial weed in pasturelands in Europe (Popay and Field, 1996). It is prevalent in marginal lands and pastures which receive lax management. Its growth potential in more intentionally managed areas is reported to be limited by grazing, herbicides, and land preparation practices such as plowing (Amor, 1974a).

Blackberry forms dense thickets of thorny shrubs from crowns under the soil surface that are the plant's main energy storage and regrowth centers. These woody, perennial storage organs can be > 20 cm in diameter (Ainsworth and Mahr, 2005) and are one of the reasons why blackberry is so difficult to control. They cause plants to be resilient to fire, cutting, and grazing, and allow them to readily sprout new stems after these events (Ainsworth and Mahr, 2005). Each new stem (or cane) typically lives for 2 yr (Ainsworth and Mahr, 2005), therefore there is substantial turnover in canes from crowns in blackberry plants.

Blackberry is capable of regrowth and dispersion via lateral rhizomes which can sprout new plants, although this method is not as prevalent in well-established stands (Amor, 1974a). This process of vegetative spread is significantly more pronounced in areas adjacent to thickets or in disrupted stands such as those treated with herbicides

(Amor, 1974b). Distribution and reproduction by seed in blackberry is viewed as not significant due to poor germination (Amor, 1974a), which has been estimated to be 10% (Popay and Field, 1996).

Regrowth characteristics of blackberry have been described in response to fire (Ainsworth and Mahr, 2005), herbicides (Amor, 1974b), and cutting of stems (Amor, 1974b). Amor (1974b) found that mechanical cutting of stems at ground level or at a 15-cm stubble resulted in increased daughter plant formation from lateral rhizomes, as did application of picloram (4-Amino-3,5,6-trichloro-2-pyridinecarboxylic acid) herbicide.

Browsing or grazing of blackberry has been viewed as a potential control option (Amor, 1974a, Ainsworth and Mahr, 2005, Ann Blount, personal communication). In a pilot study, Dellow et al. (1987) noted partial control of blackberry grazed by goats (*Capra hircus*). Amor (1974a) reported a decrease in daughter plant formation from lateral rhizomes when grazed by horses (*Equus caballus*) or cattle (*Bos* sp.), and Ainsworth and Mahr (2005) reported a preference for blackberry browse by sambar deer (*Cervus unicolor* Kerr.). There remain gaps in the literature concerning necessary frequency of grazing and stocking rate for blackberry control as well as which animal species exhibit preference for the plant. In addition, no studies were found that addressed mixed grazing by cattle and goats for control of blackberry.

In a companion grazing study conducted in a blackberry-infested, mixed rhizoma peanut-grass pasture, cattle avoided blackberry almost totally, while approximately 50 to 60% of bites taken by goats were of blackberry (Chapter 3). Because there was opportunity in the grazing study for goats to select legume, grass, and blackberry plant fractions, there was relatively little direct control over the height to which blackberry was grazed or the extent to which blackberry leaf was removed. Thus, the current study was conducted to assess the effects of controlled clipping treatments on blackberry plant responses. The hypothesis was that level of clipping height and extent of leaf removal affect blackberry regrowth, harvested biomass, and persistence. The specific objectives were to compare blackberry regrowth, biomass harvested, and persistence responses to clipping stubble height and extent of leaf removal when blackberry was growing in rhizoma peanut-grass swards. Understanding the effects of these treatments will aid in identifying defoliation strategies to control blackberry and in explaining blackberry responses observed in Chapter 3.

## Materials and Methods

### Experimental Site

The experiment was conducted at the University of Florida Forage Evaluation Field Laboratory at the Beef Research Unit, northeast of Gainesville, FL (29° 38’ N, 82° 22’ W). The pasture was an established ‘Florigraze’ rhizoma peanut-bahiagrass (*Paspalum notatum* Flügge) sward with significant blackberry infestation and some presence of maidencane (*Panicum hemitomon* Schult.) and common bermudagrass [*Cynodon dactylon* (L.) Pers.]. The perennial peanut pasture was planted in 1983 and used for a variety of grazing experiments since then. Management was generally extensive, with fertilizer applied only during approximately 10 yr when the pasture was part of an ongoing research study.

Soils at the site are in the Smyrna fine sand series (sandy, siliceous, hyperthermic, Aeric Alaquods). The Smyrna series consists of very deep, poorly to very poorly drained soils formed in thick deposits of sandy marine materials. Permeability is rapid in the A, E, and C horizons and moderate or moderately rapid in the Bh horizons.

Slopes range from 0 to 2 percent. These soils are sufficiently well drained for rhizoma peanut as indicated by the long stand life at this location. Soil test results prior to initiation of the experiment showed pH to be 6.9 and Mehlich I extractable P, K, Mg, and Ca to be 13, 35, 168, and 880 ppm, respectively.

