SOUTHERN-PINE SILVOPASTURE SYSTEMS: FORAGE CHARACTERISTICS, SOIL QUALITY, AND LANDSCAPE UTILIZATION BY CATTLE

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Uma Karki

Certificate of Approval:

David I. Bransby
Professor
Agronomy and Soils

Mary S. Goodman, Chair
Associate Professor
Agronomy and Soils

Darrell L. Rankins
Professor
Animal Sciences

Yucheng Feng
Associate Professor
Agronomy and Soils

Nedret Billor
Associate Professor
Mathematics and Statistics

William L. Kingery
Professor
Plant and Soil Sciences
Mississippi State University

George T. Flowers
Dean
Graduate school

SOUTHERN-PINE SILVOPASTURE SYSTEMS: FORAGE CHARACTERISTICS, SOIL QUALITY, AND LANDSCAPE UTILIZATION BY CATTLE

Uma Karki

A Dissertation

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Doctor of Philosophy

Auburn, Alabama
December 19, 2008

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Uma Karki

Signature of Author

Date of Graduation

VITA

Uma Karki was born in Petku, Sindhupalchok, Nepal to Dev Kumari and Hari Man Singh Karki. She completed her School Leaving Certificate in 1983 from Jalapa Secondary School, Kothe, Sindhupalchok. She then joined the Science and Technology Program at Padma Kanya Multiple Campus, Kathmandu and earned the Proficiency Certificate in Science degree in 1987. In 1988, she joined the Institute of Agriculture and Animal Science, Tribhuvan University, Nepal. She received the Bachelor of Science degree in Animal Science in 1992. She joined the Nepal Government as a livestock development officer in 1993 and worked in various districts and central level offices under the Ministry of Agriculture and Cooperatives. In the meantime, she completed the Bachelor of Veterinary Science and Animal Husbandry Program in 1994. In 1999, she obtained an Australian government (AusAID) scholarship to pursue the Master in Agriculture (animal nutrition) at the University of Western Australia. She completed her master's studies in 2001 and resumed her office under the Ministry of Agriculture and Cooperatives in Nepal and worked for four years. In 2005, she received a research assistantship in the Department of Agronomy and Soils at Auburn University, Auburn, Alabama, USA to pursue the Doctor of Philosophy degree in Agronomy with focus on the ecology of southern-pine silvopasture systems.

DISSERTATION ABSTRACT

SOUTHERN-PINE SILVOPASTURE SYSTEMS: FORAGE CHARACTERISTICS, SOIL QUALITY, AND LANDSCAPE UTILIZATION BY CATTLE

Uma Karki

Doctor of Philosophy, December 19, 2008
(M.Sc.Ag., the University of Western Australia, 2002)
(B.V.Sc. & A.H. Tribhuvan University, Nepal, 1994)
(B.Sc.An.Sc., Tribhuvan University, Nepal, 1992)

170 Typed Pages

Directed by Mary S. Goodman

Silvopasture is considered a more attractive land management option for diversified economic returns and environmental quality compared to open-pasture (pasture without trees) monocultures. However, little is known about temporal and spatial dynamics of pasture-plant species composition, forage productivity, and forage and soil quality as pasture-to-silvopasture conversion proceeds or the possible benefits silvopasture systems offer for improved forage and landscape utilization by grazing animals. Major objectives of this research were to determine the influence of: 1) pasture type (silvopasture versus open-pasture) on forage and soil parameters, and the distribution and behavior of cattle; 2) N source (legume-N versus fertilizer-N) on forage and soil parameters; 3) forage species and soil pH level on soil quality parameters.

To quantify pasture-type and N-source effects, studies were conducted in a young (3-7 yr) longleaf pine (*Pinus palustris*)-bahiagrass (*Paspalum notatum*) silvopasture and open bahiagrass pasture at Americus, Georgia. Pasture-plant species composition, biomass, and quality (2003-2007) and soil quality parameters (2005-2007, water stable aggregates, WSA; density of fungal hyphae, DFH; penetration resistance, PR) were evaluated. Legume-N (*Trifolium incarnatum*) and fertilizer-N treatments were applied to both pastures from 2005 to 2007. A second field study was conducted in a 20-yr old loblolly-pine (*Pinus taeda*) silvopasture and open-pasture at Chipley, Florida in 2007 to examine diurnal distribution and behavior of cattle (*Bos taurus*) and relationship to microclimate and forage characteristics. Short-term (12-wk) impacts of forage species and pH level (field-state versus adjusted-pH) on soil quality (WSA and DFH) were studied in coastal plain soil microcosms under protected culture during three experimental periods: fall 2005 and summer and fall 2006.

Compared to open-pasture, young longleaf-pine silvopasture produced similar forage shoot dry matter with lower quality; lower levels of WSA and PR were detected in silvopasture. Legumes improved forage productivity and forage and soil quality compared to fertilizer-N use. Cattle distribution was more even and grazing hours were longer in mature loblolly-pine silvopasture versus open-pasture. WSA levels in microcosm soil under subterranean clover (*Trifolium subterraneum*) were greater than or equal to WSA levels in soils under other cool-season forages; the same relationship was observed for WSA levels in soil under Illinois bundleflower (*Desmanthus illinoensis*) versus other warm-season legumes. WSA and DFH levels were higher in field-state versus adjusted-pH soil.

ACKNOWLEDGEMENTS

The author would like to express sincere gratitude to Dr. Mary S. Goodman for her continuous support, guidance, and precious suggestions while conducting experiments and preparing the dissertation manuscript. The author is thankful to members of the advisory committee for their valuable time serving on the committee and providing suggestions to maintain the program of study up-to-date as well as for their comments on the dissertation draft and overall research work. The author acknowledges Ms. Susan Sladden for her help with sample collection and lab analysis of forage quality samples. The author also would like to thank Dr. Nedret Billor and Dr. Edzard Van Santen for their suggestions on statistical analyses. The author is thankful to the Agronomy and Soils Department family and Auburn University community for the necessary support to complete the Ph.D. studies. Special thanks to family members, respected mother Dev Kumari Karki for her blessings for success, beloved husband Dr. Lila Bahadur Karki for his help in taking care of all family hurdles and providing moral as well as physical support whenever necessary, lovely daughter Alima and son Amod for understanding mother's busy schedule and taking care of themselves, sister Shova Karki for financial and moral support, other sisters, brother and all family members for their moral support. The author also acknowledges the Auburn-Nepali community and local as well as international friends and well wishers whose names remain beyond this page for all their support and cooperation.

Style manuals used: Publication Handbook and Style Manual of the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America for the abstract, introduction, and summary and conclusions; *Agriculture, Ecosystems & Environment* (journal) for chapter I; *Rangeland Ecology & Management* (journal) for chapter II; *Agroforestry Systems* (journal) for chapter III; *Plant and Soil* (journal) for chapter IV.

Computer software used: Microsoft Word v. 2003; Microsoft Excel v. 2003; Microsoft PowerPoint v. 2003; SAS v. 9.1; Endnote v. 9.

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INTRODUCTION

Pasture production was adopted as a major land use pattern in the Southeast USA after the Second World War to mitigate the severe soil erosion that resulted from overproduction of row crops (Bouton, 2007). Currently, there are over 24 million ha of perennial pasture and eight million ha of annual pasture in the Southeast USA (Ball et al., 2007). Bouton (2007) has estimated the economic value of forage production in the Southeast USA for cow-calf production to be approximately US$11.6 billion annually; cow-calf production is the major livestock enterprise dependent on pasture in this region. However, profitability of this livestock enterprise fluctuates, often with little or no profit for around fifty percent of years. According to USDA-ERS (2008), the profitability (gross value of production less cash expenses) of beef cow-calf production for the Southeast remained positive for seven of 14 years from 1982 through 1995; for US this profitability remained positive for 14 of 25 years from 1982 through 2006. This situation has compelled farmers and professionals involved in this sector to look for more economically viable land management options that are environmentally sustainable. Previous studies have suggested that silvopasture systems can be a better option to pasture or forest monoculture (Clason, 1995; Clason, 1999; Sharrow and Fletcher, 1995; Sharrow and Ismail, 2004).

Silvopasture definition and adaptation

Silvopasture is an intensive land management system where forage and trees are grown together and integrated with grazing animals (Clason and Sharrow, 2000). Many studies have highlighted environmental benefits of silvopasture systems (Sharrow and Ismail, 2004; Shrestha and Alavalapati, 2004a; Shrestha and Alavalapati, 2004b; Stainback et al., 2004). Silvopasture systems may enhance land productivity through combination of production of multiple commodities, promotion of biodiversity, and improvement of economic returns with short-term income from the forage-livestock component and long-term income from high-quality saw logs (Sharrow and Fletcher, 1995; Stainback and Alavalapati, 2004; Zinkhan, 1996). Possible short-term economic returns from silvopasture systems have become more attractive to producers in the Southeast since prices for pulpwood obtained from periodic thinning of planted pine stands remains low as many domestic mills in the region have closed or shifted production (Hamilton, 2008).

Another attraction for Southeastern producers is that silvopasture is adapted most successfully in regions with mild, moist climates suited for commercial timber and grazing animal production, such as climates found on the Southern Coastal Plain (Rietveld and Francis, 2000). In fact, much of the Southern Coastal Plain (MLRA 133A), which spans 285,050 km^2 across Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Tennessee and Virginia, supported mixed oak-pine forest vegetation including loblolly (*Pinus taeda* L.), longleaf (*Pinus palustris* Mill.), slash (*Pinus elliottii* Engelm.) and shortleaf pines (USDA-SCS, 1981). Grelen and Duvall (1966) reported that in its virgin state, the longleaf pine-bluestem type in this region was characterized by park-like stands of longleaf pines and an understory dominated by bluestem grasses. Except for hardwood and mixed hardwood-pine forests bordering streams, the longleaf pine-bluestem type reached virtually unbroken from west Florida to east Texas in presettlement time (Earley, 2004). However, at present, only 1.4% of the Atlantic and Gulf Costal Plains support longleaf. Therefore, there is much interest in restoration of longleaf in the Southeast (Kush et al., 2004).

Pasture changes during silvopasture development

Silvopasture can be developed either by thinning down existing tree stands then adding or improving the forage component, or by introducing low densities of trees into existing pasture. When trees are introduced into an existing pasture, changes in the microclimatic conditions, soils, and understory forage crops can be expected. The major changes in the microclimatic conditions associated with tree development occur through creation of shade with interception of solar radiation and lowered wind speed as trees develop to form a physical barrier. Valigura and Messina (1994) reported lower net radiation and photosynthetically active radiation (PAR) loads, lower daytime air temperatures, the same or slightly lower daytime vapor pressures and lower wind speeds within 30 cm of the soil surface in an approximately 50-yr old loblolly pine shelterwood compared to a clear-cut in east Texas. Van Miegroet et al. (2000) found canopy shading inside the tree island of sub-alpine fir (*Abies lasiocarpa*) and Engelman spruce (*Picea engelmannii*) slowed soil moisture loss and decreased the magnitude and fluctuation of soil temperatures relative to the exposed semi-arid meadows during summer in Northern Utah. Rawat et al. (1993) mentioned significant reduction in wind speed at a distance of

3H (H: tree height) on the leeward side of a *Eucalyptus* sp. windbreak compared to that in the open agricultural area in Uttar Pradesh, India. Moreover, they found lower solar radiation in the protected area versus the open area during the morning and evening hours.

Along with microclimatic modifications, the extensive root systems of trees can influence soil quality through changes in soil penetration resistance and nutrient and moisture cycling. Wilson (2002) found that soil bulk density increased systematically (0-10 cm, from the mineral soil surface), while carbon, nitrogen, phosphorus, and pH decreased with increased distance (2-m intervals along a 20-m transect) from a *Eucalyptus* tree species in the Northern Tablelands of New South Wales, Australia. Hulugalle and Ndi (1993) reported increased soil bulk density and water infiltration time as distance from native trees (not specified) increased in southern Cameroon; soil moisture (0-10 cm) was higher at the tree base than at a 2.5-m or 5.0-m distance from the tree base. Van Miegroet et al. (2000) reported higher accumulation of organic material with higher organic carbon (C) and nitrogen (N) and lower C:N ratio in the upper soil (0-5 cm) under the canopies of sub-alpine fir and Engelman spruce tree islands than in the island interior and the meadow. Most of these modifications in soil quality characteristics have been reported to occur near the trees versus away from the trees. However, no information has been documented for soil quality changes as southern-pine trees develop during pasture conversion to silvopasture.

Because trees create microclimatic modifications and bring about changes in soil quality, it is obvious that the production and quality of potential understory forages grown in silvopasture can be modified by the presence of trees. Besides modifying microclimate and soil quality, trees can influence the performance of understory crops through competition for nutrients and moisture. The influence of trees on understory crops may be positive or negative depending on the crop and tree species, tree density, climatic conditions, and soil type (Bird, 1998; Kort, 1988). Studies conducted in silvopasture developed by thinning down mature (20-yr or older) loblolly-pine stands have estimated lower biomass of bermudagrass in silvopasture as compared to open-pasture (pasture without trees), but similar biomass of bahiagrass in both pastures (Clason and Robinson, 2000; Clason, 1999). Jackson and Ash (1998) reported that nitrogen (N) concentration and dry matter digestibility of mixed pasture species tended to be higher under eucalyptus trees than in inter-tree areas in NE Queensland. Dye and Spear (1993) found differences in forage yield and species composition between cleared plots and plots with shrubs. Conversely, Moyo and Campbell (1998) did not find any differences in composition, yield, or quality of moderately grazed grasses grown in areas with widely spaced trees (*Terminalia sericea* and *Acacia karroo*) at the Matopos Research Station, Zimbabwe. However, there is no information available related to changes that occur in forage species composition, yield, and quality as trees develop during conversion of open-pasture to pine-silvopasture in the Southeast USA.

Grazing animal distribution in silvopasture

Grazing livestock are an important component of a pasture or silvopasture systems. Uniform distribution of livestock within a grazing unit is important for optimum forage utilization, pasture persistence, nutrient cycling, and sustainable land use. When heat and humidity are high, cattle seek shelter in the shade to maintain homoiothermy

(Blackshaw and Blackshaw, 1994; Zuo and Miller-Goodman, 2004). If there is only scattered shade in the grazing unit, cattle may develop camp areas where shade is present and jeopardize these areas through overgrazing and repeated trampling which reduce vigorous re-growth of vegetation and may expose the soil surface to erosion. Moreover, over-utilization of a particular area within a pasture causes deterioration of soil quality characteristics (Chen and Cui, 2001; Southorn and Cattle, 2004). Where natural shade is uniformly distributed in a grazing unit, as in silvopasture, it would be reasonable to expect a more even distribution of grazing cattle than in areas having scattered shade. Also cattle are expected to spend more time grazing or resting when they are comfortable (Daly, 1984; Zuo and Miller-Goodman, 2004). However, the ways in which grazing cattle distribute themselves and behave in pine-silvopasture versus open-pasture in the Southeast USA has not been quantified.

Nitrogen source impacts on forage productivity and forage and soil quality

Use of cost-effective and environmentally sound inputs in livestock production systems is advantageous to overall sustainability. One of the major inputs needed in a forage production system is nitrogen (N), and use of commercial N fertilizer to increase forage yield is a common practice. N fertilizer has been reported to enhance or deteriorate soil quality depending on the production system. Latif et al. (1992) found increased size and stability of soil aggregates with an increasing rate of N fertilizer application (0, 70, and 140 kg ha^{-1}) in maize (*Zea mays* L.) monoculture plots in Montreal, Canada, but no influence or a negative influence of N fertilizer was reported for maize plots intercropped with a legume mixture (lucerne, *Sisyrinchium angustifolium*; clover, *Trifolium* spp.; hairy vetch, *Vicia villosa*). Snyman (2002) reported that soil compaction increased with increasing N fertilizer application rate (0, 10, 30, and 50 kg ha^{-1}) to semi-arid pasture land in South Africa. Studies conducted in field crops have revealed that inclusion of legumes in a system can reduce or replace the requirement for commercial N fertilizer application in many non-leguminous crops and in turn, also improve soil quality (Latif et al., 1992; McVay et al., 1989; Rochester et al., 2001). Malhi et al. (2002) reported higher yield and quality of forage from an alfalfa (*Medicago sativa* Leyss)-bromegrass (*Bromus inermis* Leyss) mixture than from a bromegrass monoculture in an open-pasture system in Alberta, Canada. However, the influences of different N sources on forage productivity and forage and soil quality characteristics in young longleaf-pine silvopasture systems on the Southern Coastal Plain have not been studied.

Plant species and pH impacts on soil quality

Soil quality may also be modified depending on the plant species grown. Differences among plant species in terms of root structure, carbon inputs to soil, microclimate, and interaction with soil microorganisms have been shown to cause variations in soil quality (Rillig et al., 2002). Also, variation in water requirements of plant species may be responsible for creation of soil quality differences (Perfect et al., 1990; Rasiah et al., 1992). Several studies have reported variation in aggregate stability (a major soil quality indicator) in soils that supported the growth of various crops and forage species (Raimbault and Vyn, 1991; Reid and Goss, 1981); one study found variations in both aggregate stability and density of fungal hyphae in soil that supported the growth of leguminous versus graminaceous forage species (Haynes and Beare, 1997). Fungi, especially arbuscular mycorrhizal fungi, are one of the most important agents among the soil biota responsible for soil aggregate formation and stabilization (Klironomos, 2000; Rillig et al., 2002).

Both aggregate stability and fungal hyphae may also vary with soil pH levels. Haynes and Naidu (1998) mentioned that lime application (pH change) can influence soil quality through short-term dispersion of soil colloids, flocculating and cementing actions of calcium carbonate ($CaCO_3$) and precipitated hydroxyl-Al polymers, and long-term enhanced crop growth, carbon returns to the soil, and soil biological activity. Results from several studies have indicated increased stability of soil aggregates with lime addition (Baldock et al., 1994; Chan and Heenan, 1999). Another study (Roth and Pavan, 1991) reported increased clay dispersion with lime addition, an indication that lime application may have a negative effect on aggregate stability. Studies of the relationship between lime application and root colonization by mycorrhizal fungi have indicated that development of fungal hyphae may change depending on soil pH, fungal species, or origin of fungi (native to soil or inoculated) (Abbott and Robson, 1985; Sano et al., 2002). Since liming influences crop yield as well as soil quality, it can be expected that the influence of plant species on soil quality will vary with soil pH level. However, soil quality impacts of different forage species adapted to the Southeast USA grown in both field-state and adjusted pH levels have not been quantified.

Rationale and hypotheses

Silvopasture systems may provide a more attractive land management option for economic returns and environmental quality when compared to pasture or forest monocultures in the Southeast USA. However, changes in forage and soil characteristics that occur during the initial stages of pasture conversion to silvopasture have not been characterized. Since microclimatic conditions are probably less stressful in silvopasture than in open-pasture systems, cattle distribution and, therefore, more even landscape utilization and longer grazing hours can be expected in a silvopasture compared to an open-pasture landscape. Use of legumes in a field crop or forage production system has been shown to reduce or replace N fertilizer requirement and enhance other important soil quality characteristics. Soil quality can also be influenced by the forage species grown and pH level. However, the influence of different N sources and forage species adapted in the Southeast may have on soil quality have not been quantified.

Also, during early development of pines, especially until pine trees become resistant to possible damage by animals, grazing of young-pine silvopasture must be deferred; hay production is the usual practice for utilization of available forage during this period. When an appreciable amount of pine needles are present, hay quality may be reduced because hay mowing and harvesting equipment cannot selectively harvest forage devoid of pine needle as grazing animals can. Moreover, pine needle accumulation on the pasture surface intercepts light and inhibits forage growth. Therefore, it is important to understand at what point pine needle accumulation in longleaf-pine silvopasture alleys may become significant enough to impact forage productivity and quality. With this understanding, management strategies to control pine needle accumulation can be developed based on the pasture species or species combination being grown.

Background information presented in this review supported development of the following hypotheses tested in three separate studies.

1) Pasture type (silvopasture versus open-pasture) would influence plant community composition, forage productivity, and forage and soil quality during the initial stages of pasture conversion to silvopasture.
2) Alley position relative to trees would influence plant community composition, forage and pine biomass, and forage and soil quality.
3) Nitrogen source (legume-N versus fertilizer-N) would influence forage productivity, and forage and soil quality in silvopasture and open pasture.
4) Distribution and behavior patterns of grazing cattle would vary between silvopasture and open-pasture.
5) Soil quality would vary with forage species and soil pH level.

The objectives of the studies were to:

1) Determine the response of plant community composition, forage productivity, and forage and soil quality to young longleaf pine-bahiagrass silvopasture versus open bahiagrass pasture on coastal plain soil;
2) Determine the differences among silvopasture-alley positions relative to trees in terms of plant community composition, forage and pine needle biomass, and forage and soil quality of coastal plain soil;
3) Determine the response of forage productivity and forage and soil quality to nitrogen source (legume-N versus fertilizer-N) in young longleaf pine-bahiagrass silvopasture versus open bahiagrass pasture on coastal plain soil.
4) Determine the differences between mature loblolly-pine silvopasture and open-pasture landscapes in terms of distribution and behavior patterns of grazing cattle as

well as available forage quantity and quality and microclimatic conditions on the Southern Coastal Plain;

5) Determine the short-term response of coastal plain soil quality to forage species grown and pH level under protected culture.

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I BAHIAGRASS PASTURE PLANT COMMUNITY CHARACTERISTICS DURING CONVERSION TO LONGLEAF-PINE SILVOPASTURE

Abstract

Silvopasture is considered a sustainable agroforestry practice as a result of benefits the system offers for biodiversity, economic returns, and environmental quality. However, little is known about temporal and spatial dynamics of forage species composition, biomass production, and quality in pastures being converted to silvopasture. This research tested hypotheses that in young longleaf pine (*Pinus palustris* Mill.)-bahiagrass (*Paspalum notatum* Flugge) silvopasture, forage species composition, biomass, and quality would vary 1) between silvopasture and open-pasture (no trees present), and 2) among alley positions relative to trees. The objectives of this research were 1) to determine the response of forage species composition, biomass, and quality to longleaf pine-bahiagrass silvopasture versus open bahiagrass pasture environment, and 2) to determine the response of forage species composition, biomass, and quality, and pine-needle biomass to alley position relative to trees within the young longleaf pine-bahiagrass silvopasture environment. The research was conducted in a randomized complete block design with three replications from 2003 to 2007 at Americus, Georgia, USA in a longleaf-pine silvopasture established in 2000 in an existing bahiagrass pasture and an adjoining bahiagrass pasture without trees. Silvopasture forage-species composition was measured within alleys; forage biomass and quality were monitored at two (1.0 m and 6.1 m, 2003-2005) or three (1.0 m, 3.5 m, and 6.1 m, 2006-2007) permanent alley positions relative to the center of the tree base. Plant community diversity was higher in the silvopasture versus open-pasture early in the growing season, but open-pasture had higher diversity during the later growing season. Forage quality decreased in silvopasture when longleaf pine trees were 6-yr old. The 1.0-m alley positions relative to the center of the tree base produced less biomass with lower quality than did positions farther from trees when pine trees were 6-yr and 7-yr old. Overall productivity of bahiagrass pasture converted to longleaf-pine silvopasture was comparable to open-pasture. However, the silvopasture forage quality began to decline when longleaf pines were 6-yr old and had not been pruned, mainly as a result of pine needle accumulation on the understory plants closest to the trees.

Key words: Bahiagrass, Diversity index, Evenness, Longleaf pine

Introduction

Pasture has become an important land cover in the Southeast USA, especially after the Second World War when most of the region's crop land was converted to pastureland to minimize the severe soil erosion that resulted from overproduction of row crops (Bouton 2007). Presently, there are over 24 million ha of perennial and eight million ha of annual pasture in the South (Ball et al. 2007). According to USDA-ERS (2008), the profitability (gross value of production less cash expenses) of cow-calf production, the major livestock group in this region, was positive only for seven of 14 years from 1982 through 1995. This situation has compelled livestock producers to look for more economically viable land use systems that are environmentally sustainable. Many studies have suggested that silvopasture systems may provide a better option for this region compared to either pasture or forest monoculture (Clason 1999; Clason and Sharrow 2000; Shrestha and Alavalapati 2004; Stainback and Alavalapati 2004).

Silvopasture is an intensive land management system where forage and trees are grown together and integrated with grazing animals (Clason and Sharrow 2000). An existing pasture can be converted to silvopasture by adding low densities of trees. When trees are grown, modifications in microclimatic conditions, soil quality characteristics, and nutrient cycling can be expected (Bird 1998; Hulugalle and Ndi 1993; Kort 1988; Van Miegroet et al. 2000; Vetaas 1992; Wilson 2002). These modifications can influence species composition, productivity, and quality of understory crops. However, the impacts of southern-pine tree additions, particularly longleaf pine, on biomass, quality, and species composition of pasture plants adapted to the Southeast USA have not been well documented.

Lewis (1989) reported that the annual yield of some herbage species (*Aristida stricta, Sporobolus curtissii, Andropogon, Schizachyrium, Dichanthelium* [*Panicum*] spp.) decreased as the developing slash pine (*Pinus elliottii*) canopy closed, and leveled off when the pine was approximately 20-yr old; *Dichanthelium* sp. disappeared as tree shading became prominent. Studies conducted in silvopasture developed by thinning down mature (20-yr or older) loblolly pine (*Pinus taeda*) tree stands have estimated lower forage biomass production for silvopasture versus open-pasture (no trees present) (Clason 1999; Clason and Robinson 2000). Jackson and Ash (1998) indicated higher nitrogen (N) concentration and dry matter digestibility of perennial grasses from areas around live versus killed eucalypt trees in Queensland; pasture yields were greater where trees were killed compared to under intact woodland. However, Moyo and Campbell (1998) found similar yield, quality, and species composition of grasses from under widely spaced tree (*Terminalia sericea* and *Acacia karroo*) crowns versus open areas under moderate grazing pressure in Zimbabwe.

