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Research Article

Evaluation of Five East Texas Forages under Differing Shade Levels

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ABSTRACT

A pot study was conducted to measure the establishment success of five forages under 0%, 30% or 60% shade levels. The forages evaluated were 'Pensacola" bahiagrass (*Paspalum notatum* Fluegge), "Texas Tough" bermudagrass (*Cynodon dactylon* L. Pers.), "Alamo" switchgrass (*Panicum virgatum* L.), "San Marcos" Eastern gamagrass (*Tripsacum dactyloides* L.), and a native mix containing by weight 45% "Texas" little bluestem (*Schizachyrium scoparium* Michx Nash), 15% sand lovegrass (*Eragrostis trichodes* Nutt. L. Alph. Wood), 15% "Blackwell" switchgrass (*Panicum virgatum* L.), 10% "Lometa" Indiangrass (*Sorgastrum nutans* L. Nash), 10% "Haskell" sideoats grama (*Bouteloua curtipendula* Michx Torr) and 5% "Earl" big bluestem (*Andropgon gerardii* Vitman). Mean biomass under 60% shade for all forages was less than under the other shade treatments, but did not differ among shade treatments within forages. Mean nutrient tissue concentration showed significant differences among treatments and forages for several nutrients. Shade treatments had no effect on plant density, but low germination of several forages appears to have influenced plant density. Based on these results, bahiagrass, Eastern gamagrass and bermudagrass may be suitable species if maximum biomass production were the goal of a silvopasture management system in east Texas.

Keywords: Silvopasture; Loblolly pine; Bluestem; Switchgrass; Bahiagrass

INTRODUCTION

Silvopasture, which combines timber production with livestock and forage production on the same land, might benefit landowners in the Southern United States with income from producing multiple crops simultaneously from the same land. While tree crops may take 10 to 12 years before the first harvest, silvopasture systems seek to utilize the land for additional income with little impact on the tree crop [1]. Revenues generated by silvopastures depend on variables such as fertilizer programs and type of cattle used; additional revenue may be gained by allowing fee hunting, which can comprise five to nine percent of the total land value over the lifetime of the silvopasture [2]. Grasses are one of the earliest examples of the evolution of C_4 photosynthesis, having first developed in the Oligocene epoch between 24 and 35 million years ago. Roughly 7,500 C_4 plants currently exist, with 4,500 species of grasses representing the largest group [3].

While considerable research has been accomplished on forage crops in open pasture settings, little has been reported under partial shade. Specifically, analysis of light quality under loblolly pine (*Pinus taeda* L.) has not been widely performed. Common forage species such as bermudagrass (*Cynodon dactylon* L. Pers.) and fescues (*Festuca* spp.) have been previously researched, but data is lacking for many forage grasses. Under different combinations of species and shade levels, mean dry weight (MDW) of 30 species was found to vary with amount of shade, species and growing season. Warm season grasses (C_4) were found to have low shade tolerance under 50% and 80% shade regardless of season due to the poor response of the C_4 metabolic pathway to shade [4]. Comparing bahiagrass (*Paspalum notatum* Fluegge) under a canopy of *Eucalyptus grandis* to full sun found dry weight yield of bahiagrass leaf matter under full sun summer growth under the canopy to be 35% greater than full sun plots; winter growth was similar [5]. Soil moisture and nitrogen inputs from accumulated organic matter from tree leaf inputs were suggested as reasons for the increased growth under eucalypt canopies. As trees increase in age the canopy of the forest becomes denser, necessitating thinning for maintenance of forage quality and quantity, as in pine/wiregrass (*Pinus/Aristida*) and pine/bluestem (*Pinus/Andropogon*) ecosystems in the Southern United States [6].