**Treatments and Design**

The experiment included eight defoliation treatments arranged in a randomized complete block design. Each treatment was replicated four times for a total of 32, 1-m x 1-m experimental units. The experiment was conducted in an area adjacent to the experiment reported in Chapter 3 and was mowed to a 4-cm stubble during the winter prior to the initiation of the study. Treatments were imposed in 2011 and 2012, with the first clipping in early June and last clipping each year in September, providing four defoliation events each year. The regrowth interval between defoliation events was 35 d in all cases.

Six treatments were the factorial combinations of three levels of clipping stubble height (8, 16, and 24 cm) with two levels of leaf removal below the clipping stubble height (all leaf removed or all left intact). Clipping was carried out using a battery-powered shear. Leaf removal was done manually. There were also two non-clipped control treatments. For one of them, all leaves on the blackberry plants were removed manually every 35 d, but the plants were not clipped. For the second control, there was no clipping or leaf removal. The combined peanut-grass component of all treatments was clipped to a height of 16 cm at each defoliation event based on recommended post-graze stubble for rhizoma peanut under rotational stocking (Ortega et al., 1992).

The clipped treatments with no leaf removal were chosen to represent a range of defoliation intensities that might be achieved by grazing. The clipped treatments with leaf removal represented the same defoliation intensities, but they were designed with the assumption that goats may remove leaf deeper in the canopy than the height to which the stem is grazed. The non-clipped control with leaf removal represented a scenario where goats were highly selective and ate only leaf without reducing plant height, and the non-clipped control with no leaf removal provided an entirely non-defoliated comparison with the other treatments.

**Measurements**

Responses measured included regrowth height of blackberry, blackberry biomass harvested (all biomass above target stubble), leaf biomass harvested (leaf biomass below target stubble), blackberry percent cover, blackberry stem survival, and nutritive value of blackberry plant-part components. Regrowth height and biomass harvested were measured at every clipping event, while blackberry cover and change in stem number per plot were determined at the beginning and end of the experiment each year. Nutritive value was measured only at the last defoliation event of each growing season.

Regrowth height was determined immediately prior to each defoliation event in both years by taking height measurements of five representative blackberry plants per plot. Data from the first defoliation event each year were not analyzed because at that time in 2011 the treatments had not yet been imposed, and in 2012 this height represented total growth during the spring period as opposed to height following a recent defoliation event. Blackberry biomass harvested was the plant material removed above the target stubble. Leaf below stubble was not included in this measure in order that a standard basis be achieved for comparison of regrowth for treatments with and without leaf removal below stubble height. These data are also presented for second through fourth harvests of each year for the reasons already described for regrowth height. Leaves below the target stubble were collected separately, and leaf biomass harvested was compared for the four treatments in which leaf removal occurred. All biomass samples were dried at 60°C to constant weight and weighed to determine dry biomass harvested.

Cover was estimated visually by the same two observers at the beginning and end of each growing season. Prior to each cover estimate, the observers spent time estimating blackberry cover in surrounding non-treatment areas to arrive at similar rating criteria. To determine survival, the total number of blackberry stems was counted in each plot prior to the first and last grazing of each year, and changes in stem density were determined by difference. Nutritive value was assessed by determining crude protein (CP) and in vitro digestible organic matter (IVDOM) concentrations for samples taken at the fourth defoliation event each year. Samples were dried at 60°C to a constant weight, separated into leaf and stem, and weighed. Leaf, stem, and leaf plus stem, the latter combined according to their ratio by weight from that plot for the portion of the plant above stubble height, were ground to pass through a 1-mm screen with a Wiley mill. Total N was determined by digesting samples using a modification of the aluminum block digestion procedure of Gallaher et al. (1975). Nitrogen in the digestate was determined by semiautomated colorimetry (Hambleton, 1977). Crude protein was calculated as the product of 6.25 and N concentration. In vitro organic matter digestion was measured using a modification of the two-stage technique (Moore and Mott, 1974).

**Statistical Analysis**

The data were analyzed using PROC MIXED of SAS (SAS, 1996). The *P* values for different sources of variation for response variables reported in Chapter 4 are shown in Table 4-1. Stubble height, leaf removal treatment, and year were considered fixed effects and block random. Year was considered fixed because of the potential for cumulative effects of Year 1 treatment on Year 2 responses. Analyses were conducted using two approaches. The first included the six factorial treatments only and evaluated the effects of stubble height (8, 16, and 24 cm), leaf removal below stubble height (yes or no), year, and their interactions. The effects of stubble height were evaluated using polynomial contrasts to test linear and quadratic effects, and the effect of leaf removal was assessed using the F test. The second analysis included treatment (all eight treatments), year, and their interaction and allowed comparison of the six factorial combinations of stubble height and leaf removal with the two controls (no defoliation, and leaf removal only). These comparisons were made using pre-planned contrasts and were considered different if $P \leq 0.05$. Clipping date was a repeated measure in analyses of regrowth height and biomass harvested responses, i.e., those measured at each defoliation event.