Other than the influence of altered microclimate and soil quality, accumulation of pine needles on the understory plant community in a pine-silvopasture system may modify the plant species composition and decrease the productivity of forages by reduction in the amount of solar radiation available for pasture plant growth. Also, during early development of longleaf pines, especially until trees become resistant to possible damage by animals (5-7 yr), grazing in young longleaf-pine silvopasture must be deferred; hay production is the usual practice for utilization of available forage during this period. When an appreciable amount of pine needles are present, hay quality may be reduced because, unlike grazing animals, hay mowing and harvesting equipment cannot selectively harvest forage devoid of pine needles. Therefore, it is important to understand at what point pine needle accumulation in longleaf-pine silvopasture alleys may become significant enough to impact forage productivity and quality. With this understanding, management strategies to control pine needle accumulation can be developed based on the pasture species or species combination being grown.

Within a production system with trees present, forage characteristics at a given date may be influenced by position relative to trees since microclimatic and soil quality modifications are enhanced closer to the tree (Hulugalle and Ndi 1993; Ujah and Adeoye 1984; Wilson 2002). Moreover, since pine needle accumulation occurs closer to the trees versus farther away from trees, alterations in forage productivity and quality as well as the plant-community composition would be expected to be higher in areas closest to trees.

However, information on the temporal and spatial dynamics of forage species composition, biomass, and quality in southern pastures being converted to longleaf-pine silvopasture is lacking. Therefore, this research was conducted with the following hypotheses and objectives.

Hypotheses

1. Forage species composition, biomass, and quality would vary between young longleaf pine-bahiagrass silvopasture versus open bahiagrass pasture.

2. Forage species composition, biomass, and quality and pine needle biomass would differ among alley positions relative to trees in a young longleaf pine-bahiagrass silvopasture.

Objectives

1. Determine the response of forage species composition, biomass, and quality to a young longleaf pine-bahiagrass silvopasture versus open bahiagrass pasture.
2. Determine the impact that alley position relative to trees has on forage species composition, biomass, and quality and pine-needle biomass in a young longleaf pine-bahiagrass silvopasture.

Methods

Study site and design

This research was conducted from 2003 to 2007 in a 4-ha young longleaf pine (*Pinus palustris* Mill.)-bahiagrass (*Paspalum notatum* Flugge) silvopasture and adjoining 4-ha bahiagrass pasture without trees (open-pasture) at Americus, Georgia, USA (32° 3' N, 84° 14' W). The bahiagrass pasture conversion to silvopasture began in summer 2000 with in-row sub-soiling and application of glyphosate in a double-row set configuration: 1.82-m tree-to-tree-in-row spacing and 3.04-m spacing between the double-row sets of trees; alleys between double-row tree sets were 12.2-m wide (Fig. I.1). In December 2000, longleaf-pine seedlings were planted in double-row sets; trees were not pruned at any time during the study. All trees had emerged from the grass-stage by April 2005 and had reached an average height of 5.5 ± 0.10 m and diameter at breast height (DBH) of 11.3 ± 0.25 cm by the end of the study in fall 2007; average tree density was 433 ha^{-1}. Soil at the site was an Orangeburg loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults) with a particle size distribution of 850 g kg^{-1} sand, 125 g kg^{-1} silt, and 25 g kg^{-1} clay, 22 g kg^{-1} organic matter, and an estimated ion exchange capacity of 6.23 cmol kg^{-1}. Using annual Auburn University soil test recommendations for bahiagrass pasture, levels of plant available P and K were adjusted by applying mixed commercial fertilizer in late spring in combination with 67 kg ha^{-1} N; soil pH was maintained at 6.0 with addition of dolomitic limestone in the fall when needed.

The experimental design was a randomized complete block with three replications within each pasture type. Initially, each block measured 0.46-ha. Sampling points for species composition, biomass, and quality measurements were located throughout the entire 0.46-ha block for all data collected from May 2003 through May 2005 (Fig. I.1A). In June 2005, block size was reduced to 0.16 ha each to prepare for the transition from haying to grazing. The 0.16-ha block size was used for all sample collection dates from July 2005 to September 2007. Regardless of size, silvopasture blocks each included four double-row tree sets and three 12.2-m alleys (Fig. I.1A, B, C).

Measurement of ground cover and forage species composition

Composition of ground cover and understory vegetation was measured by the point intercept method (USDA-FS 1996) using an optimal point projection device (Buckner 1985) during the early growing season (mid-April to mid-May) and late growing season (late-August to early-November) each year from 2003-2007, except in 2004 and 2006 when measurements were not made during the late growing season.

From May 2003 to May 2005, permanent locations for species composition measurements were located at ten random points along a baseline that ran diagonally across each 0.46-ha silvopasture block (Fig. I.1A). Areas within or between the tree rows of each double-row set were avoided as transects were drawn perpendicularly to the baseline at each of the ten random points. Whether the transect was drawn to the right or left at each point along the baseline was also randomly determined. Measurements were made at ten positions spaced one meter apart on the transect by starting at one meter from the baseline and ending at ten meters from the baseline, or further if the double-row tree sets were encountered. The point projection device was placed at each measurement position and cover categories recorded at 0^{o}, 45^{o}, 90^{o}, 135^{o}, and 180^{o} relative to each transect by moving the projection device in a semi-circle (500 readings per block); live vegetation was recorded by species. Disturbance of vegetation on the side of the transect where cover was being recorded was avoided until all readings for that transect were complete. A similar measurement scheme was applied in the open-pasture blocks.

From September 2005 to September 2007, baselines were established in the 0.16-ha silvopasture blocks across alleys perpendicular to tree rows on either side of the alley at five permanent points (Fig. I.1B, C). Measurements were made at five alley positions directly on the baseline relative to the tree base by starting at one meter from the center of the tree base on left side of the alley and ending at one meter from the center of the tree base on the right side of the alley; three middle points between the two one-meter positions were flagged equidistant to one another. The point projection device was placed at each measurement position and cover categories recorded at 0^o, 45^o, 90^o, 135^o, and 180^o relative to each baseline by moving the projection device in a semi-circle (125 readings per block); live vegetation was recorded by species. Measurement of overstory coverage in silvopasture began in September 2005, and understory cover composition by alley position along the baseline was recorded during the 2006-2007 observation periods.

Forage sample collection and analysis

During 2003 and 2004, forage samples for biomass and quality were collected at ten permanent points randomly selected along the length (100 m) of the alley in each silvopasture block (Fig. I.1A). At each point, sample collection locations represented alley-center or alley-side position; the alley-center position was located 6.1 m from the center of the tree base and the alley-side position was located 1.0 m from the center of the tree base. The result was 10 sub-samples from each alley-center and alley-side position within each block. A similar sampling scheme was established in the open-pasture blocks.

When silvopasture block size was reduced to 0.16-ha in 2005, a similar sampling scheme was used as in the 0.46-ha block configuration except sample size was reduced to five sub-samples from each alley-center and alley-side position within each block (Fig. I.1B). These sub-samples were collected along the same permanent baselines where forage species composition was measured. A similar sampling scheme was established in the open-pasture blocks. In 2006, an additional sample location was added at 3.5 m from the center of the tree base (equidistant between the 1.0-m and 6.1-m sample locations) for all permanent points along alleys in the silvopasture and samples were collected from all three locations for the remainder of the study (Fig.I.1C).

Forage samples were collected three times a year: early-growing season (April or May), mid-growing season (June or July), and late-growing season (August or September). All vegetation rooted within a 0.25-m^2 quadrat was clipped to 5 cm. Pine needles present within the quadrat at a height of 5 cm or more were collected separately. Immediately after sample collection, blocks were mowed (2003-2005, 2007) or grazed (2006) to 5 cm then allowed to re-grow. Samples were dried at 60^oC for 72 h. Pine needles present in the biomass sample were separated and weighed in May 2005 and at all sampling dates during 2006 and 2007. Legume and non-legume species present in the forage sample were separated and weighed during 2005-2007 early growing seasons. All components of oven-dried shoot biomass samples including pine needles (when present) were then combined and ground to pass a 1-mm sieve. Ground tissue samples were composited by alley position within a block to estimate Kjeldahl-N and acid detergent fiber (ADF) (Goering and Van Soest 1970).

Data analysis

Species diversity and evenness indices were calculated using Shannon's method (Magurran 1988) and the similarity index was calculated using the method described by Cook and Stubbendieck (1986). The equations used to calculate diversity, evenness, and similarity indices are presented below.

Diversity index, $H' = -\sum pi \ln pi$

Where, $pi = \frac{ni}{N}$, the proportional abundance of the i^{th} species

ni = abundance of particular plant species observed in the study area

N = total number of observation

Evenness index, $E = \frac{H'}{\ln S}$

Where, S = total number of plant species observed in the study area

Similarity index, $SI = \frac{2C}{A+B}$

Where,

A = number of plant species present in study area A

B = number of plant species present in study area B

C = number of plant species common to both study areas

Occurrence of different understory and overstory plants as well as litter and pine needles as land covers was tabulated. The mixed procedure (SAS 9.1) was used to analyze the forage shoot biomass and quality data with block as a random factor and sampling date as a repeated factor with spatial power law as a covariance structure for unequally spaced sampling dates (Littell et al. 2006). Main sources of variation included pasture type and sampling date. For samples from silvopasture, alley position relative to the tree base was an additional source of variation. All possible interaction effects were also assessed. Alpha probability level for rejection of the H_0 (null hypotheses) in favor of H_a (alternative hypotheses) was set at 0.05. The general model used to analyze shoot biomass and quality data is presented below.

$$Y_{ijk} = \mu + \alpha_i + \beta_k + (\alpha\beta)_{ik} + e_{ijk}$$

Where,

Y_{ijk} = value of an observation taken at the k^{th} sampling date in j^{th} block and i^{th} pasture type

μ = grand mean

α_i = main effect of i^{th} pasture type, i = 1, 2

β_k = main effect of k^{th} sampling date, l = 1, 2, ….., k

$(\alpha\beta)_{ik}$ = interaction effect of i^{th} pasture type and k^{th} sampling date

e_{ijk} = error associated with the k^{th} sampling date in j^{th} block and i^{th} pasture type

Results

Weather conditions

Total monthly precipitation fluctuated for different years during the study period (Fig. I.2). Precipitation was very low in March and October 2004, September and October 2005, and remained below the 47-yr average during most of the growing season in 2006 and 2007. Average monthly minimum and maximum temperatures for all experimental years were similar (Fig. I.3).

Pasture-type effect

Forage species and ground cover composition

The diversity of understory plant species in silvopasture was higher compared to open-pasture during the early-growing season of 2003, 2004, and 2007 but was lower than in open-pasture during all late-season periods included in the study (Table I.1). Species evenness was lower in silvopasture versus open-pasture for most observation dates; similarity was low whenever differences in diversity and evenness were high between the pasture types. Bahiagrass (*Paspalum notatum*) was the most dominant forage species found during all observation dates in silvopasture and for a majority of the observation dates in open-pasture (Table I.2). The occurrence of bahiagrass, *Bromus* species, and other grasses was higher in silvopasture than open-pasture but bermudagrass (*Cynodon dactylon*) occurrence was lower in silvopasture versus open-pasture at all observation dates. Occurrences of ryegrass (*Lolium multiflorum)* and total legumes (vetch + other legume) were less frequent in silvopasture than in open-pasture during the 2004-2007 observation dates.

Litter (senesced vegetation that is standing or fallen) was the second most dominant ground cover category after the total live understory plant species at all observation dates in both pasture types, except in August 2007 when litter covered approximately 54% of the open-pasture ground (Table I.2). In silvopasture, pine needles accounted for about 6% of the total ground cover in September 2005 and 10% in August 2007. Overstory coverage by the pine canopy on the alleys was approximately 7% in September 2005 and April 2006, and 11% in April 2007.

Forage biomass

Forage shoot dry matter (SDM) production from both pastures was similar for all observation dates, except in July 2003 and 2004 when SDM from silvopasture was higher (Fig. I.4). Though not statistically significant, SDM production from silvopasture was lower versus open-pasture at all observation dates during 2007. Legume biomass remained lower in silvopasture versus open-pasture in May 2005 and 2006, and April 2007 though the difference was not significant (data not presented).

Forage quality

Forage-N concentration was similar between pasture types during 2003-2005 growing seasons (Table I.3). However, in May and August 2006 and July and September 2007, N concentration was lower for forages sampled from silvopasture versus open-pasture. ADF concentration was higher for forages sampled from silvopasture versus open-pasture in May 2003, July and September 2004, August 2006, and July and September 2007 (Table I.3). In silvopasture, a significant amount of pine needles were present in the forage tissue samples collected in June and August 2006 and July and September 2007 (Fig. I.5).

Alley-position effect in silvopasture

Forage species and ground cover composition

Diversity of understory plant species was similar among alley positions in April 2006 (Table I.4). However, in April and August 2007, diversity was higher at the 1.0-m versus the 3.5-m alley position; diversity at the 1.0-m alley position was higher than that at the 6.1-m position in August 2007. Species evenness at the 1.0-m position was lower versus the 3.5-m or the 6.1-m alley positions for all observation dates during 2006-2007, except in April 2007 when evenness was higher at the 1.0-m versus the 3.5-m alley position. Similarity was approximately 0.5 or less for all observation dates, and was lowest in August 2007 (Table I.4). Among ground cover categories, bahiagrass and litter were highest at the 3.5-m position versus the other two positions for 2006 and 2007 observation dates (Table I.5). However, little barley (*Hordeum pusillum*) and legumes (vetch + other legumes) occurred more frequently at the 1.0-m position versus the other two positions. Overstory coverage of pine canopy at the 1.0-m alley position reached approximately 17% in April 2006 and 27% in April 2007; the other two positions had no overstory coverage.

Forage biomass

There was no alley-position effect on SDM yield from 2003 to 2005 when SDM was compared between the 1.0-m and the 6.1-m alley positions relative to the center of the tree base (Fig. I.6). Legume biomass present at the 1.0-m position was 27% higher than that at 6.1-m position in May 2005 although this difference was not statistically significant (data not presented). When SDM was compared among three alley positions, SDM was higher at the 3.5-m alley position versus the 1.0-m or the 6.1-m alley position in May 2006; July 2007 SDM was lower at the 1.0-m alley position versus the other two positions.

Forage quality

Forage-N concentration was similar between alley positions during 2003 and 2004 (Table I.6). However, N concentration in forage sampled from the 1.0-m versus the 6.1-m alley position was higher in May and lower in July 2005. In May and August 2006, N concentration of forage sampled from the 1.0-m and the 6.1-m alley positions was similar but higher than from the 3.5-m position. In July and September 2007, N concentration of forage sampled from the 1.0-m alley position was lower than from the 6.1-m position and similar to or lower than from the 3.5-m position. Forage-ADF concentration remained similar for both the 1.0-m and 6.1-m alley positions during 2003-2005 growing seasons. However, in May 2006 and July and September 2007, forage sampled from the 1.0-m position had higher ADF concentration as compared to forage sampled from the other two positions. In June 2006, forage sampled from the 1.0-m position contained higher ADF concentration versus the 6.1-m position. Forage quality samples from the 1.0-m alley position contained a significant amount of pine needles in June and August 2006 and July and September 2007, while samples from the other two positions had no pine needles or a negligible amount (Fig. I.7).

Discussion

Higher diversity of understory plant species in silvopasture during the early-growing seasons of 2003 and 2004 could be the result of an initial difference in the cool-season species present between the pasture types. The similar or lower diversity found for silvopasture versus open-pasture during the early-growing seasons of 2005 and 2006 could be the result of possible microclimatic changes brought about by the pine trees in the silvopasture system. Some microclimatic changes in a young-pine silvopasture can be expected since presence of older trees belonging to other species has been reported to bring microclimatic changes in their surroundings. Valigura and Messina (1994) highlighted the microclimatic differences between areas with and without pine shelter. They found lower net radiation and photosynthetically active radiation (PAR) loads, lower daytime air temperatures, similar or slightly lower daytime vapor pressures and lower wind speeds within 30 cm of surface environment in an area with loblolly pine (*Pinus taeda* L.) shelter than in a clear cut in east Texas. Van Miegroet et al. (2000) reported that canopy shading inside the tree island of sub-alpine fir (*Abies lasiocarpa*) and Engelman spruce (*Picea engelmannii*) slowed soil moisture loss and decreased the magnitude and fluctuation of soil temperatures relative to the exposed semi-arid meadows during summer in Northern Utah.

The higher diversity of plants in silvopasture versus open-pasture in April 2007 could be the result of the protective effect of trees on the understory plant species during drought conditions. Precipitation amounts below the 47-yr average that occurred from January to April 2007 might have exerted a more detrimental effect on the cool-season plant species in the open-pasture versus the silvopasture. Higher occurrence of litter (46%) in the open-pasture versus the silvopasture (36%) at the April 2007 observation date also supports the above logic. The lower diversity observed in silvopasture versus open-pasture during all late-season growing periods could be because of higher occurrence of bahiagrass in silvopasture. The dense, thick sod of bahiagrass most likely inhibited the growth of other plant species. This growth pattern could also be responsible for the lower species evenness in silvopasture versus open-pasture for most of the observation dates. An increasing difference in evenness found between pasture types during the late growing seasons could be the result of a greater modification of microclimate as the pines matured.

Higher forage shoot dry matter (SDM) production from silvopasture versus open-pasture in July 2003 and 2004 could be the result of higher percentage of bahiagrass versus bermudagrass presence in silvopasture. Comparable SDM production from both pasture types during the 2005-2007 growing seasons indicates that longleaf-pine trees that are not pruned up to seven years of age do not hinder forage production within alleys in the silvopastural configuration used with forage species present in this study.

Higher ADF concentration in forage sampled from silvopasture versus open-pasture in May 2003 and July and September 2004 could be the result of differences in species composition. Lower N and higher ADF concentrations of forage sampled from silvopasture versus open-pasture during the 2006 and 2007 growing seasons could be the result of differences in forage species composition between pasture types and presence of pine needles in the forage quality samples from silvopasture.

Higher diversity at the 1.0-m and 6.1-m versus the 3.5-m alley position in silvopasture could be the result of a higher predominance of bahiagrass at the 3.5-m position. As already discussed, bahiagrass may have inhibited other forage species because of its dense, thick sod. Higher diversity for the 1.0-m position versus the other two positions may also be the result of a protective influence of the trees on some of the plant species during the drought conditions experienced in 2006 and 2007. However, lower evenness at the 1.0-m position versus the other two positions at two out of three observation dates raises the question whether proximity to trees stimulates plant species diversity. Further study for a longer period including normal precipitation years is needed to arrive at a definite conclusion.

Higher May 2006 SDM production at the 3.5-m versus the 6.1-m alley position could be the result of more favorable microclimatic conditions and soil quality characteristics for forage growth at the 3.5-m versus the 6.1-m alley position. Wilson (2002) found systematically increasing soil bulk density (0-10 cm from the mineral soil surface), and decreasing carbon, nitrogen, phosphorus, and pH with increasing distance from eucalyptus trees measured at 2-m interval on a 20-m transect in Northern Tablelands of New South Wales, Australia. Hulugalle and Ndi (1993) reported that soil bulk density and water infiltration time increased with increasing distance from the tree trunk. Lower SDM production at the 1.0-m versus the 3.5-m alley position could have resulted from microclimatic modifications, especially reduction in solar radiation. Sharrow (1991) found the production of planted clover (*Trifolium subterraneum*) and resident tall fescue (*Festuca arundinacea*) surrounding 9 to10-yr old Douglas fir (*Pseudotsuga menziesii,* planted in cluster) near Corvallis, Oregon increased rapidly with increasing distance from trees over the initial 4 m. In July 2007, lower SDM from the 1.0-m versus the 3.5-m or the 6.1-m alley position could also be attributed to shading as a result of pine needle accumulation on the forage closest to the tree base.

Higher N concentration of forage sampled from the 1.0-m versus the 6.1-m position in May 2005 was the result of higher legume biomass present at the 1.0-m position. Lower forage-N concentration at the 1.0-m versus the 6.1-m position in July and September 2007 was attributed to a significant amount of pine needles present in forage quality samples from the 1.0-m position. Lower N concentration of forage sampled from the 3.5-m position versus the other two positions for the majority of observation dates during the 2006-2007 growing seasons could be attributed to the greater contribution of bahiagrass to the forage sample from the 3.5-m position. Higher ADF concentration in forage from the 1.0-m position versus the other two positions for most of the sampling dates during the 2006-2007 growing seasons was the result of pine needles present in the forage sampled from the 1.0-m position.

Conclusions

Diversity of the pasture-plant community varied based on pasture type and weather conditions. When bahiagrass was the major forage species, the productivity of longleaf-pine silvopasture alleys was comparable to that of open-pasture. However, forage quality in longleaf pine-bahiagrass silvopasture decreased when trees were approximately 6-yr old. Forage productivity and quality at the 1.0-m alley position relative to longleaf-pine trees was reduced compared to positions farther from trees when trees were approximately 7-yr of age and had not been pruned. Pine needle accumulation was likely the major reason for the lower quality of forage from longleaf pine-bahiagrass silvopasture versus open bahiagrass pasture, as well as lower productivity and quality of forage from the alley position nearest to the tree base versus positions farther from trees.

Acknowledgements

The authors acknowledge the Natural Resources Conservation Service, the USDA National Agroforestry Center, and the Southern Sustainable Agriculture Research and Education Program for funds that supported this research. The authors are especially grateful to Mr. Malcome Kirkland, Associate Director of the Jimmy Carter Plant Materials Center for field support.

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Table I.1. Diversity, evenness, and similarity indices of forage species in young longleaf pine-bahiagrass silvopasture (Silvo) versus open bahiagrass pasture (Open) at different observation dates during the 2003-2007 growing seasons, Americus, GA, USA.

Observation date		Diversity index		Evenness index		Similarity index
		Silvo	Open	Silvo	Open	
2003	May	$1.18^{\dagger a****}$	0.55^{b}	0.41	0.25	0.52
	Nov.	0.80^{b}	1.10^{a****}	0.30	0.50	0.61
2004	May	1.57^{a*}	1.41^{b}	0.52	0.53	0.76
2005	April	2.02	2.03	0.75	0.87	0.74
	Sept.	0.24^{b}	1.09^{a****}	0.17	0.56	0.55
2006	April	1.90^{b}	2.16^{a**}	0.72	0.82	0.79
2007	April	1.88^{a*}	1.70^{b}	0.78	0.74	0.76
	Aug.	0.08^{b}	0.77^{a****}	0.07	0.55	0.29

[†] Diversity index in a row with different superscript are different ($*P < 0.05$, $**P < 0.01$, $****P < 0.0001$).

Table I.2. Ground cover categories in young longleaf pine-bahiagrass silvopasture (Sil) versus open bahiagrass pasture (Op) at different observation dates during the 2003-2007 growing seasons, Americus, GA, USA.

Observation date	Ground cover category																	
	Bahia[†]		Bermuda		Bromus		Ryegrass		Other grasses		Vetch		Other legumes		Forbs		Litter	
	Pasture type																	
	Sil	Op	Sil	Op	Sil	Op	Sil	Op	Sil	Op	Sil	Op	Sil	Op	Sil	Op	Sil	Op
	%																	
May03	53.3	34.1	8.5	38.1	5.2	3.2	4.2	1.9	4.1	3.7	0.1	0.0	1.8	0.0	2.5	1.2	20.3	17.9
Nov.03	52.6	34.2	1.6	29.2	0.9	0.0	3.3	0.0	1.9	0.3	6.4	5.3	0.5	0.0	1.9	4.3	29.6	25.0
May04	33.4	10.4	1.7	11.1	4.1	3.5	2.3	4.0	5.0	4.5	8.7	14.6	0.5	0.7	4.3	3.9	39.9	47.2
Apr.05	28.3	18.0	3.8	8.7	5.2	1.5	1.8	9.6	17.4	6.4	10.1	14.4	2.2	8.9	9.8	9.1	20.8	23.3
Sept.05	66.7	49.3	0.0	12.3	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	3.5	11.2	23.5	26.1
Apr.06	20.3	5.1	0.0	17.5	6.1	2.4	0.8	11.0	9.1	3.2	9.1	4.3	0.3	10.5	11.0	9.6	39.5	36.4
Apr.07	12.5	4.0	0.0	0.0	13.3	2.4	10.9	17.9	5.3	2.7	16.3	17.3	1.9	8.3	3.2	1.3	36.0	46.1
Aug.07	42.4	31.5	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.5	2.4	46.9	53.9

[†] Bahiagrass, *Paspalum notatum;* Bermudagrass, *Cynodon dactylon*; Bromus, *Bromus* sp., Ryegrass, *Lolium multiflorum;* Vetch, *Vicia sativa*.

Table I.3. Nitrogen (N) and acid detergent fiber (ADF) concentration of forage (least-squares means) sampled from longleaf pine-bahiagrass silvopasture versus open bahiagrass pasture at different sampling dates during the 2003-2007 growing seasons, Americus, GA, USA.