Spectral light range between 400 nm and 700 nm, known as photosynthetically active radiation (PAR), describes the range of light which is most active in inducing photosynthetic reactions in plants [7,8]. Spatial and temporal variations in light are further

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limited by the specific leaf area of a given tree species [9]. Shade cast by vegetation has also been shown to influence Red:Far Red (R:FR) light ratios, where vegetation absorbs or reflects high amounts of red wavelength, while far red wavelengths increased under the vegetation canopy. R:FR light is known to influence tiller production in grasses and induce photoperiod responses in reaction to R:FR absorption in plant cells [10-12].

Differences also exist between plant nutrient content under full sun and shade environments [4]; grasses under shade generally produce increased non-protein nitrogen and silica concentration, have increased average leaf area, and because leaves contain less fiber and more total protein than stems, the quality for foraging livestock may be greater. Internode length may increase, and increased lignification may occur under shade conditions.

Moisture content of surface soils has been found to be higher under forest canopy gaps than under a closed canopy due to the lack of overhead vegetation to intercept falling precipitation. However, the physical conditions under canopies and canopy gaps are variable and unpredictable [13], as greater tree density increases shade, and therefore lowers the transpiration of subcanopy forage species [5].

Some forages require specific physical conditions for germination and establishment, while others are adapted to a broader range of conditions, and Panciera M [14] suggests addressing limitations in forages with one or more of the following methods: breed out the problem, simply "overcome it", and adjust management for it.

The objectives of this study were to measure plant density, assess changes in tissue nutrient content, and quantify biomass production of common forages after one year under three uniform shade densities in east Texas.

METHODS

Five forages were evaluated: 'Pensacola" bahiagrass (*Paspalum notatum* Fluegge), "Texas Tough" bermudagrass, "Alamo" switchgrass (*Panicum virgatum* L.), "San Marcos" Eastern gamagrass (*Tripsacum dactyloides* L.), and a native mix containing 45% "Texas" little bluestem (*Schizachyrium scoparium* Michx Nash), 15% sand lovegrass (*Eragrostis trichodes* Nutt. L. Alph. Wood), 15% "Blackwell" switchgrass (*Panicum virgatum* L.), 10% "Lometa" Indiangrass (*Sorgastrum nutans* L. Nash), 10% "Haskell" sideoats grama (*Bouteloua curtipendula* Michx Torr) and 5% "Earl" big bluestem (*Andropgon gerardii* Vitman) by weight.

Bahiagrass (*Paspalum notatum* Fluegge) is native to South America but is a frequently used forage in the southern Gulf Coast region of the United States [15,16]. Bahiagrass has the ability to provide adequate forage on low fertility, dry sites, but has seed that is slow to germinate, called "hard" seed, that hinders the development of a pure stand. Bahiagrass also produces large amounts of seed, further aiding in its rapid establishment. Bahiagrass is seen as a weed species in some situations where less competitive grasses, such as bermudagrass, can be rapidly crowded out.

Bermudagrass (*Cynodon dactylon* (L.) Pers.) is native to Africa but is a common forage species in the Southern United States due to its wide growth range and adaptability. Bermudagrass is inhibited by excessively wet soils, but is able to survive drought due to deeper rooting than most other warm season forages. Forage quality of common bermudagrass is similar to the Coastal cultivar; however, common bermudagrass has a generally lower yield than other cultivars [17].

Native grasses of the United States, once common across central United States, include little bluestem (*Schizachyrium scoparium* (Michx) Nash), Indiangrass, "Haskell" sideoats grama (*Bouteloua curtipendula* (Michx) Torr), switchgrass, sand lovegrass (*Eragrostis trichodes* (Nutt.) Alph. Wood) and big bluestem. Although adapted to a broad range of conditions these plants are notorious for their difficulty to establish from seed [14]. Native grasses often take 1 to 2 years to become well established and during that critical period weed species should be suppressed. One possible explanation for the prevalence of low germination and establishment rates may be the lack of selection pressures on the native species compared to naturalized forage species [18]. Switchgrass (*Panicum virgatum* L.) is a native warm season perennial grass, and cultivars vary regarding germination rates, cold tolerance, and drought tolerance [19]. Cultivars such as the "Alamo" cultivar are better suited for high biomass production, while the "Blackwell" cultivar has been shown to be a suitable forage [20]. Eastern gamagrass, (*Tripsacum dactyloides* (L.), a perennial bunchgrass, grows naturally in North, Central and South America and parts of the Caribbean. The primary limitation of establishing Eastern gamagrass is low germination. Although seeds generally have high viability, overcoming dormancy often poses a problem [21].