## Results and Discussion

### Blackberry Regrowth Height

There was a stubble height × leaf removal × year interaction (Table 4-1) for blackberry regrowth height ($P < 0.001$). Regrowth height was also affected by stubble height ($P < 0.001$), leaf removal ($P < 0.001$), year ($P < 0.001$), and the interaction of year × leaf removal ($P = 0.001$).

In both years, there was a decrease in regrowth height as stubble height increased (Table 4-2). This was attributed to shorter stubble heights removing lateral branches of the blackberry, thus concentrating regrowth in the primary vertical stem. Greater regrowth resulting from shorter clipping heights agrees with results from

Ainsworth and Mahr (1995). They reported that the blackberry underground crown and rhizome system quickly produced substantial regrowth after aboveground biomass was cleared to ground level by fire. Across stubble heights and leaf removal regimes, regrowth height was greater in Year 2 than Year 1 ($P < 0.001$), averaging 15 and 9 cm, respectively. This was most likely associated with 592 mm more rain from May through October 2012 vs. 2011, and 350 mm more rain in 2012 than the 30-yr average for May through October (Table 3-8).

In Year 1 and Year 2, regrowth height was affected by leaf removal only at the 24-cm stubble height ($P = 0.011$ and $P = 0.002$, respectively) although there was a strong trend ($P = 0.053$) for a leaf removal effect at the 16-cm stubble height in Year 1 (Table 4-2). In both years, the pronounced negative effect of leaf removal beneath target stubble on subsequent regrowth height for the 24-cm treatment was likely due to quantity of leaf harvested (Table 4-3). Leaf harvested for the 24-cm treatment was 20 to 21 g $m^{-2}$, while for the 8-cm stubble height treatment it was only 7 to 9 g $m^{-2}$. Thus there was relatively little difference in residual leaf biomass between leaf removed and leaf-intact treatments when stubble was 8 cm, but when stubble was 24 cm the difference was nearly three times as great. For non-clipped treatments, leaf removal resulted in shorter regrowth height in both Year 1 and 2 ($P = 0.033$ and $P = 0.001$, respectively; Table 4-2). Within a level of leaf removal, regrowth height of all clipped treatments (i.e., 8-, 16-, and 24-cm stubble heights) was greater than regrowth of the non-clipped control treatment (Table 4-2).

**Blackberry Biomass Harvested**

Blackberry leaf biomass below the stubble height was affected by stubble height only ($P < 0.001$; Table 4-1).. Leaf biomass increased with increasing stubble height, with the greatest increase occurring between 16- and 24-cm stubble height treatments (Table 4-3). It is reasonable that there is greater leaf biomass below taller stubble heights. As noted earlier, this greater leaf biomass for taller stubble appears to have played a significant role in the increase in height of 24-cm stubble treatments during the regrowth period. In the section that follows, a similar effect of residual leaf biomass will be noted for blackberry biomass harvested above the stubble height.

Biomass harvested was affected by stubble height, leaf removal, and year ($P$ = 0.019, $P < 0.001$, and $P = 0.002$, respectively). There was also an interaction between stubble height and leaf removal ($P < 0.001$; Table 4-1). There was greater biomass harvested in Year 2 vs. Year 1 (17 vs. 12 g $m^{-2}$; $P = 0.002$), most likely associated with greater May through October rainfall in Year 2 than Year 1 (Table 3-8).

Stubble height × leaf removal interaction occurred because there was a linear decrease in blackberry harvested as stubble height increased when leaf below stubble was removed, whereas the opposite was the case for no leaf removal below stubble height (Table 4-4). The interaction suggests an important role of residual leaf in subsequent biomass accumulation and a lesser role of residual stem. This is supported by the data showing a small range in the response (8.5-12.8 g $m^{-2}$) and no benefit of taller stubble heights on biomass accumulation when leaf below stubble was removed (Table 4-4). Although residual stem mass below the target stubble height was not measured, it can reasonably be presumed that greater stem biomass would be associated with increasing stubble height. Despite this, taller stubble did not result in greater subsequent biomass accumulation when accompanied by leaf removal below stubble. In contrast, when leaf below stubble remained intact there was a much larger range in the biomass harvested response (12.1-26.0 g $m^{-2}$), and it increased with increasing stubble height. This increase in biomass harvested above stubble height was associated with greater leaf biomass below stubble for the taller stubble height treatment (Table 4-3).

It is worth noting that when leaf below stubble remained intact the response of blackberry regrowth height (Table 4-2) and blackberry biomass harvested above stubble height (Table 4-4) were inversely related. As noted earlier, close defoliation tended to remove branches and result in plants with more dominant main stems that grew taller rapidly, and there was no role of residual leaf biomass in the regrowth height response except for the 24-cm stubble height treatment (Table 4-2). In contrast, differences in residual leaf biomass among stubble height treatments (Table 4-3) appeared to play a major role in subsequent biomass harvested when leaf below stubble was left intact (Table 4-4). From a general perspective, Ainsworth and Mahr (2005) found that blackberry has the ability to quickly restore above-ground biomass following damage to standing plant parts, and our data support this finding.