Sampling date		N		ADF	
		Silvopasture	Open-pasture	Silvopasture	Open-pasture
		---------------------------------- $g\ kg^{-1}$	-------------------------------------		
2003	May	15.2	14.5	417^{a*}	407^{b}
	July	11.4	12.8	416	396
	Sept.	11.6	12.1	405	391
2004	July	12.7	13.8	425^{a***}	390^{b}
	Sept.	15.0	13.8	414^{a*}	395^{b}
2005	May	15.1	13.9	392	383
	July	13.0	12.5	421	416
	Aug.	13.6	12.7	418	423
2006	May	$14.3^{\dagger b}$	18.7^{a****}	402	389
	June	20.5	20.4	396	379
	Aug.	21.5^{b}	23.9^{a*}	365^{a**}	341^{b}
2007	April	18.5	18.7	374	362
	July	22.6^{b}	24.5^{a*}	396^{a***}	361^{b}
	Sept.	18.6^{b}	22.8^{a****}	437^{a****}	388^{b}
	SE	0.63		6.3	

[†] Least-squares means for N or ADF concentrations within a row with different superscripts are different (*P < 0.05, **P < 0.01, ***P < 0.001, ****P < 0.0001).

Table I.4. Diversity, evenness, and similarity indices of forage species at three alley positions relative to the center of the tree base in longleaf pine-bahiagrass silvopasture at different observation dates during the 2006-2007 growing seasons, Americus, GA, USA.

Observation date		Alley position relative to center of the tree base						Similarity index
		1.0 m	3.5 m	6.1 m	1.0 m	3.5 m	6.1 m	
		------Diversity index-----			---Evenness index ---			
2006	April	1.86	1.79	1.82	0.75	0.78	0.83	0.48
2007	April	$1.91^{\dagger a*}$	1.69^{b}	1.95^{a}	0.87	0.81	0.89	0.53
	Aug.	0.93^{a***}	0.69^{b}	0.69^{b}	0.59	0.97	0.99	0.40

[†] Diversity index with different superscripts within a row are different (*$P < 0.05$, ***$P < 0.001$).

Table I.5. Understory and overstory cover category at three alley positions relative to the center of the tree base in longleaf pine-bahiagrass silvopasture at different observation dates during the 2006-2007 growing seasons, Americus, GA, USA.

	Observation date								
	April 2006			April 2007			August 2007		
	Alley position relative to center of the tree base								
Cover category	1.0 m	3.5 m	6.1 m	1.0 m	3.5 m	6.1 m	1.0 m	3.5 m	6.1 m
Understory	--%	---							
Bahiagrass	6.2	10.1	4.0	3.7	6.9	1.9	15.7	17.3	9.3
Bromus	1.6	2.9	1.6	5.6	5.6	2.1	0.0	0.0	0.0
Little barley[†]	4.3	2.7	1.1	2.7	0.5	0.8	0.0	0.0	0.0
Ryegrass	0.3	0.3	0.3	5.3	3.7	1.9	0.0	0.0	0.0
Other grasses	0.3	0.8	0.0	0.8	0.0	0.5	0.0	0.0	0.0
Vetch	4.0	4.0	1.1	7.5	6.1	2.7	0.0	0.0	0.0
Other legumes	0.3	0.0	0.0	1.3	0.3	0.3	0.0	0.0	0.0
Forbs	5.4	4.0	1.9	0.3	1.9	1.1	0.5	0.0	0.0
Litter	14.1	15.2	10.1	12.3	14.9	8.8	16.0	21.1	9.9
Pine needle	3.5	0.3	0.0	0.5	0.0	0.0	7.7	1.6	0.8
Overstory									
Pine	16.7	0	0	27.0	0	0	22.2	0	0
Sky	83.3	100	100	73.1	100	100	77.8	100	100

[†] *Hordeum pusillum*

Table I.6. Nitrogen (N) and acid detergent fiber (ADF) concentrations of forage (least-squares means) sampled from different alley positions relative to the center of the tree base in longleaf pine-bahiagrass silvopasture on various sampling dates during the 2003-2007 growing seasons, Americus, GA, USA.

		N			ADF		
		Alley position relative to center of the tree base					
Sampling date		1.0 m	3.5 m	6.1 m	1.0 m	3.5 m	6.1 m
		--------------------------------g kg^{-1}----------------------------------					
2003	May	14.6		15.9	419		415
	July	11.8		11.0	413		419
	Sept.	11.6		11.7	407		404
2004	July	12.9		12.5	425		425
	Sept.	15.2		14.8	409		419
2005	May	$16.3^{\dagger a**}$		13.9^{b}	397		386
	July	11.8^{b}		14.3^{a**}	420		422
	Aug.	13.1		14.1	422		414
	SE	0.63		0.63	4.6		4.6
2006	May	17.1^{a**}	13.9^{b}	16.1^{a*}	423^{a}	396^{b**}	388^{b***}
	June	19.4	21.0	21.2	408^{a*}	397^{ab}	385^{b}
	Aug.	22.6^{a*}	20.3^{b}	23.4^{a**}	370	366	359
2007	April	19.1	17.8	18.5	375	384	364
	July	22.2^{b}	23.0^{ab}	24.8^{a**}	415^{a*}	393^{b}	389^{b}
	Sept.	18.2^{c****}	20.4^{b*}	22.3^{a}	482^{a****}	412^{b}	418^{b}
	SE	0.62	0.62	0.62	8.2	8.2	8.2

[†] Least-squares means for N or ADF within a row with different superscripts are different (*P < 0.05, **P < 0.01, ***P < 0.001, ****P < 0.0001).

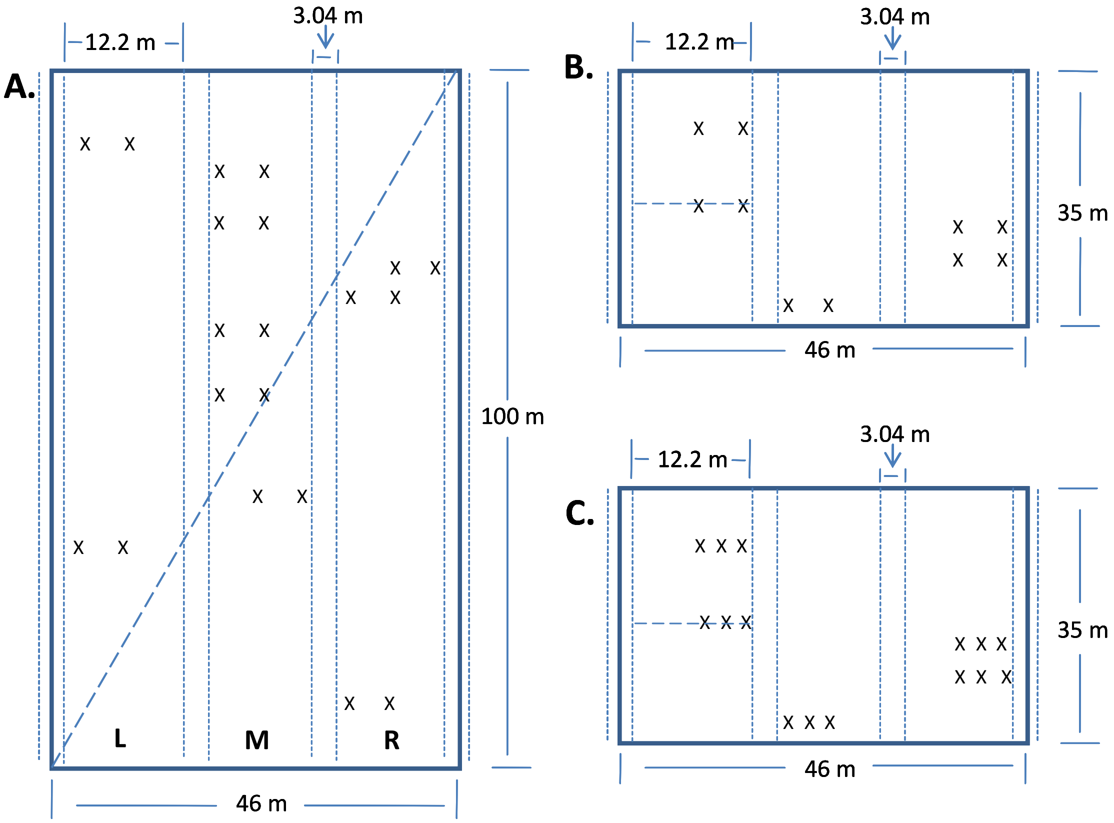

Figure I.1. A. Plot size and example sampling locations for species composition (– – –) and biomass (X) relative to longleaf pine double-row sets (¦ ¦) in left (L), middle (M), or right (R) alleys May 2003 to May 2005; B. July 2005 to September 2005; C. May 2006 to August 2007, Americus, GA, USA.

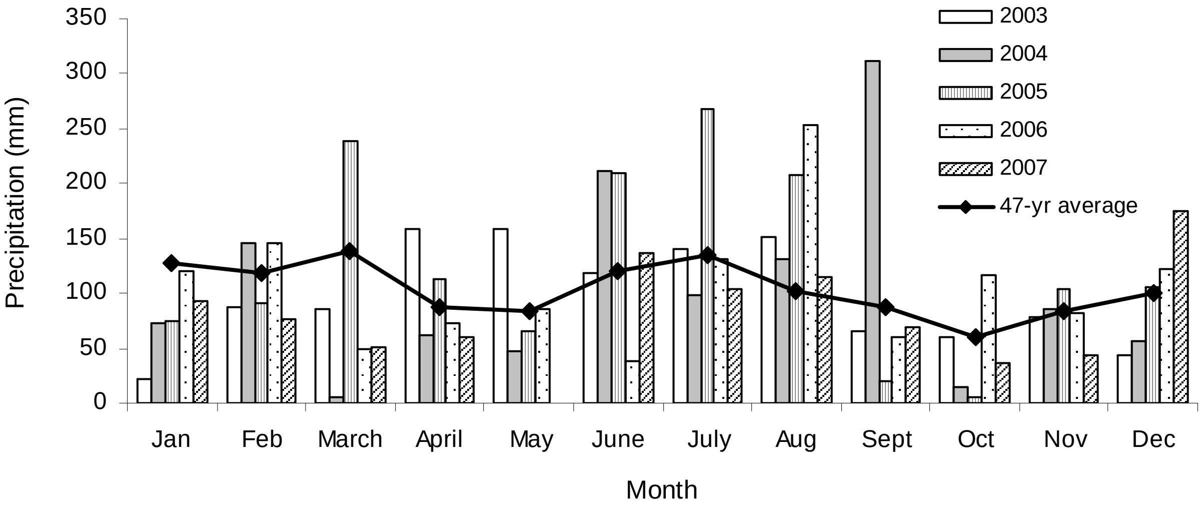

Figure I.2. Monthly total precipitation from 2003 to 2007 and 47-yr average total precipitation for each month, Americus, GA, USA.

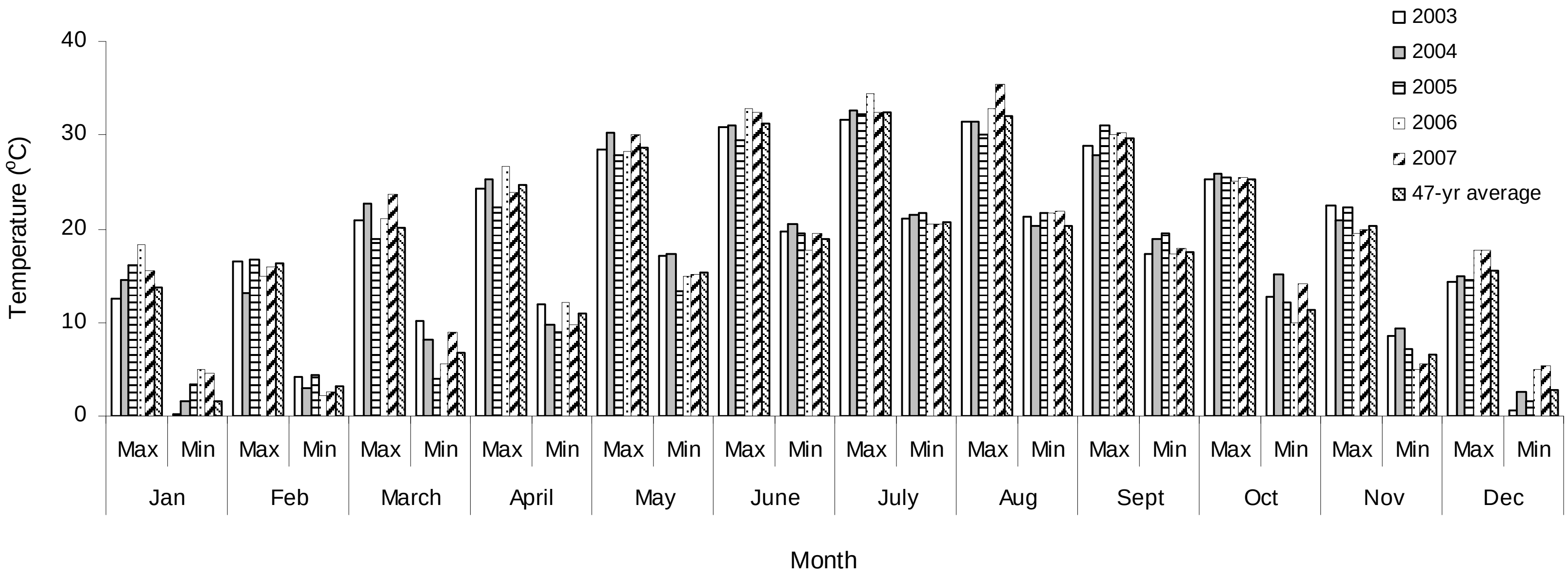

Figure I.3. Monthly maximum (max) and minimum (min) temperatures from 2003 to 2007 along with 47-yr average temperatures, Americus, GA, USA.

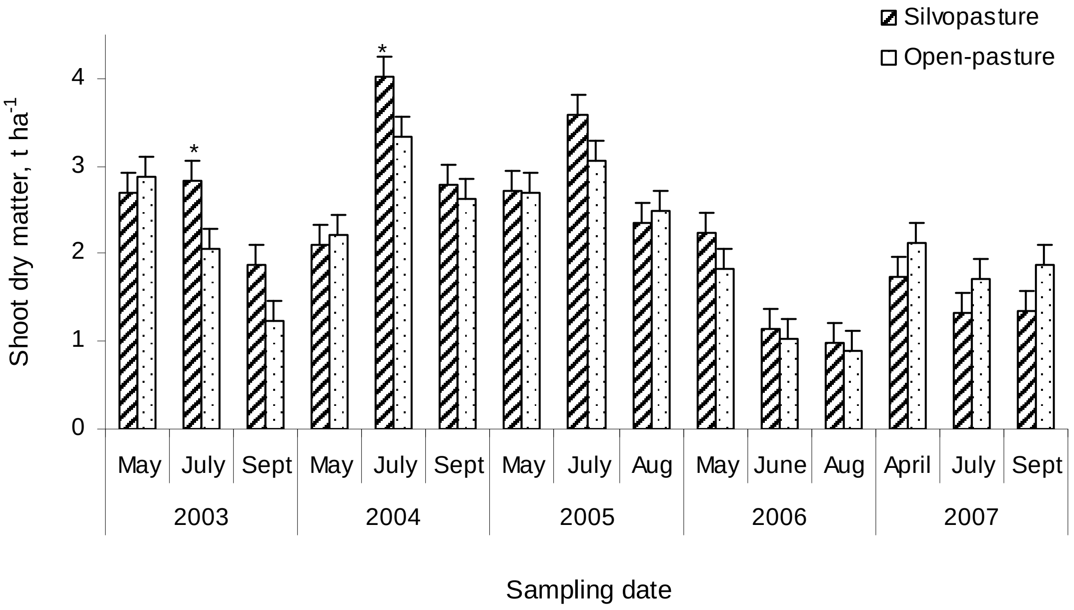

Figure I.4. Forage shoot dry matter production (least-squares means ± SE) from longleaf pine-bahiagrass silvopasture versus open bahiagrass pasture at different sampling dates during the 2003-2007 growing seasons, Americus, GA, USA (*P < 0.05).

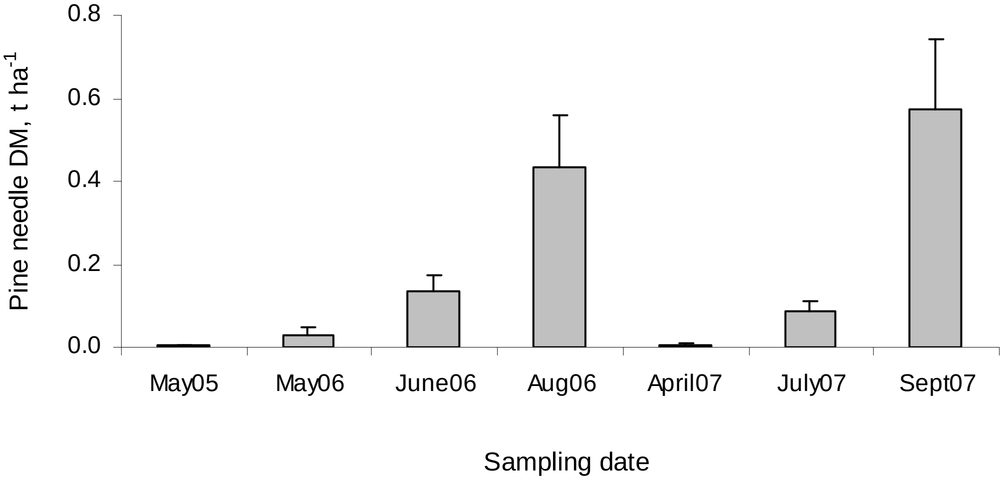

Figure I.5. Pine needle dry matter (DM) (means ± SE) present in forage quality samples from longleaf pine-bahiagrass silvopasture at different sampling dates during the 2005-2007 growing seasons, Americus, GA, USA.

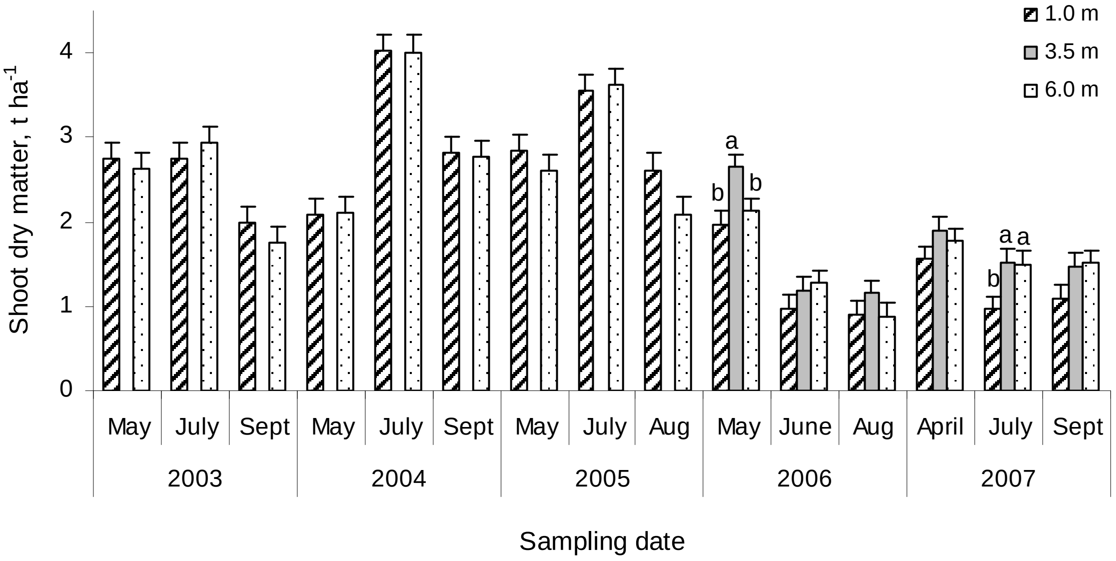

Figure I.6. Forage shoot dry matter (SDM) yield (least-squares means ± SE) from the 1.0-m, 3.5-m, and 6.1-m alley positions relative to center of the tree base in longleaf pine-bahiagrass silvopasture at different sampling dates during the 2003-2007 growing seasons, Americus, GA, USA (SDM with different letters for the same sampling date are different [$P < 0.05$]).

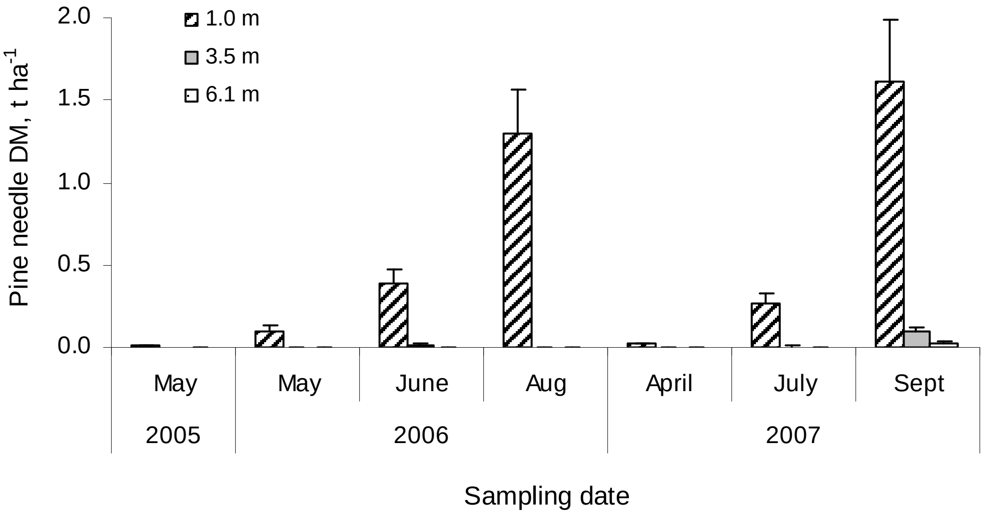

Figure I.7. Pine needle dry matter (DM) (means ± SE) present in forage quality samples from the 1.0-m, 3.5-m, and 6.1-m alley positions relative to center of the tree base in longleaf pine-bahiagrass silvopasture at different sampling dates during the 2005-2007 growing seasons, Americus, GA, USA.

II NITROGEN SOURCE INFLUENCES ON FORAGE AND SOIL IN YOUNG LONGLEAF PINE-BAHIAGRASS SILVOPASTURE

Abstract

Silvopasture is considered a sustainable agroforestry practice as a result of benefits the system offers for biodiversity, economic returns, and environmental quality. However, little is known about temporal and spatial dynamics of forage productivity and forage and soil quality in pastures being converted to silvopasture. This research tested three hypotheses in young longleaf pine (*Pinus palustris* Mill.)-bahiagrass (*Paspalum notatum* Flugge) silvopasture that forage productivity and quality, and soil aggregate stability, density of fungal hyphae, and compaction would vary depending on 1) nitrogen (N) source (legume-N versus fertilizer-N), 2) pasture type (silvopasture versus open-pasture, pasture with no trees), and 3) alley position relative to trees. The objectives of this research were: 1) to determine the impact of N source (legume-N versus fertilizer-N) and pasture type (silvopasture versus open-pasture) on forage productivity and quality, and soil aggregate stability, density of fungal hyphae, and compaction; 2) to determine the impact of alley position relative to trees in young longleaf pine-bahiagrass silvopasture on forage and pine needle biomass, forage quality, and soil aggregate stability, density of fungal hyphae, and compaction. This research was conducted in a randomized complete block design with three replications from 2005 to 2007 at Americus, Georgia, USA in a young longleaf pine-bahiagrass silvopasture and adjoining bahiagrass open-pasture. Treatments included either fertilizer-N or overseeded crimson clover (*Trifolium incarnatum* L. 'Dixie'). Silvopasture forage was monitored at two (1.0 m and 6.1 m, 2005) or three (1.0 m, 3.5 m, and 6.1 m, 2006-2007) alley positions relative to the center of the tree base; soil parameters were monitored at two alley positions (1.0 m and 6.1 m). May 2005 forage SDM was 40% higher for the legume-N versus fertilizer-N treatment. Higher forage-N was found for legume-N versus fertilizer-N treatment in May 2005 (28%) and April 2007 (27%). Lower forage-N and higher forage-ADF were found in silvopasture versus open-pasture in August 2006, and July and September 2007. Water stable aggregates were 5% lower in silvopasture versus open-pasture. Soil compaction was lower in silvopasture versus open-pasture at the 10-15 cm and 15-20 cm in 2005, and at the 15-20 cm in 2007. In silvopasture, forage productivity and quality at the 1.0-m alley position began to decrease versus the other two positions when pine trees were approximately 7-yr old; soil compaction was lower at the 1.0-m position versus the 6.1-m position. This research suggested that forage productivity and quality, and soil quality could be enhanced, and N fertilizer additions could be replaced by introducing and maintaining legumes in a young longleaf pine-bahiagrass silvopasture system on coastal plain soil in the Southeast USA. Results also suggested that forage productivity of longleaf pine-bahiagrass silvopasture alleys may be similar to that of open-pasture but silvopasture forage quality may decrease when pine trees are 6-yr old mainly as a result of pine needle accumulation on understory plants.

Key words: Aggregate stability, Compaction, Crimson clover, Hyphae

Introduction

Silvopasture is an intensive land management system where forage and trees are grown together and integrated with grazing animals (Clason and Sharrow, 2000). Silvopasture can be established by thinning an existing forest stand then adding or improving a forage component, or by adding low densities of trees to existing pasture. Several studies have highlighted the diversified economic, biological, and environmental benefits of silvopasture systems (Clason, 1999; Clason and Sharrow, 2000; Stainback and Alavalapati, 2004). A study conducted in mature-pine silvopasture has estimated lower forage biomass production for silvopasture than open-pasture (no trees present) (Clason, 1999). However, information on the temporal and spatial dynamics of forage productivity and quality in southern pastures being converted to silvopasture is lacking. Also, previous studies did not account for the contribution of pine needles to hay quality, which is a major concern of farmers in Southeast USA. Although grazing animals can avoid pine needles, the impact of pine needle presence needs to be considered in forage quality, especially early in a pasture to silvopasture conversion when hay production is the major option for forage utilization. Furthermore, forage productivity and quality at a given date may be influenced by alley (wide lane between tree 'sets') position relative to trees since microclimatic modifications are increased closer to trees (Marin *et al*., 2006; Ujah and Adeoye, 1984). However, the influence of alley position on forage productivity and quality has not been examined previously in southern-pine silvopasture systems. In addition, to fully understand forage productivity dynamics in a young silvopasture system, it is important to consider impacts on soil quality as the conversion proceeds.