Germination rates were determined for bahiagrass, bermudagrass and switchgrass using guidelines established by the Association of Official Seed Analysis (AOSA). Germination rate was assessed for Eastern gamagrass using methods described [22]. Native mix seed was 90% pure. All other seed was at least 98% pure.

Forages were seeded by hand on April 25, 2008 (Table 1). The 13.2L pots were 30cm in diameter and filled with a commercial bagged potting mix. Approximately 84 g of Osmocote standard 9-month release 13-13-13 fertilizer was incorporated using a cement mixer in each pot. One forage was randomly assigned to one of five pots in each plot. Plots were blocked and randomly assigned 0%, 30% or 60% shade treatments, achieved using 30% and 60% black knitted polyethylene shade cloth (DeWitt (Sikeston, MO)). Plots receiving 0% shade were left in full sun. Five blocks were created with each containing all species-treatment combinations. Plots were spaced at 1.5m intervals so shading from adjacent plots did not occur.

Pots were arranged equidistant from one center pot and were elevated on wooden pallets. Shade cloth was supported by one post at each of the four corners of each plot. Shade cloth formed a canopy over the pots and stretched between corner posts to form side walls around the pots. This design reduced light from all directions. Shade cloth was fastened to the corner posts and underlying wooden pallets with nails (Figure 1). The canopy of each enclosure was approximately 0.5m above the top of the pots. Pots were watered to saturation each morning using drip emitters regulated by a battery-powered automatic timer. Rates were 1.9 lph (liters per hour) for one hour min each morning at 6:30 am from seeding to June 6, regardless of weather pattern. Irrigation was increased to 90 min each morning after June 6 in response to higher summer temperatures. Undiluted Round-Up (2% Glyphosate isopromaline salt, 2% pelargonic acid and related fatty acids) was brushed on to weed species that appeared, and forage species were visually monitored for negative effects from transference of the herbicide.

Plant density and biomass

Plants in each pot were counted before vegetation was cut for

Figure 1: Shade cloth enclosures in the foreground are 60%, middle-ground 0%, and background 30% shade treatments.

biomass sampling in August, 2008. Stoloniferous and rhizomatous species, such as bahiagrass and bermudagrass, were tabulated by counting each plant crown as one plant and not counting runners which had rooted. Successful establishment (%) was calculated by dividing plant density by number of seeds sown then multiplying by 100. Mean weight (mg) of 10 seeds of each species was used to determine the number of seeds sown into each pot. Biomass production was assessed with the vegetation clipped and dried to a constant weight (grams) at 60°C in August, 2008.

Forage analysis

Forage analysis was conducted on above-ground biomass samples at the Stephen F. Austin State University Soil, Plant and Water Analysis Laboratory, Nacogdoches, Texas. Samples were collected in August 2008, dried at 60°C and ground with a Thomas-Wiley Laboratory Mill (Model 4) by Thomas Scientific with 0.5mm screen attached. Analysis was made for crude protein (CP), acid detergent fiber (ADF) and estimated total digestible nitrogen (TDN), as well as for P, K, Ca, Mg, S (mg kg^{-1}). Except for N, nitric digestion was used to prepare samples. Nutrient analysis was performed using an inductively coupled plasma mass spectrometer unit. N (mg kg^{-1}) was determined using a CN Analyzer.