**Blackberry Cover Dynamics**

Change in blackberry cover within plots was affected by stubble height ($P <$ 0.001), leaf removal ($P = 0.007$), and year × leaf removal interaction ($P = 0.040$; Table 4-5). There was a strong trend ($P = 0.056$) toward a stubble height × leaf removal interaction (Table 4-6).

Reduction in cover was more pronounced in 2011 for treatments in which leaves were removed, but in the second year there was no effect of leaf removal (Table 4-5). This is probably due to the benefit of greater rainfall in Year 2 (Table 3-8). There were linear increases in cover as clipping height increased for both leaf removal treatments

(Table 4-6), although the range in response was much greater for plots where leaf below target stubble remained intact. Additionally, the only difference between leaf removal treatments occurred for the 24-cm stubble height, where cover was much greater when no leaf removal below stubble height occurred. This again illustrates the importance of residual leaf in affecting blackberry response. It should be noted, however, that unlike the response for biomass harvested above stubble, blackberry cover was greatly affected by stubble height even when leaf was removed.

These data provide rationale to explain why grazing alone may not be sufficient to eradicate blackberry. Grazing animals select primarily leaf and do not reduce blackberry height greatly (Chapter 3). The 24-cm stubble height with leaf removal treatment represents this general approach to defoliation, and there was no effect of this treatment on cover. When no leaf below stubble was removed and the plants were not clipped there was a large increase (31%) in blackberry cover, indicating the potential of blackberry to negatively impact rhizoma peanut-grass pastures if not regularly defoliated.

These data suggest that leaf removal alone is not sufficient to decrease cover of established blackberry. This is in agreement with observations by Popay and Field (1996), who noted the resiliency of blackberry stands and that significant control of blackberry by grazing can be realized if infested areas are also mechanically cleared (equivalent to the low stubble height plus leaf removed treatment in the current experiment). Amor and Harris (1981) noted the shortcomings of mechanical control alone of blackberry in a study in which blackberry was mowed twice a year, sprayed once a year, or sprayed once and then mowed once a year over 3 yr. Nine months after the last treatment, mowing resulted in lower blackberry cover than did untreated (44 vs. 91%, respectively), yet the combination of spraying and mowing reduced blackberry cover to 5%.

**Blackberry Survival**

Change in number of blackberry stems per experimental unit was affected by stubble height ($P < 0.001$), year ($P < 0.001$), leaf removal ($P = 0.026$), stubble height × leaf removal interaction ($P = 0.016$), and year × leaf removal ($P < 0.001$) interaction (Table 4-7). The year × leaf removal interaction occurred because in 2011 there was a leaf removal effect, but there was no effect in 2012. In 2011, blackberry density decreased by 10 stems $m^{-2}$ when leaves below stubble were removed and by only 4 stems $m^{-2}$ when leaves remained intact (Table 4-7). These data are similar to those of Amor and Harris (1981), who reported a decrease of 3 blackberry stems $m^{-2}$ after 2 yr in plots that were mowed twice a year; more pronounced decreases were not observed until the third year.

Blackberry stem density decreased with decreasing stubble height in both years (Table 4-8). There was stubble height × leaf removal interaction, however, because there was effect of leaf removal only for the 16- ($P = 0.004$) and 24-cm ($P = 0.057$) stubble height treatments. For both, there was a greater decrease in stem density when leaf was removed compared to when leaf below stubble remained intact (Table 4-8). Greater impact of leaf removal on blackberry stem density with taller plants follows a pattern similar to that observed for blackberry biomass harvested and blackberry cover. Stem density in control plots that were not clipped was not affected by leaf removal ($P = 0.29$). When leaf below stubble height was removed, plots clipped to 8- or 16-cm stubble experienced greater blackberry stem loss than control plots that were not clipped. In contrast, when leaf below stubble remained intact, only the 8-cm stubble height treatment lost more stems than the non-clipped control treatment (Table 4-8).

### Nutritive Value

There was no effect of stubble height on CP or IVDOM concentration of leaf, stem, or total blackberry biomass harvested above the target stubble. Total blackberry harvested CP and IVDOM averaged 136 and 409 g $kg^{-1}$, respectively. Leaf CP and IVDOM averaged 164 and 417 g $kg^{-1}$, respectively, and stem CP and IVDOM averaged 76 and 351 g $kg^{-1}$, respectively. Leaf proportion in biomass harvested above the target stubble averaged 67% and was not affected by treatment.

## Implications of the Research

For blackberry plants in mixed rhizoma peanut-grass pastures, the objective of this experiment was to quantify regrowth height, biomass harvested, persistence, and nutritive value responses to clipping stubble height and to leaf removal below the stubble height. Plots were defoliated every 35 d to stubble heights of 8, 16, and 24 cm, and either all or none of the leaves below the target stubble were removed manually. Understanding the effects of these treatments should aid in identifying defoliation strategies to control blackberry and in explaining blackberry responses observed in Chapter 3.