Aggregate stability and compaction are major physical indicators of soil quality (Singer and Ewing 2000). Soil aggregate stability is important to reduce erosion, maintain porous structure, enhance infiltration and microbial activity, and maintain pasture productivity (Franzluebbers *et al.*, 2000). Soil compaction is related to pore-space, and therefore impacts infiltration, air and water movement, and root growth (Stephenson and Veigel, 1987). Studies conducted on few forage and crop species have revealed that plant species can have a significant impact on aggregate stability (Haynes and Beare, 1997; Reid and Goss, 1981). Franzluebbers *et al.* (2000) highlighted the influence of pasture age and management practices on aggregate stability. The role of fungi in aggregate formation and stabilization has been highlighted in many studies (Kay and Angers, 2000; Klironomos, 2000). Few studies conducted with crop species have been concerned with the influence of fertilization or type of fertilizer on aggregate stability and hyphal length. Dapaah and Vyn (1998) reported that soil aggregate stability and corn growth and development were affected more by cover crops than applied nitrogen. Bittman *et al.* (2005) found significantly greater hyphal length in untreated soil than in manured and fertilized soil. Shannon *et al.* (2002) mentioned that total and active fungi were more abundant in organically-managed soils than in conventionally-managed soils. However, there is no information on soil quality dynamics in young-pine silvopasture, especially based on alley position relative to trees.

This research was conducted in a young silvopasture to test the following hypotheses: 1) forage productivity and quality would vary depending on N source (legume-N versus fertilizer-N), pasture type (silvopasture versus open-pasture), and alley position relative to trees in silvopasture; 2) soil quality indicators (aggregate stability, density of fungal hyphae, and compaction) would differ in response to N source (legume-N versus fertilizer-N), pasture type (silvopasture versus open-pasture), and alley position relative to trees in silvopasture. The objectives of this research were: 1) to determine the impact of N source (legume-N versus fertilizer-N), pasture type (silvopasture versus open-pasture), and alley position relative to trees in young longleaf pine-bahiagrass silvopasture on forage productivity and quality; 2) to determine the amount of pine needle accumulation at various alley positions in young longleaf pine-bahiagrass silvopasture; 3) to determine the impact of N source (legume-N versus fertilizer-N), pasture type (silvopasture versus open-pasture), and alley position relative to trees in young longleaf pine-bahiagrass silvopasture on soil aggregate stability, density of fungal hyphae, and compaction.

Methods

Study site and design

This research was conducted from 2005 to 2007 in a 4-ha young longleaf pine (*Pinus palustris* Mill.)-bahiagrass (*Paspalum notatum* Flugge) silvopasture and adjoining 4-ha bahiagrass pasture without trees (open-pasture) at Americus, Georgia, USA (32° 3' N, 84° 14' W). The bahiagrass pasture to be converted to silvopasture was prepared in summer 2000 by in-row sub-soiling and application of glyphosate in a double-row set configuration: 1.82-m tree-to-tree-in-row spacing and 3.04-m spacing between the double-rows of trees; alleys between double-row tree sets were 12.2-m wide. In December 2000, longleaf pine seedlings were planted in the double-row sets; trees were not pruned at any time during the study. All trees had emerged from the grass-stage by April 2005 and had reached an average height of 5.9 ± 0.05 m and diameter at breast height (DBH) of 11.5 ± 0.11 cm by the end of the study in fall 2007; tree height and DBH were not different between N treatment plots (MANOVA, Wilk's Lambda, F probability = 0.4674). Tree density was 449 ha^{-1} at the end of study in fall 2007. Soil at the site was an Orangeburg loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults) with a particle size distribution of 850 g kg^{-1} sand, 125 g kg^{-1} silt, and 25 g kg^{-1} clay, 22 g kg^{-1} organic matter, and an estimated ion exchange capacity of 6.23 cmol kg^{-1}. Using annual Auburn University soil test recommendations, levels of plant available P and K were adjusted as needed with mixed commercial fertilizer in late spring, and soil pH was maintained at 6.0 with addition of dolomitic limestone in the fall. The research was designed as a randomized complete block with three replications within each pasture type.

Treatments

Silvopasture and open-pasture were each divided into three blocks and within each block, two 0.2-ha plots were randomly assigned one of two N-source treatments: commercial N fertilizer (NH_4NO_3) or crimson clover (*Trifolium incarnatum* L. 'Dixie'). Silvopasture plots included four double-row tree sets and three 12.2-m alleys. N fertilizer was applied annually as a single application of 67 kg ha^{-1} N in late spring; this rate was based on current Auburn University soil test recommendations for bahiagrass pasture. Crimson clover was overseeded with a Truax FLEXII (Truax Co., Inc, New Hope MN) grass drill with no-till attachment in October 2004 at a rate of 11.2 kg ha^{-1}. Crimson clover was overseeded again in October 2006 because drought conditions in September and October 2005 inhibited clover re-seeding resulting in an almost non-existent stand of crimson clover in the treatment plots in spring 2006.

Sample collection and analysis

In 2005, permanent points for sample collection in each plot were located at five random locations within the three 12.2-m alleys included in each treatment plot per block in silvopasture. At each location, points were located to represent the alley center or alley side relative to trees. Points representing the alley center position were located 6.1 m from the center of the tree base; the alley side position was located 1.0 m from the center of the tree base. The result was five sub-samples from both alley center and alley-side positions within each plot. A similar sampling scheme was established in the open-pasture. In 2006, an additional sample point for shoot biomass was added at 3.5 m from the center of the tree base (equidistant between the 1.0-m and 6.1-m sample points) for all alley locations in the silvopasture and sampling was continued accordingly thereafter.

To estimate shoot biomass and quality, forage within a 0.25-m^2 quadrat was clipped to 5 cm from the ground. Pine needles included within the quadrat at a height of 5 cm or more were collected separately. Immediately after sample collection, plots were mowed (2005, 2007) or grazed (2006) to 5 cm then allowed to re-grow. Shoot samples were collected three times a year: April or May (early-growing season), June or July (mid-growing season), and August or September (late-growing season). Shoot biomass tissue samples were dried at 60°C for 72 h. Crimson clover, all other legumes (legumes other than crimson clover), and non-legumes in the shoot sample were separated, and weighed individually in May 2005 and 2006, and April 2007. All components of oven-dried shoot biomass samples including pine needles (when present) were combined, then ground to pass a 1-mm sieve. Ground tissue samples were composited by alley position within a plot to estimate Kjeldahl-N and acid detergent fiber (ADF) (Goering and Van Soest, 1970).

Root samples were collected in August 2005 and October 2007 with a 5-cm (diameter) x 10-cm (depth) core sampler and kept cool (4°C) until analysis was completed within 14 days of collection. Soil was washed from root cores over a 500-µm sieve. After debris was removed, the root tissue was dried at 60°C for 72 h.

Soil samples for water stable aggregates (WSA) were collected to 7.6 cm in May and August 2005 and 2006, and April and September 2007. Samples were sieved (2-mm) in a field-moist condition, allowed to air dry, then analyzed following the method of

Nimmo and Perkins (2002) using an Eijkelkamp wet-sieving apparatus (Soil Moisture Equipment Corp., Goleta CA) equipped with 0.250-mm sieves; 2.0 g L^{-1} NaOH was used as the dispersing agent.

Samples for density of fungal hyphae (DFH) were collected in August 2005, May and August 2006, and April and September 2007; samples were kept cool (4°C) until analysis was completed within 14 days of collection. DFH was estimated using the membrane filter technique (Bardgett, 1991) to prepare two membrane filtrate slides for each sample. Slides were examined at 200x magnification by observing five random fields of view on each slide; total hyphal length for each slide was estimated following method four of Olson (1950). Average hyphal length from the two slides prepared for each sample was used to estimate DFH in m g^{-1} of wet soil. This value was then converted to m g^{-1} of oven-dried soil based on the gravimetric water content of a subsample of the initial DFH sample.

In June 2005 and October 2007, soil compaction was measured in terms of penetration resistance (PR) *in-situ* at four depths from the soil surface: 0-5 cm, 5-10 cm, 10-15 cm, and 15-20 cm using a dynamic cone penetrometer (Herrick and Jones, 2002). Soil samples (0-5 cm) were taken at the same time from points nearby the PR measurement locations, oven dried at 100°C for 72 h then weighed to determine soil moisture content.

Data analysis

The mixed procedure (SAS 9.1) was used to analyze the data with block as a random factor. Sampling date was used as a repeated factor with spatial power law as a covariance structure for shoot biomass, WSA, and DFH for unequally spaced sampling dates for these variables (Littell *et al.*, 2006). For soil PR, data from 2005 and 2007 were analyzed separately with depth as a repeated factor and first-order auto-regressive (AR 1) as a covariance structure for equally spaced measurement depths (Littell *et al.*, 2006); AR 1 covariance structure was also used for analyzing root biomass data. All possible interaction effects were also assessed. Main sources of variation included pasture type, N source, and sampling date. Data from silvopasture were also analyzed separately to assess the alley position effect as a result of proximity to trees. Probability level of alpha for rejection of the H_0 (null hypotheses) in favor of H_a (alternative hypotheses) was set at 0.05. The general model used to analyze the data is presented below.

$$Yijkl = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma_l + (\alpha\gamma)_{il} + (\beta\gamma)_{jl} + (\alpha\beta\gamma)_{ijl} + e_{ijkl}$$

Where,

Y_{ijkl} = value of an observation taken at the lth sampling date in kth block with jth N source and ith pasture type

μ = grand mean

α_i = main effect of i^{th} pasture type, i = 1, 2

β_j = main effect of j^{th} N source, j = 1, 2

$(\alpha\beta)_{ij}$ = interaction effect of i^{th} pasture type and j^{th} N source

γ_l = main effect of l^{th} sampling date, l = 1, 2, ….., l

$(\alpha\gamma)_{il}$ = interaction effect of i^{th} pasture type and l^{th} sampling date

$(\beta\gamma)_{jl}$ = interaction effect of j^{th} N source and l^{th} sampling date l

$(\alpha\beta\gamma)_{ijl}$ = interaction effect of i^{th} pasture type, j^{th} N source, and l^{th} sampling date

e_{ijkl} = error associated with the l^{th} sampling date in k^{th} block with j^{th} N source and i^{th} pasture type

Results

Climatic conditions

March to August 2005 precipitation was consistently higher than the 47-yr average except in May, but was consistently lower than the 47-yr average in September and October. Precipitation in 2006 was consistently lower than the 47-yr average from January to June, except in May, and in September. Precipitation also remained below the 47-yr average from January to May, July, and from September to November 2007 (Fig. II.1). With few exceptions, monthly average minimum and maximum temperature were similar for all three years (Fig. II.2).

Forage productivity and quality

N source

There was a successful stand of clover in May 2005 and although the 2005 stand was managed to reseed, the May 2006 stand was sparse to non-existent in most plots (Table II.1). Overall, total forage shoot dry matter (SDM) production was not different between N sources. When analyzed over sampling dates, higher ($P < 0.01$) SDM was found for the legume-N (3.8 ± 0.28 t ha^{-1}) versus the fertilizer-N treatment (2.7 ± 0.40 t ha^{-1}) in May 2005; this difference was observed for both pasture types. Crimson clover SDM was higher in legume-N versus fertilizer-N plots in May 2005 and April 2007; conversely, SDM of other legumes was lower in legume-N versus fertilizer-N treatment plots for both of these sampling dates (Table II.1). Root dry matter was not different between N sources at either sampling date.

Forage-N concentration was not different between N source treatments, overall. However, when analyzed over sampling dates, higher N concentration was found in forage from legume-N versus fertilizer-N treatment plots in May 2005 and April 2007 (Fig. II.3). Conversely, in July 2007, forage-N concentration was lower for the legume-N versus the fertilizer-N treatment. Forage-ADF concentration was not different between N source treatments.

Pasture type

No pasture-type effect was found for either total forage shoot or root dry matter production. However, SDM of crimson clover and total legumes were consistently less in silvopasture versus open-pasture although the differences observed were not statistically significant; biomass of legumes other than crimson clover was similar between the pasture types (Table II.1). Lower N concentration was found in forage sampled from silvopasture versus open-pasture in May and August 2006, and July and September 2007 (Table II.2). Conversely, ADF concentration was higher in forage sampled from silvopasture versus open-pasture in June and August 2006, and July and September 2007.

Alley position in silvopasture

There was no alley-position effect on SDM production in 2005; however, differences were found among alley positions in May 2006, and April, July, and September 2007 (Fig. II.4). Crimson clover and total legume SDM were lower ($P < 0.05$) at the 1.0-m versus the 3.5-m or the 6.1-m alley position in May 2005 and April 2007; conversely, SDM of legumes other than crimson clover was higher ($P < 0.05$) at the 1.0-m versus the 3.5-m or the 6.1-m alley position in April 2007 (data not shown). Pine needle biomass was higher at the 1.0-m versus the 3.5-m or the 6.1-m alley position for all sampling dates in 2006 and 2007 (Fig. II.5). Root biomass was not different among alley positions for any sampling date. Forage-N concentration was higher ($P < 0.05$) when sampled from the 6.1-m (13.2 ± 0.55 g kg^{-1}) versus the 1.0-m position (11.8 ± 0.38 g kg^{-1}) in July 2005. Forage-N concentration was also different among alley positions in August 2006, and July and September 2007 (Table II.3). Likewise, ADF concentration was higher in forage sampled from the 1.0-m versus the 3.5-m or the 6.1-m alley position in July and September 2007.

Soil quality indicators

N source

Overall differences in water stable aggregates (WSA) were not detected between N sources. However, when analyzed over sampling dates, higher ($P < 0.01$) WSA concentrations were found in soils sampled from legume-N (635 ± 22.9 g kg^{-1}) versus fertilizer-N (555 ± 30.6 g kg^{-1}) treatment plots in May 2006; this difference was observed for both pasture types. Overall, density of fungal hyphae (DFH) was not different between N sources. However, in August 2005, DFH was higher ($P < 0.05$) for the legume-N (90 ± 3.6 m g^{-1}) versus fertilizer-N (80 ± 3.4 m g^{-1}) treatment; this response was observed only for open-pasture (100 ± 5.4 m g^{-1} vs. 79 ± 6.0 m g^{-1}) when data from each pasture type were analyzed separately. Soil penetration resistance (PR) was not different between the N-source treatments in June 2005. However, in October 2007, PR was lower ($P < 0.05$) for legume-N versus fertilizer-N treatment at 10-15 cm and 15-20 cm (Fig. II.6). Soil moisture was similar for both N treatments in June 2005 (legume-N: 9.7%, fertilizer-N: 10.0%) and October 2007 (legume-N: 10.8%, fertilizer-N: 11.1%).

Pasture type

Lower ($P < 0.01$) concentrations of WSA were found in soils from silvopasture (617 ± 8.3 g kg^{-1}) versus open-pasture (650 ± 3.3 g kg^{-1}) averaged over all dates, while DFH was higher ($P < 0.05$) in silvopasture (58 ± 3.8 m g^{-1}) versus open-pasture (46 ± 3.9 m g^{-1}) in August 2006 only. June 2005 soil PR was lower in silvopasture versus open-pasture at the 10-15 cm and 15-20 cm, and at the 15-20 cm in October 2007 (Fig. II.7). Soil moisture was not significantly different between pasture types at any date when soil PR was measured.

Alley position in silvopasture

Concentrations of WSA were similar at all sampling dates regardless of alley position relative to the center of the tree base. However, DHF was higher in soils from the 6.1-m (87 ± 4.4 m g^{-1}) versus the 1.0-m alley position (75 ± 3.0 m g^{-1}) in August 2005. June 2005 soil PR was higher at the 6.1-m versus the 1.0-m alley position for all depths; but only for depths greater than 0-5 cm in October 2007 (Fig. II.8).

Discussion

Forage biomass and quality

The null hypothesis against the first alternative hypothesis that forage productivity and quality would vary depending on N source (legume-N versus fertilizer-N), pasture type (silvopasture versus open-pasture), and alley position relative to trees in silvopasture was rejected. Nitrogen source influenced both forage SDM and quality, especially when there was an appreciable amount of legume present in the treatment plots. The May 2005 stand of clover explained the higher (40%) SDM production for the legume-N versus fertilizer-N treatment; this result is supported by previous studies. Cuomo *et al*. (2005) found higher biomass production from smooth bromegrass-legume mixtures without N fertilizer versus smooth bromegrass monocultures with N fertilizer applications up to 336 kg ha^{-1}. Malhi *et al*. (2002) reported that bromegrass-legume mixtures without N fertilizer produced more forage versus bromegrass monoculture with N fertilizer applied at 50 kg N ha^{-1}; forage biomass from bromegrass-legume mixtures without N fertilizer and bromegrass monoculture with N fertilizer applied at 100 to 150 kg N ha^{-1} was equivalent. In our study, similar SDM production levels for forage sampled from both N treatments at sampling dates when clover was dormant could be attributed to earlier total N fixation by legumes in the system. This indicates that SDM production in this system can be maintained without applying N fertilizer if legumes are introduced. Higher forage-N concentrations in SDM sampled from the legume-N versus fertilizer-N treatment in May 2005 (28%) and April 2007 (27%) can be attributed to the large contribution of crimson clover to the available forage. The work of Malhi *et al.* (2002) supports this finding:

higher protein concentration was found in forage from a bromegrass-legume mixture than from bromegrass monoculture. In our study, lower forage-N concentration in SDM from legume-N versus fertilizer-N treatment observed in July 2007 (11%) could be the result of nitrate accumulation in forage plants sampled from fertilizer-N plots. Nitrate accumulation can occur in forage plants heavily fertilized with N when there is low soil moisture or low humidity (Ball *et al*., 1996); drought conditions were severe at the study site for the July 2007 sampling date.

Pasture type did not affect SDM production, but influenced forage quality. Lack of SDM production response between pasture types in this study contradicts findings of Clason (1999) and Kallenbach *et al.* (2006); differences in forage species studied and tree stand age and species are the probable reasons for this contradiction. Lower May 2006 N concentration in forage SDM from forage in silvopasture versus open-pasture may be the result of differences in the forage species composition between pasture types, especially the total legume. Our observations for May 2005, May 2006, and April 2007 suggested differences in leguminous species composition between silvopasture and open-pasture although this difference did not approach statistical significance in terms of SDM production. This difference might have been enough to cause variation in forage-N concentrations. Lower N and higher ADF concentrations in SDM from silvopasture versus open-pasture in August 2006, and July and September 2007 can be explained by the presence of pine needle in the forage samples from silvopasture and possible differences in forage species composition between pasture types.

Higher May 2006 and April 2007 SDM production at the 3.5-m versus the 6.1-m alley position could be attributed to lower soil penetration resistance (PR) at the 3.5-m position. Though soil PR was not measured at the 3.5-m, lower PR at the 1.0-m versus the 6.1-m alley position suggested the possibility of lower PR at the 3.5-m versus the 6.1-m alley position. Lower SDM production from the 1.0-m versus the 3.5-m alley position could be the result of microclimatic modifications, especially reductions in solar radiation or soil moisture. In July and September 2007, lower SDM yield from the 1.0-m versus the 3.5-m or the 6.1-m alley position could be attributed to shading as a result of pine needle accumulation on the forage at the 1.0-m alley position. Similarly, lower N and higher ADF concentration in biomass from the 1.0-m versus the 3.5-m or the 6.1-m alley position in July and September 2007 can be attributed to the higher quantity of pine needles at the 1.0-m alley position.

Soil quality indicators

The null hypothesis against the second alternative hypothesis that soil quality indicators (aggregate stability, density of fungal hyphae, and compaction) would differ in response to N source (legume-N versus fertilizer-N), pasture type (silvopasture versus open-pasture), and alley position relative to trees in silvopasture was rejected. Higher (14%) May 2006 WSA concentration in soils from the legume-N versus fertilizer-N treatment could be the result of an interaction between climatic conditions and plant species; further research is required to fully understand this interaction. Likewise, higher DFH in legume-N versus fertilizer-N plots in August 2005 can also be attributed to possible climate-plant species interactions. Lower October 2007 soil PR in legume-N versus fertilizer-N plots can be attributed to different influences of these N sources on PR. Latif *et al*. (1992) found significantly lower soil PR following legume versus non-legume cultivation in cotton cropping systems. Rochester *et al.* (2001) reported increased soil compaction with increasing rate of N fertilization (0, 10, 30, 50 kg N ha^{-1}) on South African rangeland.

Lower (5%) WSA concentration in silvopasture versus open-pasture could be attributed to differences in microclimate and root penetration in soils between the pasture types. In one of our studies conducted in Chipley, Florida, wind speed was 29 to 58% lower and total solar radiation was 14 to 58% lower in 20-yr old loblolly-pine silvopasture versus open-pasture (unpublished). Ujah and Adeoye (1984) highlighted the influence of trees on microclimate based on a study of approximately 20-yr old eucalyptus (*Eucalyptus camaldulensis)* shelterbelts in the Sudan Savanna zone of Nigeria. They found lower wind velocity at 20 m (20%) and 150 m (10%), and higher air temperature at 20 m (0.8^oC – 1.5^oC) on the leeward side of trees versus the open field; maximum soil temperatures at 5 cm depth were 0.5 to 1.0^oC higher closer to the trees and soil moisture depletion (0-10 cm) was less rapid on the protected side versus the open field. However, Marin *et al.* (2006) reported lower soil and air monthly temperature averages (6^oC and 2^oC) under the crown of 6-yr old *Gliricidia sepiem* versus positions away from the trees. Wilson (2002) found systematically increasing soil bulk density, and decreasing carbon, nitrogen, phosphorus, and pH with increasing distance from Eucalyptus trees measured at 2 m interval on a 20 m transect in Northern Tablelands of New South Wales, Australia.

Higher (26%) August 2006 DFH in silvopasture versus open-pasture could be the result of more favorable temperature, moisture, and nutrient status in the silvopasture rhizosphere. The cause of differences in DFH between positions in silvopasture observed in August 2005 could be the result of possible differences in microclimate, soil properties, and root systems between the two positions at the given sampling dates. Differences in root systems, microclimatic conditions, and soil properties brought about by the trees could also be responsible for the difference in soil penetration resistance (PR) between pasture types and alley positions within silvopasture.

Conclusions

This research suggested that forage productivity and quality could be enhanced, and N fertilizer additions could be replaced through introduction and maintenance of legumes in a young longleaf pine-bahiagrass silvopasture system on coastal plain soil in the Southeast USA. Results also support the beneficial effect of legumes for soil quality. Pasture type was a major source of variation for water stable aggregates and penetration resistance in the soil studied. Moreover, alley position relative to trees in young longleaf pine-bahiagrass silvopasture caused differences in forage productivity and quality as well as soil penetration resistance. Pine needle biomass accumulation at alley positions closest to trees is a likely contributor to reduced forage quantity and quality. The effect of sampling date on all the variables measured was most likely the result of seasonal variation in climatic conditions and plant species present.

Acknowledgements

The authors acknowledge the Natural Resources Conservation Service, the USDA National Agroforestry Center, and the Southern Sustainable Agriculture Research and Education Program for funds that supported this research. Authors are especially grateful to Mr. Malcome Kirkland, Associate Director of the Jimmy Carter Plant Materials Center for field support.

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Table II.1. Legume shoot dry matter (SDM) (LS means ± SE) by legume category, N source, and pasture type in longleaf pine-bahiagrass silvopasture versus open bahiagrass pasture at different sampling dates during the 2005-2007 growing seasons, Americus, GA, USA.

Legume SDM category	Variation source	Shoot dry matter		
		May 2005	May 2006	April 2007
	N source	--------------------------t ha^{-1}--------------------------		
Crimson clover	Legume-N	2.13 ± 0.289$^{\dagger a****}$	0.13 ± 0.289	0.89 ± 0.289^{a*}
	Fertilizer-N	0.01 ± 0.009^{b}	0.00	0.03 ± 0.009^{b}
Other legumes	Legume-N	0.26 ± 0.044^{b}	0.09 ± 0.044	0.13 ± 0.044^{b}
	Fertilizer-N	0.44 ± 0.044^{a**}	0.13 ± 0.044	0.25 ± 0.044^{a*}
Total legumes	Legume-N	2.40 ± 0.294^{a****}	0.22 ± 0.294	1.02 ± 0.294^{a*}
	Fertilizer-N	0.44 ± 0.059^{b}	0.13 ± 0.059	0.27 ± 0.059^{b}
	Pasture type			
Crimson clover	Silvopasture	0.88 ± 0.204	0.01 ± 0.204	0.40 ± 0.204
	Open-pasture	1.26 ± 0.204	0.12 ± 0.204	0.51 ± 0.204
Other legume	Silvopasture	0.31 ± 0.052	0.11 ± 0.052	0.19 ± 0.052
	Open-pasture	0.39 ± 0.052	0.11 ± 0.052	0.19 ± 0.052
Legume total	Silvopasture	1.19 ± 0.212	0.12 ± 0.212	0.59 ± 0.212
	Open-pasture	1.65 ± 0.212	0.24 ± 0.212	0.70 ± 0.212

[†] LS means with different superscripts within a SDM category and date are different (*P < 0.05, **P < 0.01, ****P < 0.0001).