Verification of shade cloth

Light interception and absorption by shade cloth was evaluated informally. One light reading was made beneath each shade cloth treatment between 10:00 AM and 2:00 PM. These readings were used to examine quality of light beneath the shade cloth and to quantify light intercepted and absorbed by the shade cloth.

Data analysis

This study was a randomized block design with five blocks and a 5 × 3 factorial within each block. Biomass data and plant density data were analyzed using two separate 3-ways mixed (Model III) ANOVAs, with forages and shade treatments fixed. The third factor was a random block effect. A 5 × 3 factorial existed within each block (five forages and three levels of shade). Total sample size was 75 (five forages × three shade treatments × five blocks). For each species, sample size was 15 (one individual from each forage under each shade treatment × three shade treatments × five blocks). Orthogonal contrast was used to compare each specific combination of forage and shade treatment for both biomass and plant density data, and adjusted for Tukey analysis and used the error term specified in the ANOVA table to create *p* values for each desired combination. Both 3-way ANOVAs and orthogonal contrasts were performed using SAS (SAS Institute, Inc.). Tissue nutrient content of above ground biomass was analyzed with 2-way ANOVA for each nutrient. Tukey test and orthogonal contrast was used to analyze species-treatment combinations.

RESULTS

Germination rates of the native mix and Eastern gamagrass were below 50% (Table 1), and switchgrass was the highest of the five forages. Viability of ungerminated seed was not determined.

Forage analysis

Analysis of forage tissue macronutrients (Table 2) found significant differences among shade treatments (Figure 2). Nitrogen concentration under 60% shade was significantly different from under 0% shade (p=0.013). Vegetation beneath 60% shade and 30% shade showed significantly different concentrations of Phosphorus (p<0.001) and Potassium (p<0.001), compared to vegetation grown beneath 0% shade. Magnesium concentration was found to be significantly different beneath 0% and 60% shade treatments (p=0.007). Calcium concentration was significantly different beneath 60% shade (p<0.001). Comparison of all forage species revealed significant (p<0.001) variation of macronutrient concentration under the shade treatments among forages (Figure 3). Phosphorus concentration in Eastern gamagrass was found to be significantly lower than the other forages, while Potassium concentration was significantly higher in bahiagrass, followed by bermudagrass, native mix and switchgrass, but significantly lower in Eastern gamagrass. Bermudagrass and bahiagrass had the highest Calcium concentration followed by the native mix and switchgrass; the lowest was in Eastern gamagrass. Total Nitrogen was found to be statistically similar for the native mix, bermudagrass and bahiagrass and significantly different for Eastern gamagrass. Crude protein concentration was statistically similar for the native mix, bermudagrass and bahiagrass and significantly lower for Eastern gamagrass. ADF concentration was significantly less for Eastern

Table 1: Seeding and germination rates of forages.

Forages	kg PLS ha^{-1}*	lbs PLS ac^{-1}	Germination (%)
Bahia grass	33.6	30.0	50.5
Bermuda grass	4.5	4.0	61.3
Native Mix	7.2	6.8	17.3
Switchgrass	6.7	6.0	77.0
Eastern Gama grass	22.4	20.0	31.0

*PLS=Pure Live Seed.

Table 2: Above ground tissue macronutrient concentration by treatment.

% Shade	N	P	K	Ca	Mg	S
	mg kg^{-1}					
0	9415b	1345b	17577b	3135b	1421b	1900a
30	12284ab	1724a	16067a	3237b	1721ab	2100a
60	16848a	2059a	13297a	4158a	1886a	2255a

Same letters within a column not significantly different (α=0.05).