Blackberry regrowth height (difference between after clipping stubble height and the following pre-clipping plant height) response was somewhat unexpected in that for both years and both leaf removal treatments, regrowth height increased as stubble height decreased. This was attributed to removal of blackberry lateral branches by short stubble treatments, thus concentrating regrowth in the primary vertical stem. Only for the 24-cm stubble height did leaf removal result in lesser regrowth height than allowing leaves to remain intact, likely because there was 1.5 to almost three times the residual leaf mass for the 24- vs. the 8- and 16-cm height treatments. Subsequent biomass harvested (above the stubble height) was affected relatively little by stubble height when leaves below stubble height were removed (range of 8.5 to 12.8 g $m^{-2}$), but when leaves remained intact, biomass harvested increased from 12.1 to 26.0 g $m^{-2}$ as stubble height increased from 8 to 24 cm. This response suggests that the amount of stem remaining after defoliation does not have as large an impact on subsequent regrowth as the amount of residual leaf.

There were large increases in blackberry cover as stubble height increased from 8 to 24 cm for both leaf removed and leaf intact treatments, although the range in response was much greater for plots where leaves remained intact. The only observed difference in cover between leaf removal treatments within a level of stubble height occurred for the 24-cm level where cover was much greater when leaf remained intact. This again illustrates the importance of residual leaf in affecting subsequent blackberry response. These data also provide explanation for why grazing alone may not reduce blackberry cover greatly. The 24-cm clipping height plus leaf removal treatment can be considered to represent the goat alone or a mixed grazing treatment in Chapter 3, i.e., a situation in which goats select much of the leaf but do not reduce blackberry height greatly. This approach did not affect blackberry cover negatively, but it did avoid the increase in cover that occurred when leaves remained intact for the 24-cm height or the no clipping treatment. These latter treatments represent more nearly the impact of cattle alone (Chapter 3), and in the current study the result was a large increase (17-31%) in blackberry cover. Blackberry stem density decreased to a greater extent with short vs.

tall stubble height in both years, and there was a greater decrease in stem density when leaf was removed compared to when leaf remained intact.

The results illustrate ability of blackberry to withstand cutting over a range of clipping stubble heights and leaf removal treatments, at least for a duration of 2 yr. Generally, the 8-cm clipping height resulted in the best control of blackberry, and leaf removal aided in blackberry control of the taller stubble height treatments. Because animals grazing blackberry may reduce its height only slightly, near complete removal of leaf by grazing animals would be required to impact blackberry stands. These results suggest that combining grazing for leaf removal with periodic clipping to reduce overall plant mass may well be a useful control strategy for blackberry. These data clearly demonstrate the potential of blackberry to negatively impact rhizoma peanut-grass pastures if not aggressively defoliated. More research is warranted on longer-term effects of practices such as clipping stubble height and leaf removal by grazing to better understand their potential for affecting blackberry persistence.

Table 4-1. *P* values for different sources of variation for response variables reported in Chapter 4.

| Source of Variation | Regrowth height | Biomass harvested | Leaf biomass† | Cover | Plant density |
|---|---|---|---|---|---|
| Stubble height (SH) | < 0.001 | 0.019 | < 0.001 | < 0.001 | < 0.001 |
| Leaf removal (LR) | < 0.001 | < 0.001 | ---- | 0.007 | 0.026 |
| Year (Y) | < 0.001 | 0.002 | 0.902 | 0.629 | < 0.001 |
| SH × Y | 0.377 | 0.851 | 0.872 | 0.330 | 0.223 |
| SH × LR | 0.918 | < 0.001 | ---- | 0.056 | 0.016 |
| Y × LR | 0.001 | 0.664 | ---- | 0.040 | < 0.001 |
| SH × Y × LR | < 0.001 | 0.551 | ---- | 0.486 | 0.946 |

†Measured only for the four plots where leaf was manually removed (not for the leaf intact plots), so leaf removal is not included in the model.