Table II.2. Nitrogen (N) and acid detergent fiber (ADF) concentration of forage (LS means ± SE) sampled from longleaf pine-bahiagrass silvopasture versus open bahiagrass pasture at different dates during the 2005-2007 growing seasons, Americus, GA, USA.

Sampling date		N		ADF	
		Silvopasture	Open-pasture	Silvopasture	Open-pasture
		----------g kg^{-1}----------			
2005	May	17.3 ± 0.45	15.7 ± 0.71	398 ± 4.6	387 ± 6.8
	July	12.5 ± 0.45	12.1 ± 0.71	425 ± 4.6	413 ± 6.8
	Aug	13.1 ± 0.45	12.4 ± 0.71	420 ± 4.6	416 ± 6.8
2006	May	$14.9 \pm 0.45^{\dagger b}$	$18.7 \pm 0.71^{a****}$	396 ± 4.6	387 ± 6.8
	June	19.5 ± 0.45	20.0 ± 0.71	$398 \pm 4.6^{a*}$	378 ± 6.8^{b}
	Aug	20.5 ± 0.45^{b}	$23.4 \pm 0.71^{a**}$	$375 \pm 4.6^{a***}$	342 ± 6.8^{b}
2007	April	20.6 ± 0.45	21.7 ± 0.71	376 ± 4.6	363 ± 6.8
	July	21.0 ± 0.45^{b}	$23.8 \pm 0.71^{a**}$	$403 \pm 4.6^{a****}$	362 ± 6.8^{b}
	Sept	17.9 ± 0.45^{b}	$22.5 \pm 0.71^{a****}$	$443 \pm 4.6^{a****}$	387 ± 6.8^{b}

[†] LS means for N or ADF concentrations with different superscripts within a row are different (*P < 0.05, **P < 0.01, ***P < 0.001, ****P < 0.0001).

Table II.3. Nitrogen (N) and acid detergent fiber (ADF) concentrations of forage (LS means ± SE) sampled from three alley positions relative to the center of the tree base in longleaf pine-bahiagrass silvopasture at different dates during the 2005-2007 growing seasons, Americus, GA, USA.

Sampling date		N			ADF		
		Alley position relative to center of the tree base					
		1.0 m	3.5 m	6.1 m	1.0 m	3.5 m	6.1 m
		---g kg^{-1}---					
2006	May	14 ± 0.8	15 ± 0.7	15 ± 0.6	414 ± 14	391 ± 7	383 ± 7
	June	19 ± 0.8	19 ± 0.7	20 ± 0.6	406 ± 14	401 ± 7	387 ± 7
	Aug	21 ± 0.8$^{\dagger a}$	20 ± 0.7^{b*}	21 ± 0.6^{ab}	380 ± 14	376 ± 7	370 ± 7
2007	Apr	20 ± 0.8	20 ± 0.7	22 ± 0.6	378 ± 14	383 ± 7	368 ± 7
	July	19 ± 0.8^{b}	22 ± 0.7^{a}	23 ± 0.6^{a***}	448 ± 14^{a**}	396 ± 7^{b}	396 ± 7^{b}
	Sept	13 ± 0.8^{b}	20 ± 0.7^{a}	21 ± 0.6^{a****}	507 ± 14^{a****}	410 ± 7^{b}	412 ± 7^{b}

[†] LS means for N or ADF concentrations with different superscripts within a row are different ($*P < 0.05$, $**P < 0.01$, $***P < 0.001$, $****P < 0.0001$).

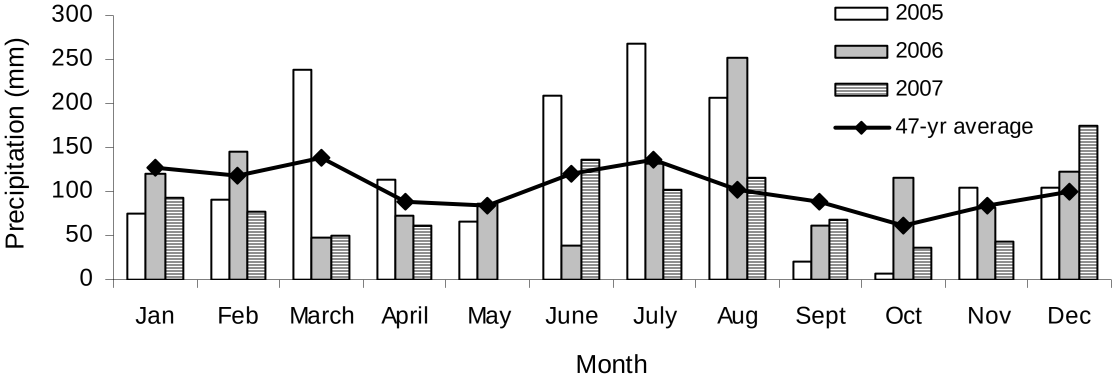

Figure II.1. Monthly total precipitation pattern for 2005-2007 and 47-yr average total precipitation for each month, Americus, GA, USA.

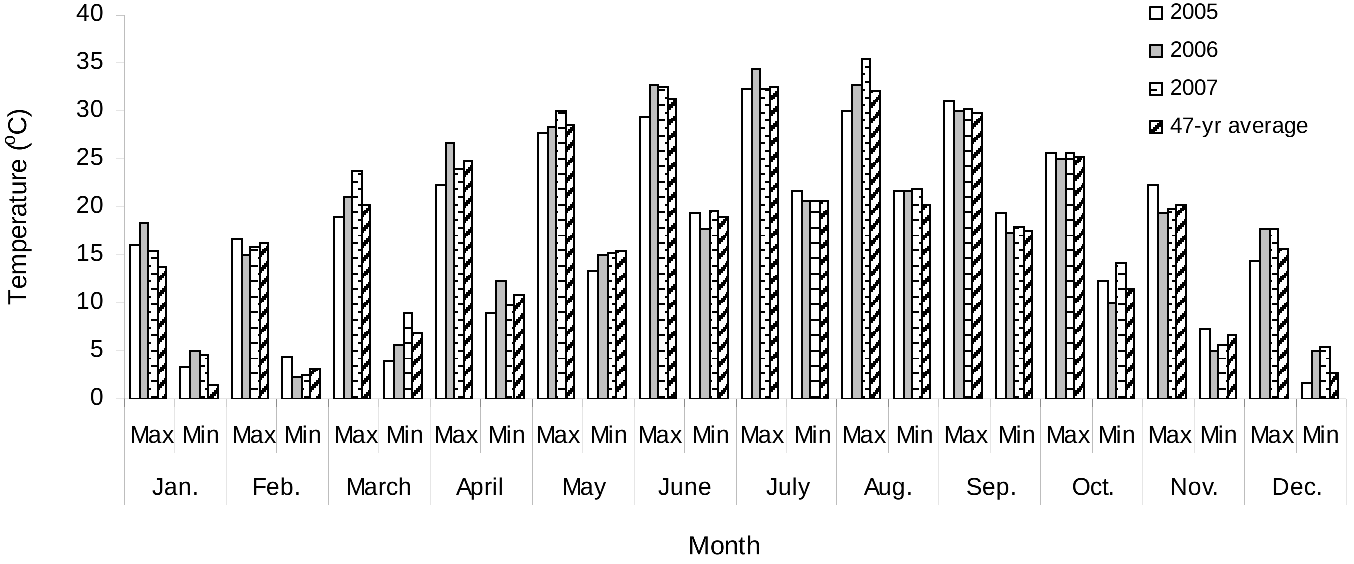

Figure II.2. Monthly average minimum and maximum temperature for 2005-2007 and 47-yr average minimum and maximum temperatures for each month, Americus, GA, USA.

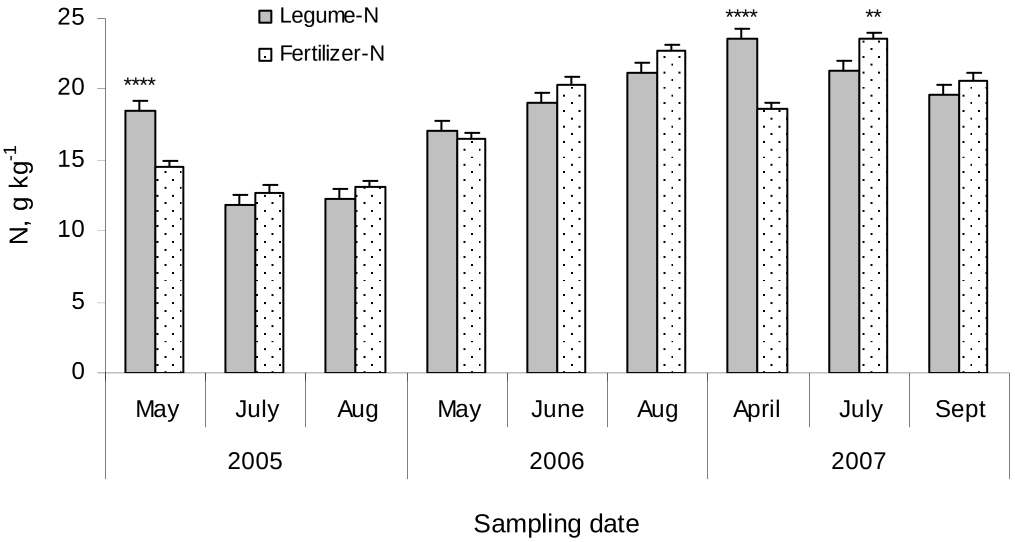

Figure II.3. N concentration (LS means ± SE) of forage sampled from the legume-N versus fertilizer-N treatment plots in young longleaf pine-bahiagrass silvopasture and open bahiagrass pasture at different dates during the 2005-2007 growing seasons, Americus, GA, USA (**P < 0.01, ****P < 0.0001).

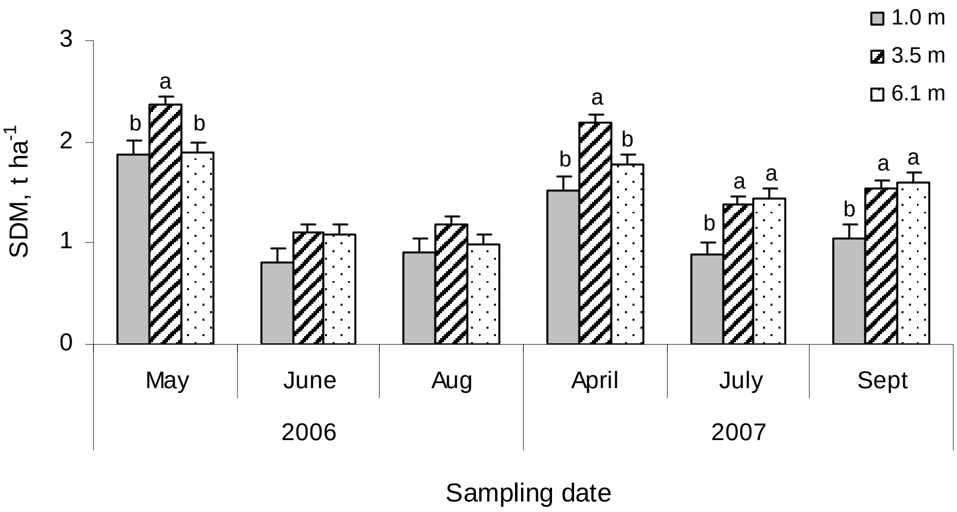

Figure II.4. Forage shoot dry matter (SDM) production (LS means ± SE) from the 1.0-m, 3.5-m, and 6.1-m alley positions relative to the center of the tree base in young longleaf pine-bahiagrass silvopasture during the 2006-2007 growing seasons, Americus, GA, USA (SDM with different letters for the same sampling date are different [May 2006, $P < 0.001$; 2007: April, $P < 0.0001$; July & Sept., $P < 0.01$]).

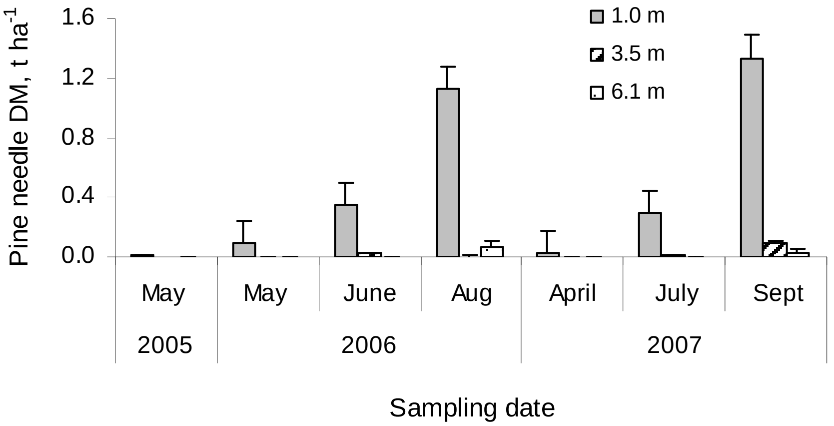

Figure II.5. Pine needle dry matter (DM) from the 1.0-m, 3.5-m, and 6.1-m alley positions relative to the center of the tree base in young longleaf pine-bahiagrass silvopasture at different sampling dates during the 2005-2007 growing seasons, Americus, GA, USA.

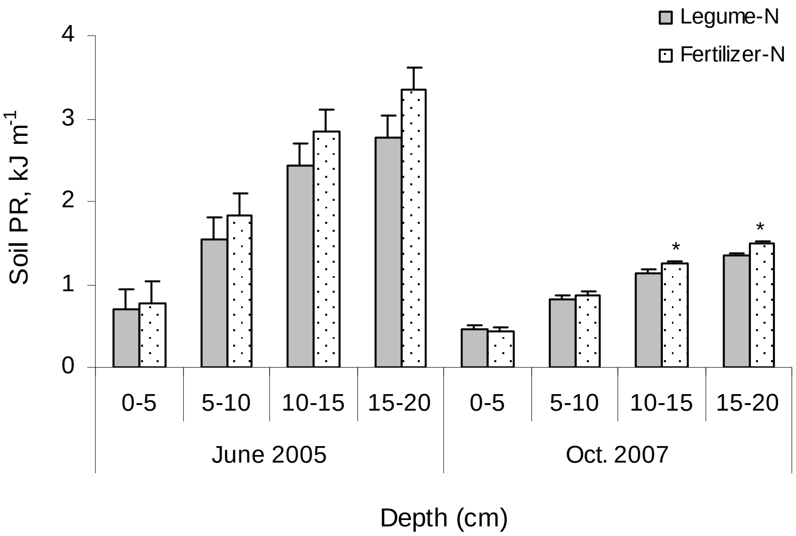

Figure II.6. Soil penetration resistance (PR) (LS means ± SE) for legume-N versus fertilizer-N treatments at different depths in young longleaf pine-bahiagrass silvopasture and open bahiagrass pasture, June 2005 and October 2007, Americus, GA, USA (*$P < 0.05$).

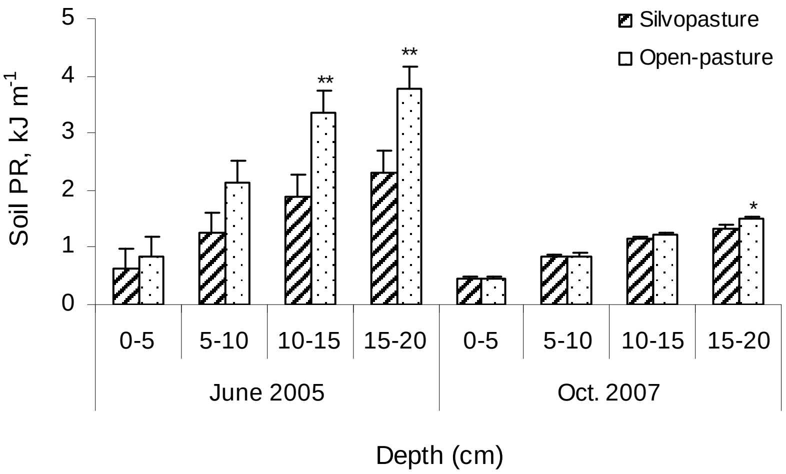

Figure II.7. Soil penetration resistance (PR) (LS means ± SE) in young longleaf pine-bahiagrass silvopasture versus open bahiagrass pasture at different depths, June 2005 and October 2007, Americus, GA, USA (*$P < 0.05$, **$P < 0.01$).

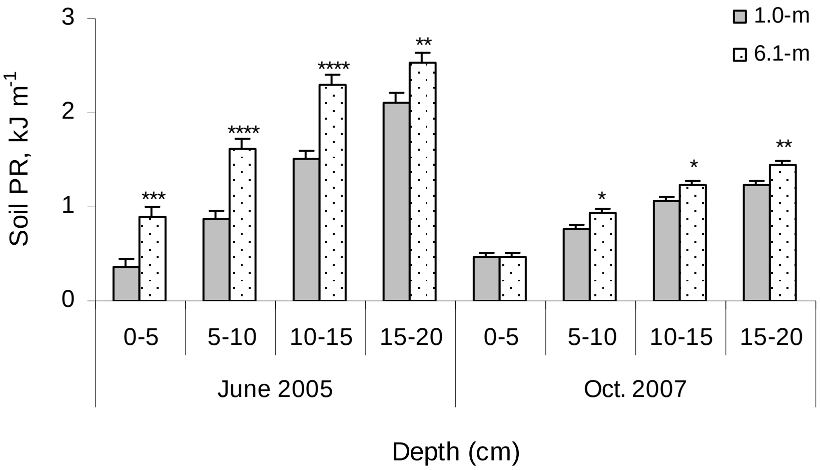

Figure II.8. Soil penetration resistance (PR) (LS means ± SE) for the 1.0-m versus 6.1-m alley position relative to the center of the tree base at different depths in young longleaf pine-bahiagrass silvopasture, June 2005 and October 2007, Americus, GA, USA (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ****$P < 0.0001$).

III CATTLE DISTRIBUTION AND BEHAVIOR IN LOBLOLLY-PINE SILVOPASTURE VERSUS OPEN-PASTURE

Abstract

Differences in environmental and forage parameters between silvopasture and open-pasture systems, and the possible influence of these differences on distribution patterns and behavior of cattle have not been quantified. The objectives of this research were: 1) to quantify diurnal distribution patterns and behavior of cattle in loblolly-pine (*Pinus taeda*) silvopasture versus open-pasture landscapes; 2) to relate the differences in available forage quantity and quality and microclimate between the two landscapes to possible differences in distribution patterns and behavior of cattle. This research was conducted at Owens' Farm, Chipley, FL, USA within a 20-yr old loblolly pine-bahiagrass (*Paspalum notatum*)-crimson clover (*Trifolium incarnatum*) silvopasture (5 ha) and a nearby open-pasture (5 ha) with a similar forage composition and access to a 1.6-ha wooded habitat. One-day observations of diurnal distribution patterns and behavior of cattle were conducted in March, June, and September to sample animal response to various weather conditions during the 2007 grazing season. Forage samples were collected from both pastures to estimate quantity and quality of available forage; weather data were collected from stations located in each pasture to characterize microclimatic conditions for each observation period. The diurnal distribution patterns of cattle were more even in the silvopasture versus the open pasture landscape and were attributed to less extreme microclimatic conditions recorded in the silvopasture, particularly reduced solar radiation. Grazing was the dominant behavior of cattle in silvopasture, while loafing or lying was the most dominant behavior in open-pasture. Shade present in silvopasture systems appears to reduce heat stress associated with weather parameters that characterize warm-season portions of the annual grazing season in the Coastal Plain of Southeast USA.

Key words: Forage, Grazing, Landscape utilization, Microclimatic conditions

Introduction

Even distribution of cattle on pasture is crucial for optimal forage plant utilization and persistence, uniform nutrient cycling within the system, and sustainable land use. Distribution of cattle among different habitats may vary depending on prevailing weather conditions. During hot days, cattle may congregate in areas where shade and water are available (Blackshaw and Blackshaw 1994; Daly 1984; Hart et al. 1993; Smith et al. 1992). In a study of cattle use of habitats within heterogenous landscapes in North Alabama, Zuo and Miller-Goodman (2004) found the most uneven landscape distribution of beef cattle (*Bos taurus*) in August, the warmest month of the study, when cattle spent the majority of diurnal time (dawn-to-dusk) lying down or loafing (activities other than grazing or lying) in wooded habitats, while grazing occurred mainly in shaded areas of grassland habitats close to wooded or shaded riparian habitats. During cooler months (March and October), cattle showed preference for grassland and wooded habitats and least preference for riparian habitat (Zuo and Miller-Goodman 2004).

To minimize uneven distribution of cattle within a pasture, development of silvopasture could be a management option for the Coastal Plain of Southeast USA. Trees provide shelter and can protect animals from heat stress associated with weather parameters (Gold et al. 2000) that characterize much of the spring, summer, and early fall portions of the annual grazing season in this region. Besides providing protection from direct sunlight, trees create evaporative cooling which facilitates heat transfer from animals (Blackshaw and Blackshaw 1994). Furthermore, even when artificial shade is available in pastures in the Southeast, Zuo and Miller-Goodman (2004) reported that cattle preferred the shade provided by trees. Because shade that occurs in silvopasture is both natural and well-distributed, the distribution of grazing cattle in silvopasture landscape may differ from that in an open-pasture (pasture without trees). Besides shading, trees can also alter other microclimatic conditions as well as forage productivity and quality (Bird 1998; Kort 1988; Valigura and Messina 1994) and eventually influence behavior of grazing cattle. However, differences in microclimatic conditions and forage productivity and quality between silvopasture and open-pasture, and the possible influence of these differences on distribution patterns and behavior of cattle, have not been quantified.

This study was conducted to test two hypotheses: 1) diurnal distribution patterns of cattle would be more even in silvopasture versus open-pasture; 2) diurnal behavioral patterns of cattle would differ between silvopasture and open-pasture. The objectives of this research were: 1) to quantify diurnal distribution patterns and behavior of cattle in silvopasture versus open-pasture landscapes; 2) to relate available forage quantity and quality and microclimatic differences between the two landscapes to possible differences in distribution patterns and behavior of cattle.

Methods

Study site and design

This study was conducted during three portions of the 2007 grazing season at Owens' Farm, Chipley, Florida panhandle ($30^o46'46.53"$ N, $85^o32'18.51"$ W) in two 5-ha pastures: one within a 20-yr old loblolly-pine (*Pinus taeda*)-bahiagrass (*Paspalum notatum*)-crimson clover (*Trifolium incarnatum*) silvopasture with a tree density of 247 ha^{-1} and a nearby open-pasture with access to a 1-ha wooded area (Fig. III.1). To assess the distribution patterns and behavior of cattle, the whole area of silvopasture under study was delineated into four (March) or five zones (June, September: one zone open); one zone contained the water source (Fig. III.1A). The open-pasture was delineated into six zones with the area around water source and wooded habitat (1.6 ha) designated as separate zones (Fig. III.1B). Cattle had free access to every zone in each pasture. The experimental design was a split-split-plot in time with pasture type as the main plot, observation date as the split-plot, and portions of a diurnal period as the split-split plot.

Observation of cattle distribution and behavior

Six to eight mature dry beef cows (*Bos taurus*) were stocked onto each pasture two days prior to each observation day. Distribution patterns and behavior of each animal were monitored simultaneously (one observer per landscape) in each pasture from tree stands established at 6-m from the ground and located such that grazing animals would not be distracted as a result of the observer's activities. Observations were made with binoculars every 15 minutes and recorded from dawn-to-dusk (diurnal) for each observation date in March, June, and September 2007. The diurnal observation period was 13 hours in March for both pastures, 15 hours for silvopasture and 15.25 hours for open-pasture in June, and 12.75 hours for silvopasture and 12 hours for open-pasture in September. Behavior categories recorded included grazing, lying, and loafing; loafing represented activities other than grazing or lying, such as moving, standing, scratching, or playing.

Forage sample collection

To estimate available forage biomass, ten random 0.25-m^2 quadrats were clipped to 5 cm within each pasture on the previous day of each observational study date. Forage tissue samples were dried at 60°C for 72 h then ground to pass a 1-mm sieve. All tissue samples were analyzed for acid detergent fiber (ADF) following the method of Goering and Van Soest (1970) and for nitrogen (N) using the Kjeldahl method to estimate total digestible nutrients (TDN) and crude protein (CP).

Weather data collection

HOBO© (Onset Computer Corp., Bourne MA 02532) weather stations were established in each landscape to monitor microclimatic conditions. Within each landscape, total solar radiation, air temperature, wind and gust speeds, soil temperature at 5-cm and 10-cm depths, relative humidity, and dew point were sampled every five minutes for a two-minute period during the observation periods.

Data analysis

Distribution patterns of cattle were quantified using the Distribution Evenness Index (DEI) developed by Zuo and Miller-Goodman (2003). DEI and behavior data as well as weather data for each observation day and landscape type were divided into three groups based on diurnal periods: morning (dawn-1100h), midday (1100h-1400h), and post-midday (1400h-dusk). The equation used for calculating DEI is presented below.

$$DEI = \left(-\sum_{i=1}^{z} pi \ln pi \right) / \ln z$$

Where,

pi = the proportion of cattle present in a particular zone at a particular diurnal period

z = number of zones included in the study

Because of a serious non-normality, DEI and behavior data were analyzed using the Wilcoxon rank-sum test (Gibbons and Chakraborti 2003) in the SAS package 9.1. Forage biomass and quality data were also analyzed using the Wilcoxon rank-sum test because of an inadequate number of observations to verify the assumptions of parametric tests. Exact P value was used for the hypothesis test; probability level of alpha for rejection of the H_0 (null hypothesis) was set at 0.05. Average values of weather parameters were tabulated for all observation dates and diurnal periods for each pasture type.