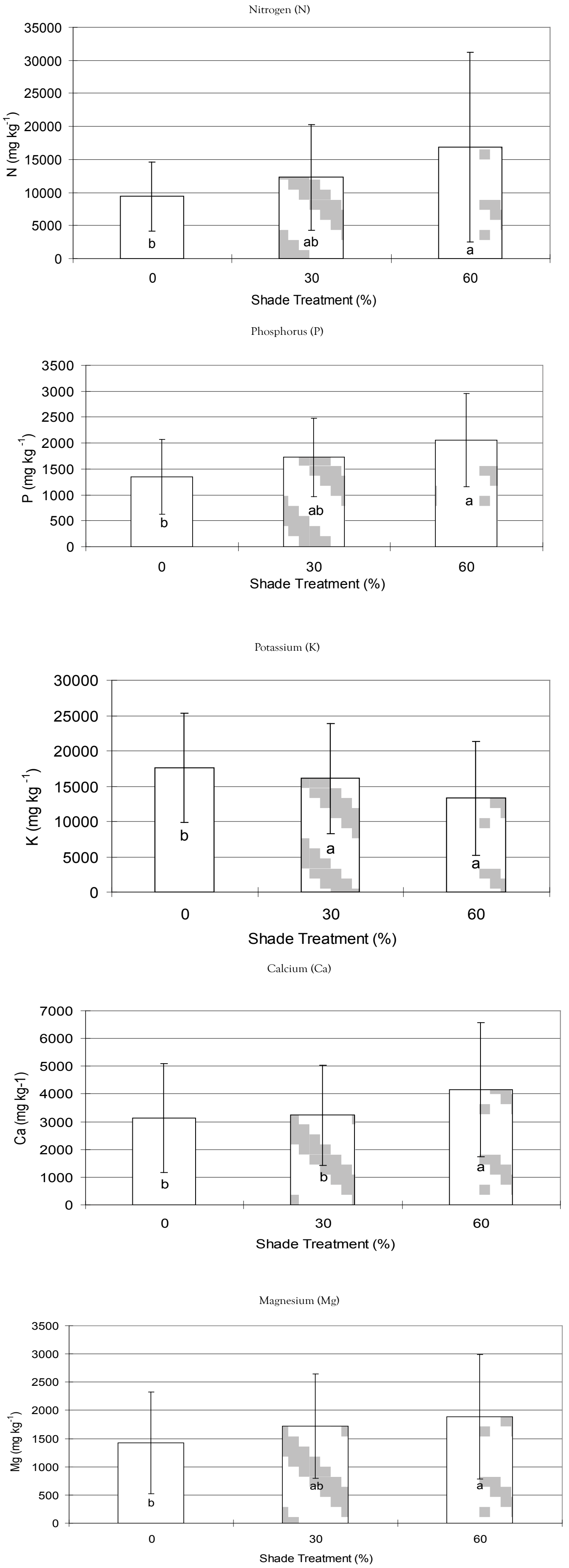

Figure 2: Mean nutrient tissue concentrations (mg kg^{1}) of above ground biomass produced beneath the three shade treatments. Treatments with different letters are statistically different (α=0.05). Standard deviations are shown as error bars.