Table 4-2. Increase in height of blackberry plants from time of defoliation to 35 d after defoliation as affected by the interaction of stubble height at cutting and leaf removal below the stubble height. Increase in height was measured for three regrowth periods each year, so data are means across three periods and four replicates (n = 12).

| | 2011 | | | 2012 | | |
|---|---|---|---|---|---|---|
| Clipping height | Leaf removed | Leaf intact | *P* value† | Leaf removed | Leaf intact | *P* value† |
| cm | --------cm-------- | | | -----------cm---------- | | |
| 8 | 16.6 | 14.3 | 0.112 | 17.4 | 16.9 | 0.696 |
| 16 | 9.2 | 12.1 | 0.053 | 12.9 | 13.2 | 0.845 |
| 24 | 6.5 | 10.3 | 0.011 | 7.4 | 12.0 | 0.002 |
| PC‡ | L**, Q** | Q* | | L*, Q** | L*, Q* | |
| Non-clipped (NC) | 0.5 | 3.7 | 0.033 | 1.4 | 6.6 | 0.001 |
| *P* values§ | | | | | | |
| 8 vs. NC | < 0.001 | < 0.001 | | < 0.001 | < 0.001 | |
| 16 vs. NC | < 0.001 | < 0.001 | | < 0.001 | < 0.001 | |
| 24 vs. NC | < 0.001 | < 0.001 | | < 0.001 | < 0.001 | |
| SEM | | | | 1.4 | | |

† *P* value for the comparison of leaf removal treatment within a year and stubble height treatment.
‡ Polynomial contrast for effect of stubble height within a year and leaf removal treatment. L = linear; Q = quadratic; * and ** indicate $P \leq 0.05$ and 0.01, respectively.
§ *P* value for pre-planned contrast comparing level of stubble height treatment with the non-clipped control within a year and level of leaf removal.

Table 4-3. Blackberry leaf biomass harvested below clipping height per 35-d regrowth period as affected by stubble height. Data are on a dry-weight basis and are averaged across four replications and three harvests per year (Harvests 2-4; i.e., those harvests that occurred after initial treatment imposition each year; n = 12).

| Stubble height | Leaf biomass |
|---|---|
| cm | g $m^{-2}$ |
| 8 | 8.2 |
| 16 | 12.9 |
| 24 | 20.6 |
| PC[†] | L**, Q** |
| Not clipped (NC) | 37.9 |
| *P* values[‡] | |
| 8 vs. NC | < 0.001 |
| 16 vs. NC | < 0.001 |
| 24 vs. NC | < 0.001 |
| SEM | 3.37 |

[†] Polynomial contrast for effect of stubble height. L = linear, Q = quadratic; * and ** indicate $P \leq 0.05$ and 0.01, respectively.
[‡] *P* value for pre-planned contrast comparing level of stubble height with the non-clipped control.

Table 4-4. Blackberry plant biomass harvested above clipping height per 35-d regrowth period as affected by stubble height and leaf removal. Data are on a dry-weight basis and are averaged across four replications, two years, and three sampling times per year (includes only those periods after initial treatment imposition each year; n = 24).

| Height | Leaf removed | Leaf intact | *P* value[†] |
|---|---|---|---|
| cm | ---------------g $m^{-2}$--------------- | | |
| 8 | 12.8 | 12.1 | 0.785 |
| 16 | 11.1 | 14.3 | 0.216 |
| 24 | 8.5 | 26.0 | < 0.001 |
| PC[‡] | L** | L** | |
| SEM | 2.58 | | |

[†] *P* value for the comparison of leaf removal treatment within a stubble height treatment.
[‡] Polynomial contrast for effect of stubble height within a leaf removal treatment. L = linear; ** indicates $P \leq 0.01$.

Table 4-5. Change in percent cover of blackberry plants as affected by the interaction of year and leaf removal. Differences were calculated as the percent cover prior to last clipping of a given year minus the percent cover prior to the first clipping of that year (i.e., a negative number equals a decrease in blackberry cover over the year). Data are means across four replicates and three stubble heights (n = 12).

| Year | Leaf removed | Leaf intact | *P* value[†] |
|---|---|---|---|
| | ----------------%---------------- | | |
| 2011 | -11 | 3 | 0.001 |
| 2012 | -4 | -2 | 0.600 |
| SEM | 3.93 | | |

[†] *P* value for the comparison of leaf removal treatment within a year.

Table 4-6. Change in percent cover of blackberry plants as affected by the interaction of stubble height and leaf removal. Differences were calculated as the percent cover prior to last clipping of a given year minus the percent cover prior to the first clipping of that year (i.e., a negative number equals a decrease in blackberry cover). Data are means across four replications and 2 yr (n = 8).

| Height | Leaf removed | Leaf intact | *P* value† |
|---|---|---|---|
| cm | ----------------%----------------- | | |
| 8 | -18 | -12 | 0.251 |
| 16 | -5 | -4 | 0.847 |
| 24 | 0 | 17 | < 0.001 |
| PC‡ | L** | L** | |
| Not clipped (NC) | 6 | 31 | < 0.001 |
| *P* values§ | | | |
| 8 vs. NC | < 0.001 | < 0.001 | |
| 16 vs. NC | 0.022 | < 0.001 | |
| 24 vs. NC | 0.218 | 0.006 | |
| SEM | 4.81 | | |

† *P* value for the comparison of leaf removal treatment within a stubble height treatment.
‡ Polynomial contrast for effect of stubble height within a leaf removal treatment. L = linear; ** indicates $P \leq 0.01$.
§ *P* value for pre-planned contrast comparing level of stubble height with the non-clipped control within a level of leaf removal.