Results

Cattle distribution and behavior

The distribution evenness index (DEI) of cattle remained higher in silvopasture versus open-pasture for all diurnal periods regardless of the observation date except for the 1400h-dusk diurnal period in June, when the DEI was similar for both pastures (Table III.1). Cattle in silvopasture were distributed in different zones during morning (dawn-1100h) and post-midday (1400h-dusk) hours but congregated in a specific zone during midday (1100h-1400h) (Fig. III.2A). Around midday in June and September, cattle congregated in the silvopasture water zone or the zone next to the water zone, however during midday in March, they congregated in a zone away from the water zone. In the open-pasture in March, cattle spent most of the morning and post-midday hours in the tree zone, and spent midday hours in the open zones or water zone (Fig. III.2B). However, in June, cattle in the open-pasture remained in the tree zone during most of the morning hours and the entire midday period, then spent most of the post-midday hours in the open zones. In September, cattle in the open-pasture remained in the water zone most of the time including the entire period during midday. During the observation period in September, in addition to the tree zone, shade was present from trees that were outside the fence that bordered the open-pasture water zone.

Average diurnal time spent grazing remained higher in silvopasture versus open-pasture for all the observation dates (Table III.2). Cattle spent 50% (6.4 h; September) to 63% (9.4 h; June) of diurnal time grazing in silvopasture; however, in open-pasture, cattle grazed for 26% (3.1 h; September) to 40% (6.0 h; June) of the total diurnal period. Time spent loafing or lying in silvopasture remained lower than or similar to that in open-pasture. Time spent loafing was highest in September in both pastures, however, highest loafing time in silvopasture (29%) was much lower than in open-pasture (54%). Time spent lying was highest in March in silvopasture (25%) and in June in open-pasture (31%).

In silvopasture, grazing was the most dominant behavior during morning and post-midday hours, and time spent grazing around midday remained similar to or less than loafing or lying time (Fig. III.3A). No zone preference was observed for any behavior of cattle in silvopasture except around midday in June and September, when loafing or lying mostly occurred nearby the water source. In open-pasture, cattle did not graze during midday except in March, when cattle spent more time grazing than loafing or lying (Fig. III.3B). Grazing time remained less than loafing or lying time, except for around midday in March and post-midday hours in June when grazing was the most dominant behavior. Loafing and lying behavior mostly occurred in the tree zone in March and June, and in the water zone in September. In both pastures, cattle spent the least time grazing in September when the available forage biomass was the highest, and the most time grazing in June when the available biomass was the lowest in open-pasture but moderate in silvopasture.

Forage biomass and quality

Forage shoot dry matter (SDM) available in silvopasture was lower in March and September, but higher in June when compared to that in open-pasture (Table III.3). Concentrations of both CP and TDN were highest for March forage and lowest for

September forage in both pastures. Both CP and TDN concentrations were lower in forage from silvopasture versus open-pasture for all the observation dates except in September, when CP was similar for both pastures. Forage was uniformly available in all silvopasture zones; there was no available forage in the tree zone associated with the open-pasture.

Microclimatic conditions

Wind speed, gust speed, solar radiation, and dew point were lower in the silvopasture versus the open-pasture landscape for all the observation dates and diurnal periods (Table III.4). During the study period, wind speed was 29 to 58% lower in silvopasture versus open-pasture, except during morning hours in June when wind speed was 2% higher in silvopasture. Gust speed was 23 to 58% lower and solar radiation was 14 to 58% lower in silvopasture versus open-pasture. With few exceptions, relative humidity (RH) and air and soil temperatures were also lower in silvopasture versus open-pasture. The highest difference in RH between pasture types was found in the morning and during midday hours in June, when RH levels in silvopasture were approximately nine points lower in the morning and 14 points lower during midday hours than in open-pasture. The maximum difference between pasture types was less than 1.5^{o}C for air temperature and 2.5^{o}C for soil temperatures.

Discussion

The higher DEI observed in silvopasture versus open-pasture for almost all observation dates and times was directly related to the less stressful environment recorded for the silvopasture landscape. Solar radiation was the major microclimatic parameter that was lower (by 14-58%) in silvopasture than in open-pasture during all observation periods. Also, lower RH, dew point, and air and soil temperatures in silvopasture versus open-pasture contributed to milder microclimatic conditions within the silvopasture landscape. In open-pasture during the June and September observation periods, cattle congregated in the shaded area to minimize heat stress (Blackshaw and Blackshaw 1994; Daly 1984; Hart et al. 1993; Smith et al. 1992; Zuo and Miller-Goodman 2004). The quality and quantity of available forage were enough to fulfill the dry matter requirement of the class of cattle (Cunningham et al. 2005; Rankins 2001) present in both pastures for the study period, and did not noticeably influence distribution patterns.

More time spent grazing and less or similar time spent loafing or lying by cattle in silvopasture versus open-pasture could be the result of less stressful microclimatic conditions in silvopasture, especially when the weather was very hot and humid. Tucker et al. (2008) found decreased time spent grazing by dairy cattle with increased heat load index. Also, the longer time cattle spent grazing in silvopasture versus open-pasture in March and September might have been related to lower biomass and quality of available forage in silvopasture during those observation dates. Intake rates of grazing herbivores may increase in areas of dense forage (Bailey et al. 1996) while in sparse-forage areas grazing herbivores compensate for a lower short-term intake rate by increasing grazing time to maintain daily intake (Allison 1985; Demment and Greenwood 1988). Also, pine needles present in the silvopasture forage might have reduced the intake rate of cattle trying to avoid them resulting in the longer grazing hours to maintain daily intake; further study is needed to confirm this relationship.

Cattle in silvopasture spent more time grazing during morning and post-midday hours, and loafing or lying during midday hours for all observation dates. However, Zuo and Miller-Goodman (1994) reported grazing as the dominant behavior for all diurnal periods during the cool-season (March and October) but only for morning and evening hours during the warm-season (May, July, and August). Differences in the behavior patterns of cattle in the cool-season between this study and that of Zuo and Miller-Goodman (2004) could be the result of lower diurnal temperatures (in March and October) in their study area in North Alabama compared to the Florida panhandle where this study was conducted.

In the open-pasture, cattle spent more time loafing or lying for most of the observational periods. This behavior was related to more stressful microclimatic conditions as well as higher quantity and quality of available forage in the open-pasture as compared to silvopasture. Cattle in open-pasture spent the least time (3.1 h) grazing when available forage was highest (4008 kg ha^{-1}) and diurnal period was shortest (12 h) in September, and the most time (6.0 h) grazing when available forage was lowest (453 kg ha^{-1}) and diurnal period was longest (15.25 h) in June. Diurnal time spent grazing by cattle in silvopasture (7.4 h, March; 9.4 h, June; 6.4 h, September) was comparable to that reported in previous studies (Hart et al. 1993; Zuo and Miller-Goodman 2004). However, grazing time in open-pasture remained 36 to 52% lower than in silvopasture.

Conclusions

The diurnal distribution patterns of cattle were more even in the silvopasture than the open-pasture landscape; this difference was attributed to the less stressful microclimatic conditions present in silvopasture compared to the open-pasture landscape. Grazing was the dominant behavior in silvopasture, while loafing dominated behavior in open-pasture. Observed behavioral differences were associated with variation in both microclimatic conditions and quantity and quality of available forage between pasture types. Shade present in silvopasture systems appears to reduce heat stress associated with weather parameters that characterize warm-season portions of the annual grazing season in the Coastal Plain of Southeast USA. Further study is needed to determine how this reduction in heat stress influences cattle performance in this environment.

Acknowledgements

The authors acknowledge the generous cooperation of Mr. George Owens, Owens Farm, Chipley, FL, USA for access to his property for location of weather stations and assistance with cattle stocking during observation dates, and the Southern Sustainable Agriculture Research and Education Program for financial support.

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Table III.1. Mean score (Wilcoxon rank-sum test) for distribution evenness index (DEI) and proportion of time spent in various behavior categories by cattle for different diurnal (dawn-to-dusk) periods in 20-yr old loblolly-pine silvopasture (Silvo) versus open-pasture (Open) on different observation dates, 2007, Chipley, FL, USA.

				Behavior category					
Observation date		DEI		Grazing		Loafing		Lying	
	Diurnal period	Silvo	Open	Silvo	Open	Silvo	Open	Silvo	Open
March 26th	Dawn-1100h	28[†]^{a****}	15^{b}	25^{a*}	17^{b}	21	21	19	23
	1100h-1400h	17^{a***}	8^{b}	11	14	10^{b}	15^{a*}	16^{a**}	9^{b}
	1400h-dusk	28^{a****}	14^{b}	26^{a**}	15^{b}	15^{b}	28^{a***}	21	21
June 29th	Dawn-1100h	38^{a****}	13^{b}	32^{a**}	19^{b}	21^{b}	30^{a*}	21^{b}	30^{a*}
	1100h-1400h	19^{a****}	7^{b}	18^{a****}	8^{b}	14	11	7^{b}	18^{a****}
	1400h-dusk	27	23	25	25	24	26	26	24
Sept. 17th	Dawn-1100h	26^{a**}	16^{b}	23	19	19	23	22	20
	1100h-1400h	19^{a****}	7^{b}	16^{a*}	10^{b}	10^{b}	15^{a*}	12	13
	1400h-dusk	26^{a***}	14^{b}	25^{a**}	15^{b}	14^{b}	26^{a**}	19	21

[†] Mean score with different superscript in a row within DEI or a behavior category are different (*P< 0.05, **P<0.01, ***P<0.001, ****P<0.0001).

Table III.2. Average percentage of diurnal time spent by cattle grazing, loafing, or lying, and corresponding mean score (Wilcoxon rank-sum test) in 20-yr old loblolly-pine silvopasture (Silvo) versus open-pasture (Open) for different observation dates, 2007, Chipley, FL, USA.

Observation date	Behavior category					
	Grazing		Loafing		Lying	
	Silvo	Open	Silvo	Open	Silvo	Open
	%					
March 26th	57	34	18	43	25	23
June 29th	63	40	22	30	15	31
September 17th	50	26	29	54	20	19
	Mean score					
March 26th	$62^{\dagger a**}$	45^{b}	44^{b}	63^{a***}	54	53
June 29th	72^{a***}	52^{b}	58	66	54^{b}	70^{a**}
September 17th	61^{a**}	44^{b}	42^{b}	63^{a***}	51	54

[†] Mean score with different superscript in a row within a behavior category are different (**P<0.01, ***P<0.001).

Table III.3. Shoot dry matter (SDM), crude protein (CP), and total digestible nutrients (TDN) of forage sampled from 20-yr old loblolly-pine silvopasture (Silvo) versus open-pasture (Open) and corresponding mean score (Wilcoxon rank-sum test) for different sampling dates, 2007, Chipley, FL, USA.

	SDM		CP		TDN	
Sampling date	Silvo	Open	Silvo	Open	Silvo	Open
	Mean ± SE					
	----------- kg ha^{-1}----------		----------------------------%------------------------			
March 25th	561 ± 091	1435 ± 191	14 ± 1.3	18 ± 1.4	66 ±1.4	71 ± 1.4
June 28th	803 ± 117	453 ± 030	11 ± 0.7	16 ± 1.1	61 ± 0.5	66 ± 0.7
Sept. 16th	2071 ± 127	4008 ± 340	8 ± 0.3	9 ± 1.2	58 ± 0.5	62 ± 1.2
	Mean score					
March 25th	6.2[†]^{b}	14.8^{a***}	7.4^{b}	13.6^{a*}	7.3^{b}	3.8^{a*}
June 28th	14.8^{a***}	6.3^{b}	6.2^{b}	14.8^{a***}	6.1^{b}	15.0^{a***}
Sept. 16th	5.9^{b}	15.1^{a***}	11.3	9.8	6.3^{b}	14.7^{a***}

[†] Mean score with different superscript in a row within SDM, CP, or TDN are different (*P< 0.05, **P<0.01).

Table III.4. Average values for microclimatic parameters recorded in 20-yr old loblolly-pine silvopasture (Silvo) versus open-pasture (Open) on various observation dates and times, 2007, Chipley, FL, USA.

		Observation date								
		March 26th			June 29th			September 17th		
		Observation time								
Microclimatic parameters	Pasture type	Dawn-1100h	1100h-1400h	1400h-dusk	Dawn-1100h	1100h-1400h	1400h-dusk	Dawn-1100h	1100h-1400h	1400h-dusk
Wind speed (m s^{-1})	Silvo	1.01	1.30	0.88	0.37	0.99	0.73	0.80	1.21	0.89
	Open	1.49	2.58	2.03	0.37	1.40	1.46	1.93	2.66	2.02
Gust speed (m s^{-1})	Silvo	1.84	2.73	1.72	0.82	2.13	1.55	1.90	2.54	1.87
	Open	2.94	5.16	3.88	1.07	3.68	3.26	4.09	5.55	4.41
Total solar radiation (W m^{-2})	Silvo	160.53	341.53	170.59	294.49	530.56	165.81	168.35	329.20	152.31
	Open	316.03	670.23	277.67	342.88	752.12	233.09	313.71	725.69	359.14
Relative humidity (%)	Silvo	81.39	48.46	49.99	79.06	30.14	66.36	78.89	49.46	41.94
	Open	83.19	49.58	48.75	88.50	44.29	65.62	80.36	53.57	45.31
Dew point (°C)	Silvo	15.99	15.33	15.35	20.53	14.24	20.93	19.79	17.92	15.31
	Open	16.13	15.71	15.40	22.77	20.14	22.39	20.59	19.79	17.61
Air temperature (°C)	Silvo	19.56	27.17	26.91	25.36	34.26	28.39	23.87	29.67	29.68
	Open	19.35	27.19	27.32	25.48	34.06	29.80	24.34	30.31	30.82
Soil temperature at 5 cm (°C)	Silvo	17.43	19.32	20.23	25.80	28.86	28.67	24.85	26.05	26.60
	Open	17.04	18.62	19.69	26.78	31.22	31.12	25.98	28.27	28.95
Soil temperature at 10 cm (°C)	Silvo	17.40	18.74	19.81	25.78	27.86	28.33	25.01	25.86	26.50
	Open	17.22	20.45	21.05	26.47	28.56	29.78	26.01	27.29	28.44

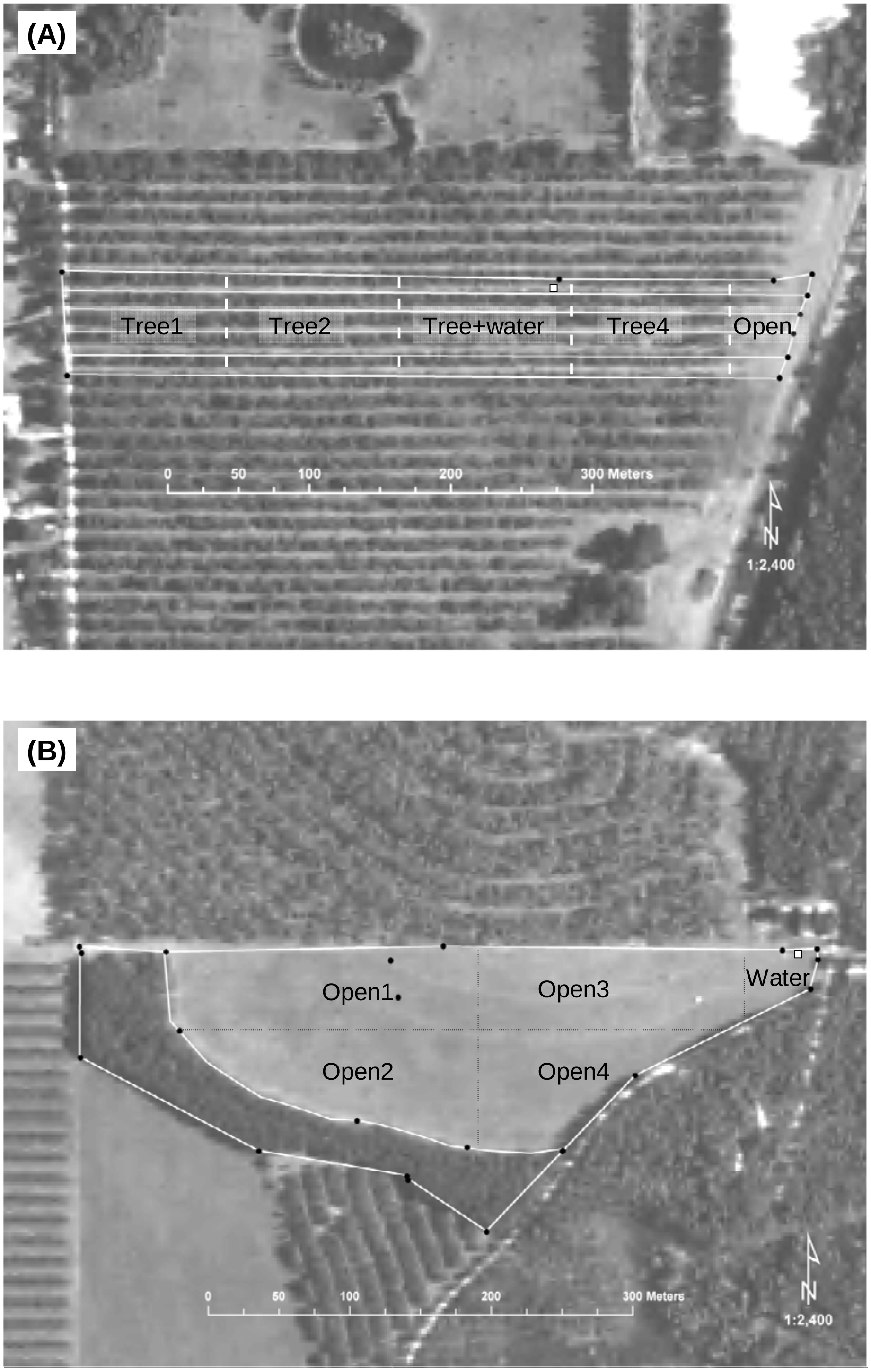
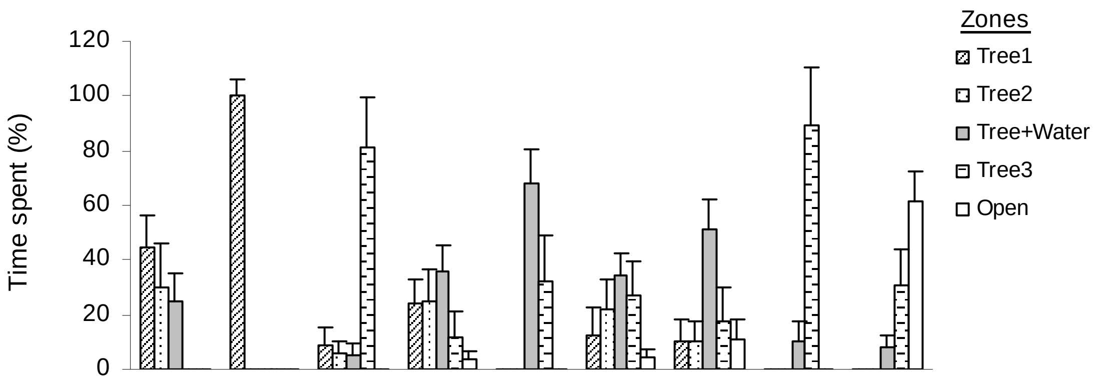
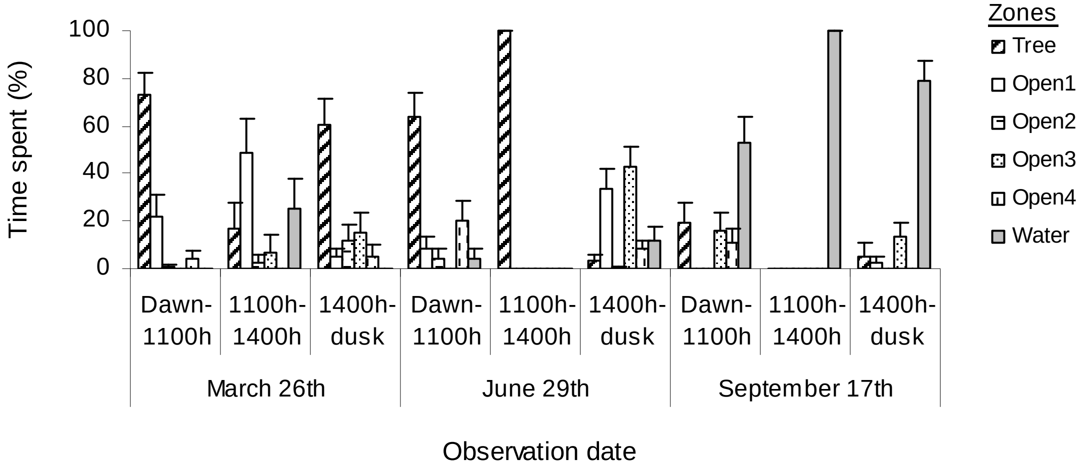


Figure III.1. Map of 20-yr old loblolly-pine silvopasture (A) and open-pasture (B) study area showing different zones for cattle distribution (triangle above the study area in each pasture indicates the observer's position), 2007, Owens' farm, Chipley, FL, USA.



(A) Silvopasture



(B) Open-pasture

Figure III.2. Average diurnal (dawn-to-dusk) time spent by cattle at different zones in the 20-yr old loblolly-pine silvopasture (A) and open-pasture (B) on various observation dates, 2007, Chipley, FL, USA.

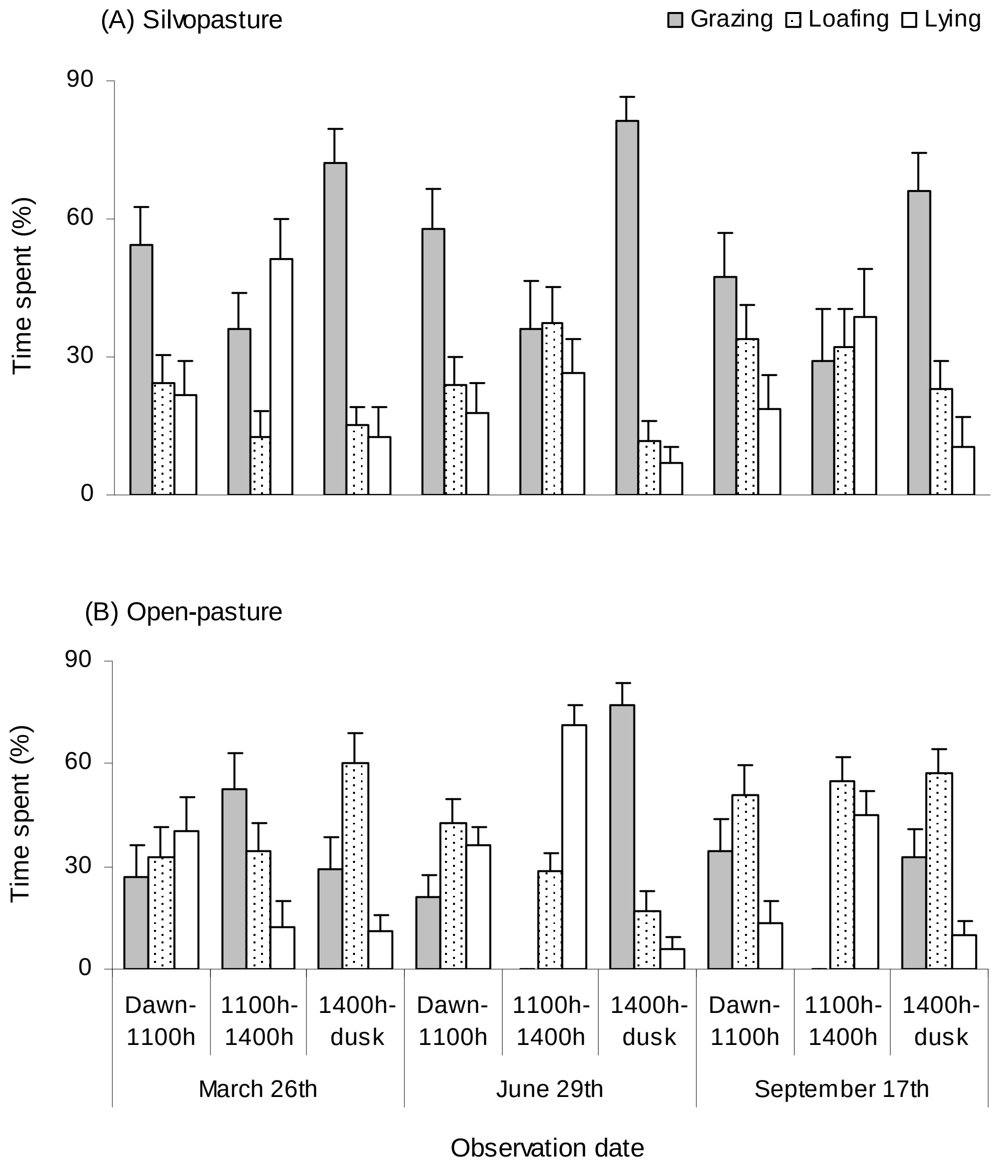


Figure III.3. Average diurnal (dawn-to-dusk) time spent grazing, loafing, or lying by cattle in the 20-yr old loblolly-pine silvopasture (A) and open-pasture (B) on various observation dates, 2007, Chipley, FL, USA.