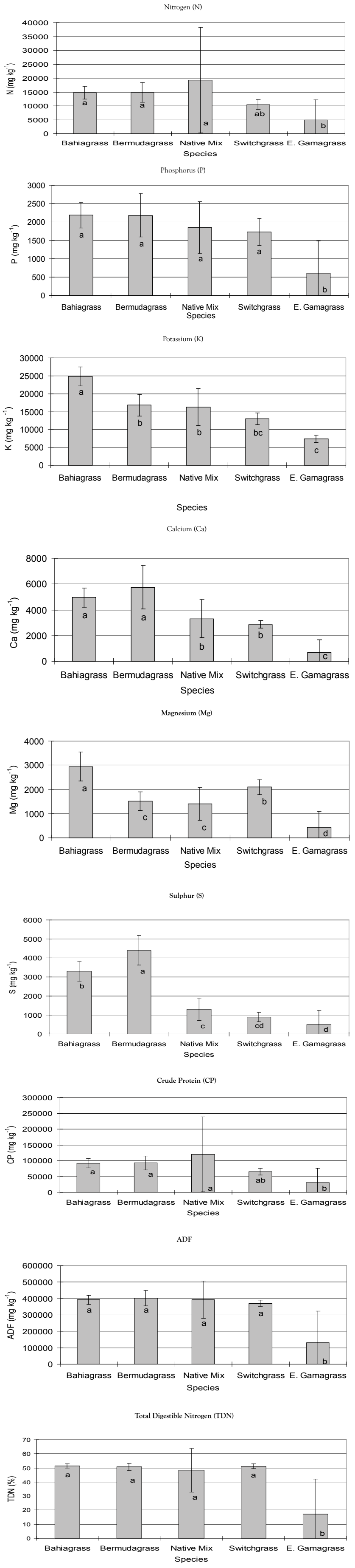

Figure 3: Mean CP tissue concentration (mg kg^{1}) of above ground biomass produced beneath the three shade treatments by the five forages. Species with different letters are statistically different (α=0.05). Standard deviations are shown as error bars.

gamagrass. TDN concentration was significantly less for Eastern gamagrass.

Some forages exhibited differences in tissue nutrient concentration between shade treatments (Table 3). Bermudagrass was found to have significantly different concentration of Ca beneath 30% and 60% shade (p=0.003) and beneath 0% and 60% shade (p=0.032). Native mix concentration of P was significantly different beneath 0% and 30% shade treatments (p=0.016). Native mix was significantly different beneath 0% and 60% shade for tissue concentrations of Potassium (p=0.004), Copper (p=0.004), Nitrogen (p=0.017), and CP (p=0.006).

Plant density

The shade treatments had no effect on plant density (p=0.056), but density did differ significantly among forages (p=0.008). Switchgrass, native mix and bahiagrass produced statistically similar plant densities (Table 4). Eastern gamagrass produced statistically lower plant densities and was found to be statistically different from the other species (p=0.008). Forages were not affected by Round-Up applied to weed species.

Biomass

Biomass production differed among the three shade treatments (p=0.004). Mean biomass beneath 0% shade was 186.7 g and 195.3 g beneath 30% shade (σ=39.5, significantly different from the 60% shade treatment (132.4 g). Biomass also varied among species (p=0.001) (Table 5). Eastern gamagrass, bahiagrass and bermudagrass all produced statistically similar amounts of biomass: 239.9 g for Eastern gamagrass, 177.4 g for bahiagrass, and 216.8 g for bermudagrass. Native mix produced statistically less biomass (62.4

Table 3: Above ground tissue macronutrient concentration by forage.

% Shade	N	P	K	Ca	Mg	S
			mg kg^{-1}			
0	9415b	1345b	17577b	3135b	1421b	1900a
30	12284ab	1724a	16067a	3237b	1721ab	2100a
60	16848a	2059a	13297a	4158a	1886a	2255a

Same letters within a column not significantly different (α=0.05).

Table 4: Mean plant density data and success rate of establishment for each forage and shade treatment combination.

Variables	Forage									
	Bahia grass		Bermuda grass		Native Mix		Switchgrass		E. Gama grass	
Shade Treatment (% shade)	mean plants per pot									
0	16.0	(1.9)	9.0	(0.8)	8.0	(1.1)	14.0	(1.9)	3.0	(0.5)
Success Rate (%)	12.8		6.5		15.7		35.3		150.0	
30	12.0	(2.8)	15.0	(1.6)	23.0	(2.7)	20.0	(0.7)	3.0	(0.5)
Success Rate (%)	9.6		10.9		45.2		50.4		150.0	
60	11.0	(1.7)	15.0	(1.7)	17.0	(2.5)	19.0	(0.4)	2.0	(0.5)
Success Rate (%)	8.8		10.9		33.4		47.9		100.0	

Standard deviation is given in parentheses.

