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Research Article

Initial Establishment Success of Five Forages in an East Texas Loblolly Pine (*Pinus taeda*) Silvopasture

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ABSTRACT

The establishment at the end of 1 year of five forages was evaluated in a loblolly pine (*Pinus taeda* L.) silvopasture system. The five forages 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 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. The silvopasture was in a 22 year old stand of loblolly pine in the Fairchild State Forest near Rusk, Texas. Five plots for each forage were sown in March 2008 and the density of each forage after one year calculated. Soil samples were taken to a depth of 10 cm from each corner of each plot using a push probe sampler and a composite sample created for chemical analyses Soil depth to B horizon or restrictive layer was determined using an 8 cm diameter hand bucket auger. In addition, light quality under the canopy was evaluated in August, October and January using a hand-held spectroradiometer: for light quality analysis, light was divided into blue, green, red, and far red bands. Irradiance (µmol photons m^{-2} s^{-1}) for each band was divided by the total for all bands to create a proportion. Soil depth was positively correlated to plant density in the silvopasture. Bahiagrass and Eastern gamagrass were well established after one growing season. Compared to full sun, light intensity in the silvopasture was reduced by 29% in August, 51% in October, and 56% in January. Proportion and light intensity of the far red band decreased from August to January. Light quality was not affected by the canopy; but the intensity of light reflected or absorbed by the canopy decreased between August and January. Light readings may have been influenced by the decrease in solar angle from August to January. Light intensity was higher than the light compensation point, but lower than the light saturation point for several of the grasses; light in the silvopasture was lowest in January when warm season forages are generally dormant.

Keywords: Light quality; Light intensity; Forages; Silvopasture

INTRODUCTION

Silvopasture systems combine the benefits of timber production with livestock and forage production. While considerable research has been accomplished on forage crops in open pastures, little screening of forages under partial shade has been reported. Observation and analysis of light quality under loblolly pine (*Pinus taeda* L.) has not been widely performed even though necessary when evaluating forage crops under such a canopy. Silvopasture systems provide multiple sources of income for landowners by producing multiple crops simultaneously from the same land. Tree crops may take 10 to 12 years before the first harvest, meanwhile there is limited opportunity for income from the investment. Silvopasture systems seek to utilize the land for additional income with little impact on the tree crop [1]. Enhanced nutrient cycling is an added benefit of silvopasture systems, particularly with trees which send roots deep into lower soil horizons. This benefit allows trees to tap into nutrients in lower B and C horizons not accessible to roots in upper horizons [2]. These nutrients are later deposited at the surface horizons in organic matter.

Tree canopies act to moderate microclimate by reducing heat loss at night and physically shielding the surface from excessive solar

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radiation [3,4]. Forage performance under varying light conditions has been evaluated for many agronomic systems and species combinations. Common forage species such as bermudagrass and fescue have been previously researched, but data is still lacking for many forage grasses. Results often show variability in production under different combinations of species and shade levels [5,6]. Increased addition of organic matter and higher retention of soil moisture are two possible physiological benefits of silvopastures. Generally, as trees increase in age the canopy of the forest becomes denser. This necessitates thinning for the maintenance of forage quality and quantity of harvest [3]. The impact of sunflecks on photosynthetic rates remains a relatively under-explored component of understory vegetation ecology [7,8]; therefore, gap size in the canopy and the size of sunflecks may be a significant factor in plant establishment and growth.

Grasses under shade generally produce increased non-protein nitrogen and silica concentration. Average leaf area is increased under shade, and because leaves contain less fiber and more total protein than stems, the quality for foraging livestock may be greater. Average leaf area and internode length increased under shade for most species examined, except for bermudagrass. Plant physiological responses to shade include altered biomass production. Big bluestem (*Adropogon girardii* Vitman) was found to produce 45.3 g above ground weight per plant in full sun compared to 33.4 g per plant under 50% shade and 17.8 g per plant under 80% shade; indiangrass (*Sorghastrum nutans* (L.) Nash) and switchgrass (*Panicum virgatum* L.) produced similar results [9].