IV FORAGE SPECIES AND pH INFLUENCE SHORT-TERM SOIL QUALITY RESPONSE

Abstract

Forages are important throughout the Southeast USA for both livestock feed and land cover. However, little is known about how different forage species adapted to this region influence soil quality characteristics. The objectives of this research were: 1) to compare the influence of various forage species and mixtures on response of water stable aggregates (WSA) and density of fungal hyphae (DFH) in a coastal plain soil at identical pH levels, and 2) to compare the influence of an individual forage species or mixture on response of WSA and DFH at field-state versus adjusted soil pH levels. Eleven cool-season (monoculture or legume-grass mixtures) and nine warm-season forage species (monoculture) were grown under protected culture in coastal plain soil microcosms. Soil quality and plant parameters were evaluated after three 12-week experimental periods: fall 2005 (field–state soil, pH 5.0); summer (field-state soil, pH 5.0 vs. adjusted-pH soil, pH 6.9) and fall 2006 (field-state soil, pH 4.8 vs. adjusted-pH soil, pH 6.5). Levels of WSA in soil that supported subterranean clover (*Trifolium subterraneum*) were significantly greater than or equal to levels observed in soil at both pH levels that supported other cool-season legumes, grasses, or mixtures studied. A similar relationship was found between Illinois bundleflower (*Dismanthus illinoensis*) and other warm-season forage species studied in soils at both pH levels. Levels of DFH observed in soils that supported the growth of warm-season grass species were greater than levels observed in soils that supported warm-season legumes. Both WSA and DFH levels were higher in soils at field-state versus adjusted pH levels for several cool-season and warm-season forage species. Further long-term studies under protected culture and field conditions are needed to understand how these relationships are expressed in more variable environments over expanded time frames.

Key words: Aggregate stability, Grass, Legume, Southeast USA

Abbreviations

AL – Alabama

CIR – Cave-In-Rock

DFH – Density of fungal hyphae

FL – Florida

GA – Georgia

IL – Illinois

LS means – Least-squares means

PSRC – Plant Science Research Center

RDM – Root dry matter

SDM – Shoot dry matter

TFE – Endophyte-infected tall fescue

TFNoE – Endophyte-free tall fescue

TFNvE – Novel-endophyte-infected tall fescue

USA – United States of America

WSA – Water stable aggregates

Introduction

Forage crops are an important land cover in the Southeast USA (Ball et al. 1996) and form the basis of the farm economy associated with livestock production in this region (Bouton 2007). In the last few decades, many studies have focused on maximizing quality and productivity of forages, and tangible progress has been achieved in this regard (Ball et al. 1996). Ball et al. (1996) have listed 64 forage species commonly grown or found in the Southeast USA. However, despite the diversity of forages adapted to this region, research on the influence of these forages on soil quality, an important factor in long-term pasture productivity, remains meager.

Soil aggregate stability, the resistance of soil aggregates to the destructive effect of water**,** is one of the major physical indicators of soil quality (Singer and Ewing 2000) and soil productivity (Franzluebbers et al. 2000). Soil aggregate stability is important for stabilization of the land surface, maintenance of porous structure, enhanced infiltration, and reduced erosion. Porous soil structure facilitates air and water movement, root growth, and microbial activity. Soil aggregates conserve organic matter from rapid degradation (Van Veen and Kuikman 1990) and thereby maintain long-term fertility. The role of fungi in aggregate formation and stabilization has been highlighted in many studies. Fungal hyphae may directly enmesh soil into aggregates and produce polysaccharides and other protein and lipidic compounds which promote stability through cementing (Kay and Angers 2000; Klironomos 2000).

Studies conducted on forage and crop species have revealed that plant species can have a significant impact on both aggregate stability and density of fungal hyphae. Haynes and Beare (1997) found higher aggregate stability under lupin, white clover, and Italian ryegrass as compared to other non-legume species studied. They also reported higher fungal hyphal length in aggregates associated with lupin growth as compared to wheat growth. Reid and Goss (1981) reported that aggregate stability was increased in soils that supported perennial ryegrass and lucerne growth, but decreased in soils that supported the growth of maize, tomato, or wheat.

Previous studies have presented conflicting results concerning the influence of pH on aggregate stability. Some studies have reported enhanced aggregate stability with increased pH (Baldock et al. 1994; de Castro et al. 1999; Chan and Heenan 1999), while another study found increased clay dispersion with lime application (Roth and Pavan 1991). An understanding of the impacts of lime application on all aspects of pasture soil quality is especially important since interest in legume use as nitrogen (N) source has increased dramatically as costs for synthetic N fertilizer continue to rise; lime application to acid soils is a standard recommendation for increased legume establishment success and persistence in Southeast environments. However, information on the influence of liming (pH change) on soil aggregate stability and density of fungal hyphae in soils that support growth of forage species adapted to the Southeast USA is scarce. Therefore, this research was conducted with the following hypotheses and objectives.

Hypotheses

1. Levels of soil water stable aggregates and density of fungal hyphae would differ depending on forage species grown.
2. Levels of water stable aggregates and density of fungal hyphae would vary with soil pH level when supporting a particular forage species.

Objectives

1. Compare the influence of various forage species and mixtures on short-term response of water stable aggregates (WSA) and density of fungal hyphae (DFH) at identical soil pH levels under protected culture.
2. Compare the influence of individual forage species or mixtures on short-term response of WSA and DFH at field-state versus adjusted soil pH levels under protected culture.

Methods

Three 12-week experiments were conducted during fall 2005, and summer and fall 2006 at the Plant Science Research Center (PSRC), Auburn University, Auburn, Alabama (AL), USA. During fall 2005, both cool-season and warm-season forage species were sown in field-state soil (pH 5.0) starting September 14. Study on the warm-season forage species was repeated during summer 2006 with sowing on May 25 and on cool-season forage species during fall 2006 with sowing on September 15; forages were grown at both field-state and adjusted soil pH levels during these periods. Eleven cool-season forage species or mixtures and nine warm-season forage species (Table IV.1) were designated as treatments; a control treatment (no plants present) was included each season at each pH level. The experimental design was a randomized complete block with five replications of each treatment combination (forage species or mixture + pH level) and the control.

Soil microcosm preparation and seeding

An Orangeburg loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults) was collected (0-15 cm) from the Jimmy Carter Plant Materials Center, Americus, Georgia (GA), USA, was sieved through a 15-cm sieve on site then transported to the PSRC greenhouse. The field-state soil was then sieved through a 2-mm sieve in the field-moist state and microcosms constructed by filling plastic pots (8.5x8.5 cm^2 bottom area, 10.5x10.5 cm^2 top area, 12.5 cm depth) with 1 kg soil each. For the summer and fall 2006 studies, each forage species or mixture treatment was sown in both field-state and adjusted-pH soil treatments. The field-state pH treatment consisted of 2-mm soil with no lime addition. For the adjusted-pH treatment, a composite sample of 2-mm soil was tested for its original pH (1:1 soil water solution). Pulverized dolomitic limestone was added to the 2-mm soil and mixed thoroughly to raise the soil pH by approximately 1.5 units then reanalyzed. Other soil characteristics of interest for the field-state soil prior to sieving and pH adjustment were: particle size distribution of 850 g kg^{-1} sand, 125 g kg^{-1} silt, 25 g kg^{-1} clay; 22 g kg^{-1} organic matter; cation exchange capacity 6.23 cmol kg^{-1}.

Before sowing, soil in each microcosm was wetted with tap water. Field-state and adjusted-pH soil treatments were each randomly allocated to five replications within each pH level, and each species treatment was allocated randomly to each replication. An equal amount of seed was sown for each replicate within each treatment to uniformly cover the soil surface area; the sown seed was then covered with a thin layer of soil with appropriate pH level. Sown microcosms of each replication were randomly allocated to the designated greenhouse bench (cool-temperature or warm-temperature zone) according to the experimental design. The day/night temperature settings for the cool-temperature zone were 24^{o}C/21^{o}C, and 28^{o}C/21^{o}C for the warm-temperature zone.

Care and management of plants

Soil in each microcosm was watered daily to maintain the moisture level at approximately 85% of field capacity. When seedlings were well-established, unwanted seedlings were thinned to leave six uniform, healthy seedlings per microcosm. For the mixtures, three seedlings of each species were maintained in each pot. Pesticides were sprayed according to the regular insect management routine of the greenhouse as well as whenever insects appeared; weeds were removed manually as they appeared. During fall

2005, 250 ppm NPK fertilizer (9:45:15) was applied as a solution to the field-state (pH 5.0) soil in each microcosm on alternate days for the last 25 days of the experiment based on an apparent plant nutrient deficiency symptom (chlorosis). No fertilizer was needed during summer and fall 2006. Treatments within each replication were re-randomized weekly to minimize possible variation among treatments caused by the greenhouse environment.

Soil and plant collection and analyses

Plant shoots were harvested at soil level after 12 weeks of sowing, dried at 60°C for 72 hours then weighed. Soil samples were collected for determination of root biomass, water stable aggregates (WSA), and density of fungal hyphae (DFH) by dividing the entire soil volume of each microcosm lengthwise into two equal halves with a sharp knife. One-half of the soil volume was used for determination of root biomass. The remaining one-half of the soil volume was sub-divided in half lengthwise resulting in two fourths: one-fourth of the soil volume was used for determination of WSA; the top 2.5 cm of the remaining one-fourth of the soil volume was used to estimate DFH. The portion of the soil volume for WSA determination was sieved through a 2-mm sieve, allowed to air dry, then analyzed following the method of Nimmo and Perkins (2002) using an Eijkelkamp wet-sieving apparatus (Soil Moisture Equipment Corp., Goleta CA) equipped with 0.250-mm sieves; 2.0 g L^{-1} NaOH was used as the dispersing agent. The portion of the soil volume designated for root dry matter and DFH was kept cool (4°C) until analyses were completed within 14 days of collection. Root cores were washed over a sieve (500-µm), debris removed, and root tissue dried at 60°C for 72 hours then weighed. DFH was estimated using the membrane filter technique described by Bardgett (1991) to prepare two 13-mm diameter membrane filters for each sample. These filters were examined under a microscope at 200x magnification by observing five fields of view for each filter; total hyphal length for each filter was estimated following method 4 of Olson (1950). Average hyphal length determined from the two filters prepared for each sample was used to estimate DFH in m g^{-1} of wet soil. This value was then converted to m g^{-1} of oven-dried soil based on the gravimetric water content of a subsample of the 2.5-cm DFH soil sample separated prior to processing for filter preparation.

Data analysis

The mixed procedure (SAS 9.1) was used to analyze the data with block as a random factor (Littell et al. 2006). Multiple comparisons among treatment means were performed by using the Tukey-Kramer method. Analyses were also performed for Pearson product-moment correlation coefficients (r) to quantify the association among plant and soil variables. Probability level of alpha for rejection of the H_0 (null hypotheses) in favor of H_a (alternative hypotheses) was set at 0.05. The general model used to analyze shoot biomass and soil quality data is presented below.

$$Yijk = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ijk}$$

Where, Y_{ijk} = value of an observation taken in kth block with jth pH level and ith forage species treatment

μ = grand mean

α_i = main effect of ith forage species treatment

β_j = main effect of jth pH level

$(\alpha\beta)_{ij}$ = interaction effect of i^{th} forage species treatment and j^{th} pH level

e_{ijk} = error associated with k^{th} block with j^{th} pH level and i^{th} forage species treatment

Results

Soil quality response to forage species at identical pH levels

Among the cool-season forage species grown in field-state soil (pH 5.0) during fall (Aug.-Dec.) 2005, average levels of water stable aggregates (WSA) in soil that supported subterranean clover were higher than in soils that supported red clover, crimson clover, endophyte-infected tall fescue-crimson clover mixture, endophyte-free tall fescue-crimson clover mixture, Gulf ryegrass, or the control (Table IV.1). Levels of WSA in soils that supported all other forage species or mixtures were not different. Density of fungal hyphae (DFH) observed in field-state soil (pH 5.0) that supported cool-season forage species grown during fall 2005 was higher for Marshall ryegrass than for endophyte-infected tall fescue, the novel-endophyte-infected tall fescue-crimson clover mixture, or the endophyte-free tall fescue-crimson clover mixture (Table IV.1). Levels of DFH observed in field-state soil that supported all other forage species or mixtures, or the control were not different.

Among the warm-season forage species grown during fall 2005, levels of WSA observed in field-state soil (pH 5.0) that supported bahiagrass, little bluestem, big bluestem, Cave-In-Rock (CIR) switchgrass, or Illinois (IL) bundleflower were higher than in field-state soil that supported partridge pea or Florida (FL) beggarweed (Table IV.1). The DFH levels observed in field-state soil (pH 5.0) that supported little bluestem or CIR switchgrass was higher than levels observed in field-state soil that supported sericea lespedeza, big bluestem, FL beggarweed, or the control (Table IV.1). Field-state soil that supported little bluestem also had higher DFH levels than did field-state soil that supported partridge pea. The DFH levels observed in field-state soil that supported all other forage species were not different.

During fall (Sept.-Dec.) 2006, levels of WSA observed in field-state soil (pH 4.8) that supported endophyte-infected tall fescue, endophyte-free tall fescue, or the endophyte-infected tall fescue-crimson clover mixture were higher than levels observed in field-state soils that supported Marshall ryegrass or the control (Table IV.2). Also, levels of WSA observed in field-state soil that supported Gulf ryegrass were higher than levels observed in field-state soil that supported Marshall ryegrass. In addition, levels of WSA in field-state soil that supported endophyte-free tall fescue were higher than levels in field-state soil that supported red clover, and levels of WSA observed in field-state soil that supported the endophyte-infected tall fescue-crimson clover mixture were higher than levels observed in field-state soil that supported crimson clover or red clover.

Unfortunately, crimson clover treatments (monoculture or mixtures) grown in adjusted-pH (pH 6.5) soil during fall 2006 were excluded from data analysis because of a combined spider mite-aphid infestation that retarded growth before the infestation could be brought under control. These insects showed preference only for crimson clover grown in adjusted-pH soil and did not infest other species grown. Among the other cool-season forage species studied during fall 2006, average levels of WSA observed in adjusted-pH soil that supported endophyte-free tall fescue or subterranean clover were higher than in adjusted-pH soil that supported novel-endophyte-infected tall fescue, red clover, or the control (Table IV.2). Similarly, levels of WSA observed in adjusted-pH soil that supported endophyte-infected tall fescue were higher than levels observed in adjusted-pH soil that supported novel-endophyte-infected tall fescue or the control.

Levels of WSA observed in adjusted-pH soil that supported all other forage species were not different. Levels of DFH were not different at either soil pH level for any cool-season forage species or the control during fall 2006 (Table IV.2).

Among the warm-season forage species grown during summer (May-Aug.) 2006, levels of WSA observed in field-state soil (pH 5.0) that supported bahiagrass, big bluestem, CIR switchgrass, Alamo switchgrass, or IL bundleflower were higher than levels observed in field-state soil that supported sericea lespedeza or partridge pea. Also, levels of WSA in field-state soil that supported bahiagrass and big bluestem were higher than levels in field-state soil that supported FL beggarweed. During the same experimental period, levels of WSA observed in adjusted-pH soil (pH 6.9) that supported bahiagrass, CIR switchgrass, Alamo switchgrass, IL bundleflower, or the control were higher than levels in adjusted-pH soil that supported sericea lespedeza, little bluestem, partridge pea, or FL beggarweed (Table IV.3).

Among the warm-season forage species studied during summer 2006, DFH level of field-state soil (pH 5.0) that supported little bluestem was higher than levels observed in field-state soil that supported sericea lespedeza, Alamo switchgrass, partridge pea, FL beggarweed, IL bundleflower, or the control (Table IV.3). In addition, DFH level in field-state soil that supported bahiagrass was higher than levels observed in field-state soil that supported sericea lespedeza, FL beggarweed, or the control. DFH levels observed in adjusted-pH soil (pH 6.9) that supported bahiagrass or IL bundleflower were higher than levels observed in adjusted-pH soil that supported sericea lespedeza or FL beggarweed, and DFH levels observed in adjusted-pH soil that supported big bluestem were higher than in adjusted-pH soil that supported FL beggarweed (Table IV.3).

Soil quality response to forage species at field-state versus adjusted-pH levels

Among the cool-season forage species grown during fall 2006, levels of WSA in field-state soil (pH 4.8) that supported novel-endophyte-infected tall fescue were higher than levels in adjusted-pH soil (pH 6.5) (Table IV.2). However, levels of WSA were not different for field-state compared to adjusted-pH soil that supported all other cool-season species or the control. DFH levels in soil that supported endophyte-infected tall fescue and Marshall ryegrass during the fall 2006 experimental period were higher at field-state compared to adjusted-pH level (Table IV.2). DFH levels in soil that supported other cool-season forage species or the control were not different between pH levels.

Among the warm-season forage species grown during summer 2006 (May-Aug.), WSA levels in field-state soil (pH 5.0) were higher compared to levels in adjusted-pH soil (pH 6.9) that supported sericea lespedeza, little bluestem, or FL beggarweed (Table IV.3). Soil that supported bahiagrass, little bluestem, big bluestem, CIR switchgrass, Alamo switchgrass, partridge pea, or FL beggarweed during the summer 2006 experimental period had higher DFH levels at field-state versus adjusted-pH level (Table IV.3).

Shoot and root dry matter

Among the cool-season forage species grown in field-state soil during fall 2005 (pH 5.0) and 2006 (pH 4.8), crimson clover and red clover each produced higher shoot dry matter (SDM) than did any other forage species or mixture; each mixture produced higher SDM than did any grass species alone (Table IV.4). Similarly, when grown in adjusted-pH soil (pH 6.5) during fall 2006, red clover produced higher SDM than any other cool-season forage species. When SDM was compared between field-state and adjusted-pH soil for any cool-season monoculture grown during fall 2006, all grass species produced higher SDM at the adjusted-pH level; however, legume species produced higher SDM at the field-state pH level. Among warm-season forage species, partridge pea and FL beggarweed each produced higher SDM than did any other species regardless of growing season and pH level (Table IV.5). During summer 2006, all grass species and IL bundleflower produced higher SDM when grown in adjusted-pH soil (pH 6.9) compared to field-state soil (pH 5.0). Conversely, partridge pea produced higher SDM when grown in field-state compared to adjusted-pH soil during the same experimental period.

With few exceptions, subterranean clover produced less root dry matter (RDM) than any other cool-season forage species regardless of experimental period or pH level (Table IV.4). Red clover produced higher RDM than did any other species grown during fall 2006 at either soil pH level. Also, RDM for most grass monocultures or subterranean clover was less than for any mixture grown during fall 2006 in field-state soil (pH 4.8). When RDM was compared between pH levels during fall 2006, production for all grass species was higher for the adjusted-pH (pH 6.5) compared to the field-state soil (pH 4.8) treatment; subterranean clover produced higher RDM in field-state versus adjusted-pH soil. Among warm-season species grown during fall 2005 (Table IV.5), FL beggarweed produced the highest RDM. Likewise, bahiagrass, big bluestem, Alamo switchgrass, and partridge pea produced higher RDM than did sericea lespedeza and little bluestem. When grown during summer 2006 in field-state soil (pH 5.0), big bluestem, partridge pea, and FL beggarweed produced higher RDM than did bahiagrass, little bluestem, CIR switchgrass, Alamo switchgrass, or IL bundleflower. When grown in adjusted-pH soil (pH 6.9) during the same experimental period, bahiagrass and big bluestem produced higher RDM than did any warm-season legume. When RDM for an individual warm-season species grown during summer 2006 was compared between soil pH levels, bahiagrass, big bluestem, Alamo switchgrass, and IL bundleflower produced higher RDM when grown in adjusted-pH versus field-state soil. Conversely, partridge pea and FL beggarweed produced higher RDM when grown in field-state versus adjusted-pH soil during the summer 2006 experimental period.

Correlations among plant and soil parameters

Significant negative correlations were found between WSA and SDM for cool-season forage species grown in field-state soil during fall 2005 (pH 5.0) and 2006 (pH 4.8), and warm-season forage species regardless of growing season and soil pH (Table IV.6). Correlations between WSA and RDM were significantly negative for cool-season forage species grown in field-state soil during fall 2006, and for warm-season forage species grown in field-state soil during fall 2005 and summer 2006. A significant negative correlation between WSA and shoot:root ratio was also observed for warm-season forage species regardless of experimental period or soil pH level. Correlations between WSA and DFH were positive for warm-season forage species grown during summer 2006 in both field-state and adjusted-pH soils.

Significant negative correlations were found between DFH and SDM for cool-season forage species grown during fall 2006 in field-state soil (pH 4.8), and warm-season forage species grown during summer 2006 in both field-state (pH 4.8) and adjusted-pH (pH 6.9) soils (Table IV.7). Also, significant negative correlations were detected between DFH and RDM for cool-season forage species grown during fall 2006 in field-state soil and with shoot:root ratio for warm-season forage species regardless of experimental period or soil pH level.

Discussion

The null hypothesis against the first alternative hypothesis that levels of soil water stable aggregates (WSA) and density of fungal hyphae (DFH) would differ depending on forage species grown was rejected for WSA levels in soil that supported both cool-season and warm-season forage species, and for DFH in soil that supported cool-season forage species grown during fall 2005 and warm-season forage species grown during both fall 2005 and summer 2006. Among the cool-season forage species, higher levels of WSA in field-state soil (pH 5.0) that supported subterranean clover versus field-state soil that supported red and crimson clovers grown during fall 2005, and higher levels of WSA in adjusted-pH soil (pH 6.5) that supported subterranean clover versus adjusted-pH soil that supported red clover grown during fall 2006 could be the result of differences among the clover species in nutrient and moisture demand and amount of exudate input to the rhizosphere. In the limited soil environment used in this study, high-biomass producing clover species (red and crimson) may have utilized most of the available soil nutrients and moisture resulting in their limited availability to microorganisms for enhanced aggregate formation and stabilization (Chan and Heenan 1999; Kay and Angers 2000; Sarah and Rodeh 2004). Also, exudate input to the rhizosphere might have been less for red clover and crimson clover than for subterranean clover, as red and crimson clovers produced higher shoot and root dry matter than subterranean clover. The finding that higher WSA levels were associated with lower root biomass production for subterranean clover is in agreement with the greenhouse study findings of Haynes and Beare (1997): higher aggregate stability levels were detected in soil that supported lupin (*Lupinus* *augustifolius*) and a similar aggregate stability was detected in soils that supported white clover (*Trifolium repens*) versus grasses studied, despite lower root biomass for the legumes. In addition, another greenhouse study by Piotrowski et al. (2004) that included both grass and non-grass species found that root biomass was not positively correlated with percent water stable aggregates, and suggested that other physiological or architectural mechanisms rather than root biomass may be responsible for aggregation.

Differences in WSA could also be the result of variations in root structure, especially presence of fine roots which can form a dense network that binds the soil aggregates (Kay and Angers 2000), and materials produced in the rhizosphere (Reid and Goss 1981; Haynes and Beare 1997) among the legume species. This relationship may also explain differences detected in WSA levels among grass species and grass-legume mixtures grown at field-state pH levels in this study. Negative correlations between WSA and shoot or root dry matter supports the earlier suggestion that plant species with higher shoot and root biomass might have extracted more nutrients and moisture from the soil. Thus, when compared to species producing less biomass, less root exudate could have been available to soil microorganisms from high-biomass producing forages for enhanced formation and stabilization of soil aggregates. Negative correlations between WSA and root dry matter could also have resulted from physical disintegration of soil aggregates by root penetration and weakening of aggregates by wetting-drying cycles with increased amplitude (Caron et al. 1992) as growth and development progressed.

Among the warm-season forage species, higher WSA levels in soils that supported bahiagrass, CIR switchgrass, or IL bundleflower than in soils that supported partridge pea or FL beggarweed could be explained by the relationship presented for differences in WSA levels among the cool-season forage species. Partridge pea and FL beggarweed both had consistently higher shoot dry matter than did any other individual grass or legume species, and stronger negative correlations were observed between WSA levels and shoot dry matter of warm-season forage species than was observed with cool-season forage species.

Few differences in DFH among field state (pH 5.0) soil that supported different cool-season forage species were observed during fall 2005, and no differences were detected when the same species were grown at either pH level during fall 2006. Possible differences in nutrient status between the 2005 and 2006 study periods might have contributed to lack of response for DFH levels. Limited response of DFH levels to forage species may be because of the limited soil available to the fungal hyphae to scavenge and supply mineral nutrients (Klironomos 2000) to mycorrhizal roots. Also, it is possible that plant roots were able to access every portion of the given quantity of microcosm soil thereby minimizing the possible role of fungal hyphae in nutrient supply.

Among the warm-season forage species studied, higher DFH levels were observed in field-state soil (pH 5.0) that supported little bluestem than in field-state soil that supported most of the other warm-season forages in both 2005 and 2006 experimental periods. Lack of similar differences when grown in adjusted-pH soil (pH 6.9) suggested better association of fungal hyphae with little bluestem than with the other warm-season forages grown in field-state soil, and modification of this association with soil pH amendment. Moreover, differences in soil DFH levels among the forage species varied based on the experimental period. For example, soil that supported CIR switchgrass had higher DFH levels than did soil that supported sericea lespedeza, big bluestem, or FL beggarweed during fall 2005. Similarly, soil that supported bahiagrass had higher DFH levels than did soil that supported sericea lespedeza and FL beggarweed during summer 2006 regardless of pH level; the same relationships did not hold during fall 2005.

The null hypothesis against the second alternative hypothesis that levels of water stable aggregates and density of fungal hyphae would vary with soil pH level when supporting a particular forage species was rejected for both cool-season and warm-season forage species. WSA levels were higher in field-state soil versus adjusted-pH soil when novel-endophyte-infected tall fescue, little bluestem, sericea lespedeza, and FL beggarweed were grown. Lower WSA at adjusted versus field-state soil pH levels could be a result of short-term detrimental effects of liming on the aggregate stability of acidic soil (Haynes and Naidu 1998). Roth and Pavan (1991) found increased dispersion and reduced infiltration when soil samples of a Brazilian Oxisol (pH_{water} 4.6) were limed to pH levels of 5.0, 6.0, 6.5, 6.8, and 7.0, and incubated for six weeks, thereby indicating less stable aggregates in the limed soil than in the control (soil not limed). The present study indicated that the short-term effect of liming on soil aggregate stability is manifested only for certain forage species.