Table 5: Above ground biomass tissue macronutrient concentration for each forage-shade treatment combination.

Forage	Treatment	N	P	K	Ca	Mg	S
	% Shade			mg kg^{-1}			
Bahia grass	0	12900	1920	22550	4647	2400	3200
	30	15500	2176	25760	5009	2900	3700
	60	16000	2447	26130	5192	3500	3200
Bermuda grass	0	12000	1714	14720	5126	1400	4200
	30	13700	2144	16360	4650	1400	4000
	60	18800	2699	19320	7480	1700	5100
Native Mix	0	8200	1195	11990	2650	1100	900
	30	18100	1803	17540	3030	1700	1300
	60	31600	2545	19140	4250	1400	1500
Switchgrass	0	10800	1531	13110	2900	2000	1000
	30	9200	1741	12060	2670	1900	900
	60	11400	1911	13750	3040	2300	800
E. Gama grass	0	3100	362	360	360	200	300
	30	5100	753	750	820	600	600
	60	6500	693	690	829	500	600

Table 6: Light quality proportion, quantum intensity and percent full sun beneath shade cloth treatments.

Treatment	Proportion to PARFR				Total PARFR QI	Full Sun
Shade Cloth Density (%)	B	G	R	FR	μmol m^{-2} s^{-1}	%
0	0.26	0.28	0.25	0.21	423.9	100.0
30	0.26	0.28	0.25	0.21	363.4	85.7
60	0.26	0.28	0.25	0.21	160.3	37.8

g). Switchgrass biomass production was not significantly different among the shade treatments. Orthogonal contrasts indicated that no significant difference in biomass exists within forages between treatments at the 95% confidence level. Bahiagrass, bermudagrass and native mix produced the greatest biomass beneath 30% shade treatments. Switchgrass and Eastern gamagrass produced the highest biomass beneath the 0% shade treatment.

Light quality and quantity

Total light quantum intensity was reduced 14.3% beneath 30% shade cloth, and 37.8% beneath 60% shade cloth. Light quality did not appear to have been altered by the shade cloth (Table 6).

DISCUSSION

Germination verification results confirmed the need for high seed rates of forages for adequate establishment, as low germination rates of some forages resulted in the absence of growth in some pots. During biomass sampling, newly germinated Eastern gamagrass were included, suggesting that ungerminated, viable seed still remained after 7 months. Seed dormancy may have been a contributing factor to plant density. Establishment rates greater than 100% is explained by variability in weight and size of Eastern gamagrass seed; seeding rates were based on weight and variability of seed weight was high, so some pots received five seeds while others received only three. Due to low germination and high dormancy of many native species, evaluation of establishment success over multiple seasons may be a more effective assessment.

Several species were found to be pot bound during biomass sampling, and may have been an unmeasured factor, particularly affecting Eastern gamagrass and switchgrass, which are known to extend roots up to 180cm into soil profiles. Crowding of large native mix species, such as switchgrass, may also have affected results by intraspecific competition. Correlation of plant density and soil depth [23] supports conclusions regarding root restrictions and low plant density.

Nutrient concentration of the native mix was effected by the shade treatments. Mean tissue content of Potassium and CP for all species was significantly higher under the 60% shade treatment. Increased crude protein content of forages beneath shade is significant for silvopasture management because it increases the value of the forage to grazing livestock and as cut hay. Interaction of species and shade treatment were found for several nutrients. The native mix also had increased tissue concentration of Copper, Nitrogen and Phosphorus beneath the 60% shade treatment, and Calcium concentration increased in bermudagrass with shade. Increased tissue nutrient concentration in response to increased shade density suggests that the native mix and bermudagrass may be nutritionally better forages under the partial shade of silvopasture systems.