Table 4-7. Change in number of blackberry stems $m^{-2}$ from June to September as affected by year by leaf removal interaction. Data are means across three stubble heights and four replicates (n = 12).

| Year | Leaf removed | Leaf intact | *P* value† |
|---|---|---|---|
| | -----------stems $m^{-2}$------------ | | |
| 2011 | -10 | -4 | < 0.001 |
| 2012 | 0 | -2 | 0.089 |
| SEM | 1.1 | | |

† *P* value for the comparison of leaf removal treatment within a year.

Table 4-8. Change in number of blackberry stems $m^{-2}$ from June to September as affected by clipping height and leaf removal. Data are means across 2 yr and four replicates (n = 8).

| Height | Leaf removed | Leaf intact | *P* value† |
|---|---|---|---|
| cm | ----------stems $m^{-2}$----------- | | |
| 8 | -7 | -8 | 0.291 |
| 16 | -6 | -1 | 0.004 |
| 24 | -3 | 0 | 0.057 |
| PC‡ | L* | L**, Q* | |
| Not Clipped | -1 | 0 | 0.291 |
| *P* values§ | | | |
| 8 vs. NC | < 0.001 | < 0.001 | |
| 16 vs. NC | 0.003 | 0.237 | |
| 24 vs. NC | 0.237 | 0.647 | |
| SEM | 1.19 | | |

† *P* value for the comparison of leaf removal treatment within a stubble height.
‡ Polynomial contrast for effect of stubble height within a leaf removal treatment. L = linear, Q = quadratic; * and ** indicate $P \leq 0.05$ and 0.01, respectively.
§ *P* value for pre-planned contrast comparing level of stubble height with the non-clipped control within a level of leaf removal.

# CHAPTER 5
# SUMMARY AND CONCLUSIONS

Integration of rhizoma peanut (*Arachis glabrata* Benth.) into C4 grass pastures in Florida has the potential to lessen dependency on N fertilizer while maintaining a high nutritive-value forage, which could be beneficial to low-input systems such as those used for beef production. An issue which arises in these established pastures is the encroachment of broadleaf weeds such as blackberry (*Rubus fruticosas* L.). Of the available means of control, higher planting densities of rhizoma peanut are expensive due to the high cost of planting material, and chemical treatments may not be desirable for some producers. Biological control of blackberry using grazing animals has not been evaluated in this context and was therefore the main theme of the two experiments described in this thesis.

The objectives of the first study (Chapter 3) were to 1) evaluate the effectiveness of goats as a means of biological control for blackberry in rhizoma peanut-grass pastures, 2) quantify diet selection in goats and cattle in the context of rhizoma peanut-grass pastures infested with blackberry, 3) compare different strategies of mixed-species grazing for the control of blackberry, and 4) compare different stocking rates of mixed-species grazing for blackberry control. The second study (Chapter 4) was conducted to 1) compare blackberry regrowth, biomass harvested, and persistence responses to clipping stubble height and extent of leaf removal when blackberry was growing in rhizoma peanut-grass swards, 2) aid in identifying defoliation strategies for blackberry control, and 3) assist in explaining blackberry responses to grazing treatments evaluated in Chapter 3.

The objectives were accomplished in experiments conducted in 2011 and 2012 at the Beef Research Unit in Gainesville, FL. Experiment 1 (Chapter 3) was designed to evaluate individual plant species and sward responses to grazing by goats or cattle and different methods of mixed-species grazing. Experiment 2 (Chapter 4) was designed to observe regrowth and persistence of blackberry under combinations of different clipping heights (8, 16, and 24 cm) and leaf removal treatments. Experimental sites were adjacent to each other and selected for homogeneity of blackberry infestation on an established mixed stand of rhizoma peanut and bahiagrass.

## Experiment 1 - Mixed Grazing

### Animal Diet Selection

In Experiment 1, goats had a much greater proportion of bites that were blackberry (51-66%) than did the cattle (0.1-2.4% of bites), due to general avoidance of blackberry by cattle. Goats exhibited a range of selection for blackberry that was affected by treatment, and greatest proportion of blackberry bites by goats occurred when goats followed cattle onto the grazed area (66%) compared with when cattle followed goats (51%). Goat bite percentage that was weeds was greater than for cattle (5-11% vs. 1-2%, respectively). Proportion of cattle bites that were forage (grass or legume) was not affected by treatment, whereas there was a strong trend for treatment to affect forage selection by goats ($P$ = 0.064). Greatest selection for forage by goats (40%) occurred when goats had access to the grazed area first and were then followed by cattle. The alternative sequential grazing treatment, where cattle had access first and were followed by goats, resulted in the lowest amount of forage selection by goats (27%).

### Sward Responses to Grazing

During grazing events, the cattle-alone treatment resulted in an increase in blackberry plant height, whereas all treatments which included goats resulted in about a 6 cm reduction in blackberry height. Reduction in weed height was also greater in treatments which included goats than the cattle alone treatment. Reduction in height of the forage component was not affected by grazing treatment.