DFH levels were higher in field-state versus adjusted-pH soil when endophyte-infected tall fescue and Marshall ryegrass among the cool-season forages, and all warm-season forage species, except sericea lespedeza and IL bundleflower, were grown. Lower DFH levels observed at adjusted versus field-state soil pH levels are in agreement with the finding of Zhu et al. (2007) who reported an inhibitory effect of liming (raising pH from 5.0 to 6.0) on mycorrhizal fungi species native to acidic soil (pH 5.0) supporting the growth of white clover; however, liming did not influence fungal species exotic to the studied soil. Another study also reported an enhanced hyphal growth response of exotic mycorrhizal fungi as soil pH levels were raised from 5.3 to 7.5 (Abbott and Robson 1985). Differences in DFH levels between adjusted and field-state soils in the present study could also be a result of possible competition between forage species and fungi for nutrients and moisture since most forage species for which differences in DFH were observed also produced higher shoot and root dry matter at the adjusted-pH versus the field-state pH level. Results from this study suggest that the inhibitory effect of liming on fungal hyphal density is more evident in warm-season than cool-season forage species.

Conclusions

Both WSA and DFH showed significant short-term response to forage species grown in coastal plain soil microcosms under protected culture, and this response differed when soil pH was adjusted from the field state with lime addition. Subterranean clover (cool-season) and IL bundleflower (warm-season) produced higher or similar levels of WSA in comparison to other forage species or mixtures studies. Warm-season grass species produced higher or similar levels of WSA and DFH when compared to warm-season legume species, regardless of growing season and pH level. When significant differences were observed in WSA or DFH between field-state and adjusted-pH levels, higher levels of each parameter were found in field-state versus adjusted-pH soil. Further studies under protected culture and field conditions are needed to understand how these relationships are expressed in more variable environments over expanded time frames.

Acknowledgements

The authors acknowledge the Southern Sustainable Agriculture Research and Education Program for funds that supported this research.

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Table IV.1. Water stable aggregates (WSA) and density of fungal hyphae (DFH) (LS means ± SE) in field-state soil (pH 5.0) that supported cool-season or warm-season forages in coastal plain soil microcosms under protected culture, Aug.-Dec. 2005, Auburn, AL, USA.

	Forage species treatment	WSA (g kg^{-1})	DFH (m g^{-1})
Cool-season	Cool-season control (No plant)	677 ± 15$^{\dagger b}$	38.4 ± 3.54^{ab}
	Tall fescue – endophyte-infected (TFE) (*Festuca arundinacea*)	722 ± 45^{ab}	36.5 ± 2.11^{b}
	Tall fescue – novel endophyte (TFNvE)	722 ± 26^{ab}	37.9 ± 6.62^{ab}
	Tall fescue – no endophyte (TFNoE)	727 ± 30^{ab}	47.4 ± 3.68^{ab}
	TFE + Crimson clover (*Trifolium incarnatum*)	627 ± 21^{b}	37.3 ± 6.44^{ab}
	TFNvE + Crimson clover	625 ± 46^{ab}	39.2 ± 2.88^{b}
	TFNoE + Crimson clover	671 ± 11^{b}	38.6 ± 2.37^{b}
	Crimson clover	623 ± 38^{b}	40.5 ± 2.88^{ab}
	Gulf ryegrass (*Lolium multiflorum)*	622 ± 24^{b}	40.1 ± 3.64^{ab}
	Marshall ryegrass	630 ± 56^{ab}	50.3 ± 1.30^{a}
	Red clover (*T. pretense*)	597 ± 42^{b}	42.2 ± 5.75^{ab}
	Subterranean clover (*T. subterraneum*)	765 ± 15^{a}	50.4 ± 5.45^{ab}
Warm-season	Warm-season control (No plant)	693 ± 38^{ab}	42.0 ± 3.54^{bc}
	Bahiagrass *(Paspalum notatum*)	791 ± 27^{a}	47.4 ± 5.31^{abc}
	Sericea lespedeza (*Lespedeza cuneata*)	711 ± 43^{ab}	39.1 ± 4.05^{bc}
	Little bluestem *(Schizachyrium scoparium)*	778 ± 35^{a}	62.9 ± 3.21^{a}
	Big bluestem (*Andropogon gerardii*)	782 ± 20^{a}	42.2 ± 4.25^{bc}
	CIR switchgrass (*Panicum virgatum)*	783 ± 24^{a}	57.7 ± 2.14^{ab}
	Alamo switchgrass	691 ± 35^{ab}	52.6 ± 6.05^{abc}
	Partridge pea (*Cassia fasciculata*)	569 ± 16^{b}	46.3 ± 3.76^{b}
	Florida beggarweed *(Desmodium tortuosum)*	554 ± 39^{b}	44.8 ± 1.92^{bc}
	Illinois bundleflower (*Desmanthus illinoensis*)	791 ± 20^{a}	52.2 ± 3.83^{abc}

[†] LS means in a column for cool-season or warm-season forage species with different superscripts are different ($P < 0.05$).

Table IV.2. Water stable aggregates (WSA) and density of fungal hyphae (DFH) (LS means ± SE) in field-state (pH 4.8) and adjusted-pH (pH 6.5) soil that supported cool-season forages and mixtures in coastal plain soil microcosms under protected culture, Sept.–Dec. 2006, Auburn, AL, USA.

	WSA		DFH	
Forage species treatment	Field-state pH 4.8	Adjusted-pH pH 6.5	Field-state pH 4.8	Adjusted-pH pH 6.5
	---------------g kg^{-1}---------------		-------------m g^{-1}----------------	
Control (No plant)	532 ± 37$^{\dagger bce}$	503 ± 21^{bc}	39.4 ± 3.09	32.6 ± 2.75
Tall fescue – endophyte-infected (TFE)	692 ± 28^{abe}	622 ± 27^{ac}	49.8 ± 3.28$_{1}$	39.4 ± 3.51$_{2}$
Tall fescue – novel endophyte (TFNvE)	611 ± 22$^{abcde}_{1}$	498 ± 20$^{bc}_{2}$	45.0 ± 6.12	36.1 ± 4.55
Tall fescue – no endophyte (TFNoE)	673 ± 15^{ab}	671 ± 12^{a}	47.0 ± 4.61	37.5 ± 2.30
TFE + Crimson clover	745 ± 37^{a}	*	39.4 ± 3.51	*
TFNvE + Crimson clover	588 ± 33^{abcde}	*	42.0 ± 3.27	*
TFNoE + Crimson clover	635 ± 17^{abcde}	*	42.3 ± 2.12	*
Crimson clover	559 ± 37^{b}	*	33.0 ± 2.06	*
Gulf ryegrass	649 ± 04^{abce}	579 ± 47^{abc}	46.8 ± 2.86	41.4 ± 3.45
Marshall ryegrass	578 ± 17^{bcde}	576 ± 42^{abc}	48.6 ± 3.11$_{1}$	35.6 ± 3.25$_{2}$
Red clover	546 ± 33^{be}	543 ± 33^{c}	39.3 ± 3.19	40.0 ± 4.58
Subterranean clover	662 ± 49^{abcde}	717 ± 18^{a}	48.0 ± 6.76	35.2 ± 4.13

†LS means in a column with different superscripts are different ($P < 0.05$); LS means for WSA or DFH in a row with different subscripts are different ($P < 0.05$). *Data lost to insect infestation.

Table IV.3. Water stable aggregates (WSA) and density of fungal hyphae (DFH) (LS means ± SE) in field-state (pH 5.0) and adjusted-pH (pH 6.9) soil that supported warm-season forage species in coastal plain soil microcosms under protected culture, May-Aug. 2006, Auburn, AL, USA.

	WSA		DFH	
Forage species	Field-state pH 5.0	Adjusted-pH pH 6.9	Field-state pH 5.0	Adjusted-pH pH 6.9
	---------------g kg^{-1}-----------		----------------m g^{-1}---------------	
Control (No plant)	641 ± 55[†]^{abcd}	728 ± 53^{a}	35.9 ± 3.05^{b}	37.0 ± 3.66^{abc}
Bahiagrass	743 ± 27^{a}	676 ± 34^{a}	60.0 ± 5.83$^{a}_{1}$	39.4 ± 2.10$^{a}_{2}$
Sericea lespedeza	523 ± 04$^{bd}_{1}$	438 ± 22$^{b}_{2}$	32.1 ± 3.30^{b}	25.0 ± 3.16^{b}
Little bluestem	623 ± 34$^{abd}_{1}$	499 ± 20$^{b}_{2}$	71.9 ± 4.50$^{ac}_{1}$	30.9 ± 3.01$^{abc}_{2}$
Big bluestem	719 ± 19^{a}	607 ± 66^{ab}	49.3 ± 6.16$^{abc}_{1}$	35.1 ± 2.15$^{ab}_{2}$
CIR switchgrass	669 ± 36^{ad}	612 ± 31^{a}	52.5 ± 6.16$^{abc}_{1}$	34.2 ± 2.79$^{abc}_{2}$
Alamo switchgrass	649 ± 33^{ad}	654 ± 23^{a}	44.8 ± 3.66$^{ab}_{1}$	32.3 ± 2.06$^{abc}_{2}$
Partridge pea	477 ± 10^{cd}	459 ± 21^{b}	45.3 ± 3.46$^{ab}_{1}$	30.1 ± 2.61$^{abc}_{2}$
Florida beggarweed	543 ± 19$^{d}_{1}$	468 ± 19$^{b}_{2}$	35.5 ± 2.52$^{b}_{1}$	27.1 ± 1.66$^{c}_{2}$
Illinois bundleflower	647 ± 34^{ad}	676 ± 38^{a}	44.9 ± 4.25^{ab}	43.1 ± 4.00^{a}

[†] LS means in a column with different superscripts are different ($P < 0.05$); LS means for WSA or DFH in a row with different subscripts are different ($P < 0.05$).

Table IV.4. Shoot and root dry matter of cool-season forage species and mixtures grown in coastal plain soil microcosms under protected culture during Aug.-Dec. 2005 in field-state soil (pH 5.0); Sept.-Dec. 2006 in field-state (pH 4.8) and adjusted-pH (pH 6.5) soil, Auburn, AL, USA.

	Experimental period					
	Aug.-Dec. 2005	Sept.-Dec. 2006		Aug.-Dec. 2005	Sept.-Dec. 2006	
	Field-state pH 5.0	Field-state pH 4.8	Adjusted-pH pH 6.5	Field-state pH 5.0	Field-state pH 4.8	Adjusted-pH pH 6.5
Forage species	Shoot dry matter			Root dry matter		
	---g---					
Tall fescue – endophyte-infected (TFE)	$1.9 \pm 0.04^{\dagger d}$	$1.8 \pm 0.12^{f}_{1}$	$3.5 \pm 0.13^{cd}_{2}$	0.8 ± 0.11^{bcd}	$0.8 \pm 0.06^{cd}_{1}$	$1.2 \pm 0.07^{b}_{2}$
Tall fescue – novel endophyte (TFNvE)	2.7 ± 0.27^{cd}	$3.1 \pm 0.14^{de}_{1}$	$4.6 \pm 0.14^{b}_{2}$	1.8 ± 0.28^{ac}	$0.9 \pm 0.05^{c}_{1}$	$1.3 \pm 0.05^{b}_{2}$
Tall fescue – no endophyte (TFNoE)	2.5 ± 0.03^{c}	$3.0 \pm 0.30^{d}_{1}$	$3.7 \pm 0.06^{cd}_{2}$	1.1 ± 0.21^{abc}	$1.1 \pm 0.12^{cd}_{1}$	$1.4 \pm 0.11^{b}_{2}$
TFE + Crimson clover	4.6 ± 0.37^{b}	6.0 ± 0.17^{bc}	*	1.2 ± 0.20^{abc}	1.1 ± 0.03^{b}	*
TFNvE + Crimson clover	4.7 ± 0.36^{b}	7.3 ± 0.48^{b}	*	0.8 ± 0.07^{b}	1.2 ± 0.08^{bc}	*
TFNoE + Crimson clover	4.7 ± 0.41^{b}	6.8 ± 0.22^{b}	*	1.5 ± 0.35^{abcd}	1.4 ± 0.04^{b}	*
Crimson clover	7.1 ± 0.38^{a}	9.9 ± 0.31^{a}	*	0.9 ± 0.10^{bc}	1.4 ± 0.08^{b}	*
Gulf ryegrass	2.1 ± 0.13^{cd}	$2.0 \pm 0.11^{ef}_{1}$	$3.7 \pm 0.18^{c}_{2}$	1.2 ± 0.10^{abc}	$0.7 \pm 0.05^{cd}_{1}$	$1.2 \pm 0.10^{b}_{2}$
Marshall ryegrass	2.4 ± 0.07^{c}	$2.1 \pm 0.10^{ef}_{1}$	$4.0 \pm 0.18^{bcd}_{2}$	1.4 ± 0.09^{a}	$0.8 \pm 0.03^{cd}_{1}$	$1.1 \pm 0.11^{b}_{2}$
Red clover	8.9 ± 0.74^{a}	$9.6 \pm 0.32^{a}_{1}$	$8.0 \pm 0.33^{a}_{2}$	1.8 ± 0.09^{a}	2.2 ± 0.06^{a}	2.3 ± 0.12^{a}
Subterranean clover	4.0 ± 0.26^{b}	$5.3 \pm 0.19^{c}_{1}$	$4.3 \pm 0.08^{bc}_{2}$	0.4 ± 0.04^{d}	$0.8 \pm 0.04^{cd}_{1}$	$0.7 \pm 0.03^{c}_{2}$

[†] LS means in a column with different superscripts are different ($P < 0.05$); LS means in a row for a response variable within an experimental period with a different subscript are different ($P < 0.05$). *Data lost to insect infestation.

Table IV.5. Shoot and root dry matter of warm-season forage species grown in coastal plain soil microcosms under protected culture during Aug.-Dec. 2005 in field-state soil (pH 5.0); May-Aug. 2006 in field-state (pH 5.0) and adjusted-pH soil (pH 6.9), Auburn, AL, USA.

	Experimental period					
	Aug.-Dec. 2005	May-Aug. 2006		Aug.-Dec. 2005	May-Aug. 2006	
	Field-state pH 5.0	Field-state pH 5.0	Adjusted-pH pH 6.9	Field-state pH 5.0	Field-state pH 5.0	Adjusted-pH pH 6.9
Forage species	Shoot dry matter			Root dry matter		
	g					
Bahiagrass	$3.0 \pm 0.39^{\dagger cd}$	$3.3 \pm 0.51^{cd}_{1}$	$8.9 \pm 0.59^{b}_{2}$	1.4 ± 0.21^{b}	$1.4 \pm 0.07^{d}_{1}$	$3.2 \pm 0.15^{acd}_{2}$
Sericea lespedeza	5.0 ± 0.41^{bc}	10.0 ± 0.41^{b}	9.8 ± 0.28^{b}	0.5 ± 0.08^{c}	2.1 ± 0.16^{b}	1.8 ± 0.10^{bc}
Little bluestem	2.0 ± 0.22^{d}	$4.4 \pm 0.37^{cd}_{1}$	$9.3 \pm 0.84^{b}_{2}$	0.5 ± 0.08^{c}	1.7 ± 0.22^{bde}	2.3 ± 0.30^{abcd}
Big bluestem	2.0 ± 0.07^{d}	$3.4 \pm 0.21^{cd}_{1}$	$11.2 \pm 0.62^{b}_{2}$	1.6 ± 0.21^{b}	$2.6 \pm 0.06^{bc}_{1}$	$4.1 \pm 0.48^{a}_{2}$
CIR switchgrass	0.7 ± 0.03^{e}	$3.0 \pm 0.29^{d}_{1}$	$5.0 \pm 0.81^{c}_{2}$	0.9 ± 0.20^{bc}	1.0 ± 0.19^{d}	1.6 ± 0.48^{c}
Alamo switchgrass	3.6 ± 0.17^{c}	$4.9 \pm 0.30^{c}_{1}$	$8.8 \pm 0.37^{b}_{2}$	1.1 ± 0.13^{b}	$1.7 \pm 0.12^{bd}_{1}$	$2.6 \pm 0.14^{acd}_{2}$
Partridge pea	15.7 ± 0.70^{a}	$22.3 \pm 1.30^{a}_{1}$	$18.2 \pm 1.54^{a}_{2}$	1.6 ± 0.11^{bd}	$3.2 \pm 0.23^{a}_{1}$	$2.2 \pm 0.09^{bcd}_{2}$
Florida beggarweed	17.4 ± 1.38^{a}	16.1 ± 1.52^{a}	18.2 ± 0.49^{a}	3.0 ± 0.28^{a}	$2.7 \pm 0.08^{ab}_{1}$	$2.0 \pm 0.09^{bcd}_{2}$
Illinois bundleflower	0.5 ± 0.03^{f}	$1.1 \pm 0.09^{e}_{1}$	$1.9 \pm 0.10^{d}_{2}$	1.0 ± 0.26^{bcd}	$1.2 \pm 0.05^{de}_{1}$	$1.9 \pm 0.20^{bcd}_{2}$

†LS means in a column with different superscripts are different ($P < 0.05$); LS means in a row for a response variable within an experimental period with a different subscript are different ($P < 0.05$).

Table IV.6. Correlations between water stable aggregates (WSA) and shoot dry matter, root dry matter, shoot to root ratio, or density of fungal hyphae (DFH) for cool-season and warm-season forages grown in 2005 and 2006 in field-state (FS) and adjusted-pH (A-pH) soil, Auburn, AL, USA.

Forage				Shoot dry matter			Root dry matter			Shoot to root ratio			DFH		
species	Date	pH		n[†]	r[‡]	p-value	n	r	p-value	n	r	p-value	n	r	p-value
Cool-season	Fall 2005	FS 5.0	WSA	54	-0.28	0.0418	55	-0.26	0.0554	54	0.10	0.4632	55	0.00	0.9719
	Fall 2006	FS 4.8		54	-0.30	0.0252	54	-0.36	0.0074	55	-0.10	0.4792	54	0.05	0.7187
		A-pH 6.5		35	-0.33	0.0546	35	-0.31	0.0732	35	0.17	0.3325	40	0.01	0.9629
Warm-season	Fall 2005	FS 5.0		45	-0.78	<0.0001	45	-0.40	0.0061	45	-0.49	0.0006	45	0.11	0.482
	Summer 2006	FS 5.0		45	-0.70	<0.0001	44	-0.46	0.0018	44	-0.70	<0.0001	45	0.38	0.0093
		A-pH 6.9		45	-0.54	0.0002	44	0.22	0.1443	44	-0.61	<0.0001	45	0.56	<0.0001

[†] Number of observations.

[‡] Correlation coefficient.

Table IV.7. Correlations between density of fungal hyphae (DFH) and shoot dry matter, root dry matter, or shoot to root ratio for cool-season and warm-season forages grown in 2005 and 2006 in field-state (FS) and adjusted-pH (A-pH) soil, Auburn, AL, USA.

				Shoot dry matter			Root dry matter			Shoot to root ratio		
Forage species	Date	pH		n[†]	r[‡]	p-values	n	r	p-values	n	r	p-values
Cool-season	Fall 2005	FS 5.0	DFH	54	-0.11	0.4411	55	-0.22	0.0987	54	0.17	0.2167
	Fall 2006	FS 4.8		55	-0.38	0.0039	55	-0.36	0.0074	55	-0.20	0.1464
		A-pH 6.5		35	0.02	0.8889	35	0.10	0.5821	35	-0.11	0.5256
Warm-season	Fall 2005	FS 5.0		45	-0.26	0.0861	45	-0.23	0.1338	45	-0.31	0.0383
	Summer 2006	FS 5.0		45	-0.36	0.0141	44	-0.26	0.0893	44	-0.37	0.0144
		A-pH 6.9		45	-0.41	0.0056	44	0.09	0.5450	44	-0.48	0.0010

[†] Number of observations.

[‡] Correlation coefficient.

SUMMARY AND CONCLUSIONS

Research results indicated that diversity of the pasture-plant community varied based on pasture system studied (silvopasture versus open-pasture) and weather conditions. The diversity of understory plant species in silvopasture was higher during the early-growing seasons of 2003, 2004, and 2007 but was lower than in open-pasture during all late-season growing periods included in the study. When bahiagrass was the major forage species, forage productivity of longleaf-pine silvopasture alleys was comparable to open-pasture as long as pine trees were less than 7-yr old and had not been pruned. However, forage quality in longleaf-pine silvopasture began to decrease when trees were approximately 6-yr old. Reduced quality measured for forage grown in longleaf-pine silvopasture as compared to that in open-pasture was likely the result of pine needle presence in the silvopasture forage. To maintain forage quality, burning is the likely the best option to reduce pine needle accumulation during the hay production period associated with the initial stages (6-7 yr) of open-pasture conversion to longleaf-pine silvopasture.

Longleaf-pine silvopasture altered the quality of coastal plain soil when pine trees were as young as 5-yr old. Mean water stable aggregates for a 3-yr observation period (2005-2007; pine tree age 5 to 7-yr) were 5% lower in silvopasture versus open-pasture. Also, when compared to open-pasture, silvopasture soil penetration resistance was approximately 43% lower at 10-15 cm and 39% lower at 15-20 cm depth in June 2005 and 10% lower at 15-20 cm depth in October 2007.

Silvopasture forage productivity and quality were reduced at the 1.0-m alley position versus positions farther away from trees when longleaf-pine trees were approximately 7-yr old and had not been pruned. The major reason for this reduction was pine needle accumulation which inhibited establishment and growth of forage at the 1.0-m position versus positions farther away from the center of the tree base. Pine needle accumulation at the 1.0-m position was measured as 1.13 and 1.34 t ha^{-1} for August 2006 and September 2007, respectively. In comparison, pine needle accumulations at the other two alley positions studied (3.5- m and 6.1-m) were negligible. Direct modification of solar radiation interception by trees at the 1.0-m alley position may have also been a factor but was not quantified in this study. Soil penetration resistance at the 1.0-m alley position compared to the 6.1-m position from the center of the tree base remained lower for all soil depths (0-5 cm, 5-10 cm, 10-15 cm, and 15-20 cm) studied in June 2005. Except for the 0-5 cm depth, this trend was repeated in October 2007.

Introduction and maintenance of crimson clover into a young longleaf pine-bahiagrass silvopasture on coastal plain soil enhanced forage productivity and quality and replaced the requirement for commercial N fertilizer application. When a vigorous stand of crimson clover was present in May 2005, shoot dry matter (SDM) production from legume-N plots was 40% higher when compared to SDM production from fertilizer-N treatment plots; SDM production from both treatments remained similar after crimson clover had senesced. A vigorous stand of crimson clover in legume-N treatment plots also increased N concentrations of forage tissue samples: tissue N concentrations were 28%

higher than tissues from fertilizer-N treatment plots in May 2005 and 27% higher in April 2007. Results also indicated a cumulative beneficial effect of crimson clover for soil quality, especially penetration resistant (PR). Soil PR levels measured in October 2007 at 10-15 cm and 15-20 cm were 9 and 10% lower, respectively in legume-N compared to fertilizer-N treatment plots.

When compared to open-pasture, mature loblolly-pine silvopasture created a less stressful microclimate for grazing cattle during warm-season portions of the annual grazing season in the Coastal Plain of Southeast USA. The major microclimatic parameter that differed between pasture types was total solar radiation which was 14-58% lower in silvopasture versus open-pasture. Relative humidity, dew point, air and soil temperatures (5-cm and 10-cm), and wind and gust speeds were also lower in silvopasture during most diurnal periods studied. The less stressful environment associated with the silvopasture landscape resulted in more even diurnal distribution of grazing cattle in silvopasture as compared to that in a similarly managed open-pasture landscape. Cattle spent more time grazing in the silvopasture versus the open-pasture landscape; silvopasture grazing time was 70%, 59%, and 94% higher than in open-pasture in March, June, and September, respectively. Time spent loafing by cattle in the silvopasture versus open-pasture landscape was 59%, 29%, and 46% less in March, June, and September, respectively. Behavioral differences observed between pasture types were associated mainly with reduced heat stress in silvopasture, however, quantity and quality of available forage in silvopasture may have also been a factor for specific observation dates. Further study is needed to determine how differences in heat stress, as well as quantity and quality of forage between pasture landscape types, influence cattle performance in this region.

Short-term (12-week) studies conducted in coastal plain soil under protected culture indicated that soil quality can be significantly altered early in the development of certain forage species, and this response differed when soil pH was adjusted from the field state with lime addition. Among the soils that supported cool-season forage species studied, levels of water stable aggregates (WSA) in soil that supported subterranean clover were higher than or similar to WSA levels in soils that supported other cool-season legumes, grasses, or mixtures, regardless of soil pH level or experimental period. Among the soils under warm-season legumes, WSA levels in soils that supported IL bundleflower were higher than or similar to WSA levels in soils that supported other legumes. WSA levels measured in soils under most warm-season grass species were higher than or similar to levels measured in soils that supported warm-season legume species, regardless of growing season and pH level.

Differences in DFH levels in soils that supported the cool-season forage species followed no apparent trend. Among the warm-season forages studied, DFH levels measured in soils that supported most grass species were similar regardless of experimental period or pH level. DFH levels in soils that supported warm-season grass species were higher than or similar to levels measured in soils that supported warm-season legume species regardless of growing season or pH level. For both cool-season and warm-season forage species that caused differences in WSA or DFH between soils at field-state and adjusted-pH levels, higher values of each soil quality parameter were found in field-state compared to adjusted-pH soils. Further long-term studies under protected culture and field conditions are needed to understand how these relationships are expressed in more variable environments over expanded time frames.