Eastern gamagrass is generally considered a high quality forage species as Mashingo [24] found ADF in "Pete" Eastern gamagrass to range from 31.1% to 44.5%; this study found the greatest mean ADF for "San Marcos" Eastern gamagrass (20.3%) produced beneath 60% shade. Low ADF indicates that livestock can efficiently digest the forage material; therefore, Eastern gamagrass becomes a more easily digestible energy source under shade. Conversely, Eastern gamagrass had relatively low mean tissue concentrations of Nitrogen and TDN. Compared to the other forages, the native mix had large variations for Copper, Zinc, Nitrogen, ADF and TDN, which may be due to variation in tissue nutrient concentration of the individuals of each species in the native mix. Pots seeded with the native mix contained different numbers of individual species which may have contributed to the large variations.

"Alamo" switchgrass is often used for biofuel production due to high biomass production, but Eastern gamagrass, bahiagrass and bermudagrass produced higher mean biomass. Biomass production of switchgrass may be better studied in the field due to root development restrictions in pots. Biomass production for all species was similar under 0% and 30% shade treatments, indicating that forages are capable of producing comparable biomass when exposed to a 30% reduction in light. Similar to Richard M, et al. [23], a 28% reduction in total quantum intensity in August did not affect plant biomass.

The light compensation point is the point of irradiance where photosynthetic CO_2 fixation matches photosynthetic CO_2 respiration rate. When photosynthesis continues beyond the light compensation point, a net gain of NADPH and ATP occurs. Establishment and success of a forage species in a silvopasture system may depend on the ability of a species to photosynthesize under decreased irradiance. Estimated light saturation point for bahiagrass is greater than 2000 μmol photons m^{-2} s^{-1} [25]. Both switchgrass and big bluestem are known to reach light saturation at quantum intensities greater than 2200 μmol photons m^{-2} s^{-1} [26].

There was no change in quality of light beneath the shade cloth. Shade density beneath the shade cloth was found to be considerably less than the density indicated for each grade cloth used. Stretching or overlapping of shade cloth would influence shade density. Black shade cloth was used in this study; however, other types of shade cloth exist. Some shade cloths are designed to absorb or reflect specific bands of light to create a desired light spectrum beneath. Shade cloths which obstruct specific wavelengths of light could be used in future research that alters light quality to more closely simulate a silvopasture canopy.

Shading as a variable is a surrogate for a number of site and physiological factors. Shading will have direct impact on soil temperature and air temperature, which in turn may influence initial germination success and also above ground plant growth.

CONCLUSION

Tissue nutrient concentration differences were found in some species grown under different shade treatments. Increased or decreased forage quality is important in silvopasture or grazing or hay harvesting. Biomass production beneath shade is also significant as an indirect measurement of biological productivity and may be used to evaluate the success of establishment. Results indicated that bermudagrass had successfully established due to high biomass production. Eastern gamagrass and bermudagrass may be a suitable species if maximum biomass production were the goal of a silvopasture management system due to their higher mean biomass production under 30% and 60% shade treatments. Environmental factors such as soil moisture were maintained at ideal levels for plant growth in the study, rendering direct comparison of these results to field data inappropriate. As an establishment study spanning one growing season, evaluations of the native mix and switchgrass were limited because many native species show significantly increased growth during the second year.

Long term evaluations of establishment of forages under silvopasture conditions after multiple growing seasons are needed to investigate the sustainability of silvopasture management systems. Research regarding cultivars, other warm season forages and the use of cool season legumes as winter cover crops may benefit future research. Further examination of changes in plant nutrient content in response to shade may benefit silvopasture management, including fertilization. Plant density and establishment success suggest that most of the forages became well established. Changes in tissue nutrient concentration beneath varying shade densities may affect the quality of forages grown beneath the partial shade of a silvopasture system. Biomass production may not be affected by a reduction in irradiance up to 30%, suggesting that silvopasture management should include consideration of shade density within the silvopasture system. Additional research on the interaction of shading on soil and air temperatures, microscale relative humidly and the resulting impact of these on photosynthesis and plant growth should be performed.

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