Removal of blackberry leaf from marked plants was greatest for concurrent mixed grazing at a high stocking rate and for goats followed by cattle (51 and 50%, respectively), and these results were greater than concurrent grazing at the recommended stocking rate and cattle grazing alone (36 and 1%, respectively). Further, treatments which included goats resulted in a greater decrease of blackberry stem density than did the cattle alone treatment.

No differences were found among treatments for change in pregraze forage component (i.e., grass plus legume) mass or percent of forage in total biomass over the course of a grazing season. Cattle grazing alone resulted in a greater increase in pregraze blackberry biomass over the season compared with treatments with goats. Treatments with goats either reduced blackberry biomass or exhibited smaller increases than cattle grazing alone. Additionally, there was a greater increase of pregraze percent blackberry within the sward for the cattle alone treatment than for treatments which included goats.

## Experiment 2 - Blackberry Responses to Targeted Clipping and Leaf Removal

As clipping stubble height decreased, 35-d regrowth height of blackberry plants increased. This appeared to be due to removal of branches and lateral stems at the lower stubble heights with subsequent regrowth being concentrated in the main vertical stem. Leaf removal did not affect regrowth height at the 8- and 16-cm stubble heights, but at the 24-cm stubble height there was significantly less increase in regrowth height when leaves were removed.

The amount of leaf biomass removed below the target stubble increased with increasing stubble height, with the greatest increase occurring between 16- and 24-cm stubble height treatments. When leaf below stubble height remained intact, this greater leaf biomass for taller stubble appears to have played a significant role in the increase in height of 24-cm stubble treatments during the regrowth period and in increases in subsequent blackberry biomass harvested.

There was a linear decrease (12.8 to 8.5 g $m^{-2}$) in subsequent blackberry harvested as stubble height increased from 8 to 24 cm if leaf below stubble also was removed. In contrast, when leaf below stubble remained intact there was a much larger range in the biomass harvested response (12.1-26.0 g $m^{-2}$), and it increased with increasing stubble height. This increase in biomass harvested above stubble height was associated with greater leaf biomass below stubble for the taller stubble height treatment. The interaction suggests an important role of residual leaf in subsequent biomass accumulation and a lesser role of residual stem.

Cover of blackberry within experimental units increased as stubble height increased, while leaf removal treatment was significant only at the 24-cm stubble height. Treatments which were clipped at 24-cm stubble and had leaves removed resulted in zero increase in blackberry cover, whereas treatments that were clipped at 24 cm and not defoliated increased cover by 17%. Greatest decline in blackberry cover (-18%) was associated with a stubble height of 8 cm and removal of all leaves below target stubble.

Blackberry stem density decreased as stubble height decreased, and this decrease was most pronounced when leaves below stubble were removed.

## Implications of Research

Our results indicate that goats exhibit a level of selection for blackberry that can be affected by utilizing different methods of mixed grazing, while cattle generally avoid consumption of blackberry. As rhizoma peanut-grass pastures are receiving more attention for use in low-input systems such as those for beef cattle production, mixed grazing methods such as cattle entering the pasture first and reducing opportunity for goats to select forage could be a means to enhance efficiency of using goats as a control agent of blackberry. Higher stocking rates within the range tolerated by rhizoma peanut could be utilized to put greater grazing pressure on blackberry in an effort to reduce infestations or at the very least limit spread of the weed.

No method of single animal species or mixed-species grazing during a 2-yr period achieved complete control or eradication of blackberry when starting with a significant blackberry infestation of rhizoma peanut-grass swards. Results from defoliation treatments imposed in Experiment 2 suggest that a high level of blackberry leaf removal, possibly achieved through grazing by goats, in conjunction with mechanical defoliation to short stubble, will significantly reduce blackberry mass, cover, and stem number in areas that are heavily infested with blackberry. Grazing by goats in absence of mechanical defoliation can prevent increases in blackberry cover, but when defoliation is by cattle alone, further increases in blackberry cover and mass are expected.

## Future Research Needs

That goats readily consume blackberry, which is considered a weed in this context, presents the possibility of using goats as a means of blackberry control. However, based on this study it is apparent that grazing by goats alone, at least over a 2-yr span, is not sufficient to eradicate dense stands of blackberry from swards. More research is warranted to evaluate if less dense stands of blackberry could be controlled by one of the methods presented in this study and to investigate whether biological control such as grazing by goats could be more effective when paired with another control method such as cutting or burning. Further investigation of goat breed, feed management techniques (such as fasting prior to turnout), and acclimation periods on blackberry control would also be warranted. Additionally, due to the perennial underground storage organs of blackberry, methods evaluating blackberry control need to be tested over a longer time span than 2 yr in order to more fully understand their efficacy.

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# BIOGRAPHICAL SKETCH

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