The role of soil moisture in shade studies has often been linked to the differential loss of moisture to evaporation in partial shade with full sun situations [10]. Tree density has been shown to affect transpiration losses in forage species as greater tree density increased shade and, therefore, lowered the transpiration losses of forage species [5]. However, increasing canopy density may correspond to an increasing loss of moisture through transpiration by the canopy species.

Bahiagrass (*Paspalum notatum* Fluegge) is native to South America but is frequently used in the southern Gulf Coast region of the United States as a turfgrass and forage [11,12]. The popularity of bahiagrass is based on the species ability to provide adequate forage on low fertility, dry sites [13]. Bahiagrass also produces large amounts of seed, further aiding in rapid establishment of this species as a forage. Bermudagrass (*Cynodon dactylon* L. Pers.) is native to Africa but is a common forage and turf species in the Southern United States due to its wide growth range and adaptability. Fertilization of bermudagrass is especially necessary to maintain forage growth and suppress weed growth [14]. Native grasses of the United States include little bluestem (*Schizachyrium scoparium* (Michx) Nash), indiangrass, "Haskell" *Sideoats grama* (*Bouteloua curtipendula* (Michx) Torr), switchgrass (*Panicum virgatum* L.), sand lovegrass (*Eragrostis trichodes* (Nutt.) Alph. Wood) and big bluestem. These grasses were once common across the plains and prairies of the central United States, as well as thte open pine savannahs of the southeastern United States. Several factors such as heavy grazing and tillage decreased their presence; however, due to their adaptability to a wide range of climates they can still be used as forage crops. Native grasses often take 1 to 2 years to become well established and during that critical period weed species should be suppressed [15]. Switchgrass is a warm season perennial grass and a native to North America. Variations exist among cultivars regarding germination rates, cold tolerance, drought tolerance and phenotypes which make cultivar selection an important aspect when establishing switchgrass [16]. The switchgrass cultivar "Alamo" has shown nearly 90% germination when a watering interval of seven days was used [17], regardless of soil type.

Eastern gamagrass (*Tripsacum dactyloides* L.), a perennial bunch grass, 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 have generally high viability, overcoming dormancy often poses a problem in developing stands. The varied combinations possible in silvopasture management require an understanding of forage response to varied light and soil conditions.

OBJECTIVES

The five forages evaluated in this study were 'Pensacola" bahiagrass, "Texas Tough" bermudagrass, "Alamo" switchgrass, "San Marcos" Eastern gamagrass, and a native mix containing 45% "Texas" little bluestem (*Schizachyrium scoparium* Michx Nash), 15% sand lovegrass (*Eragrostis trichodes* Nutt. L. Alph. Wood), 10% "Lometa" indiangrass, 10% "Haskell" *Sideoats grama* (*Bouteloua curtipendula* Michx Torr) and 5% "Earl" big bluestem by weight.

The two specific objectives of this study were to:

1. Evaluate the success rate of establishment of five forage species under a loblolly pine silvopasture;
2. Characterize light quality and quantity beneath the loblolly silvopasture canopy.

METHODS

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 previously describe methods. The native mix seed was 90% pure; all other seed was at least 98% pure.

Study site description

The study site was a thinned plantation of 22 year old loblolly pine in the I.D. Fairchild State Forest (Figure 1) near Rusk, Texas (31° 48' 12" N, 95° 22' 08" W) with a slope of less than 1%. Soils were Bowie series fine-loamy siliceous, thermic, Plinthitic Paleudults. The trees were thinned two years earlier to an approximate basal area of 9.2 m^2 ha^{-1}. Tree diameter at breast height (DBH) was measured for all trees within the plantation.

Seed bed preparation and seeding

Field treatment plot dimensions were 7.9 m × 12.2 m. Five replicates were established for each forage with 25 plots total. Seed beds were prepared by hand raking pine straw and removing large woody debris from each plot. Plots were lightly tilled with a four-wheeler towed disc. Forages were sown into randomly selected individual plots on March 19, 2008 using a cyclone spreader and rolled into the soil using a 106 L 48 cm diameter by 61 cm hand-pushed polyethylene lawn roller filled with water. Weight of the lawn roller was approximately 115 kg when filled with water. Because seed was not drilled, the plots were seeded at twice the recommended rate for proper stand development (Table 1). Field plots were treated

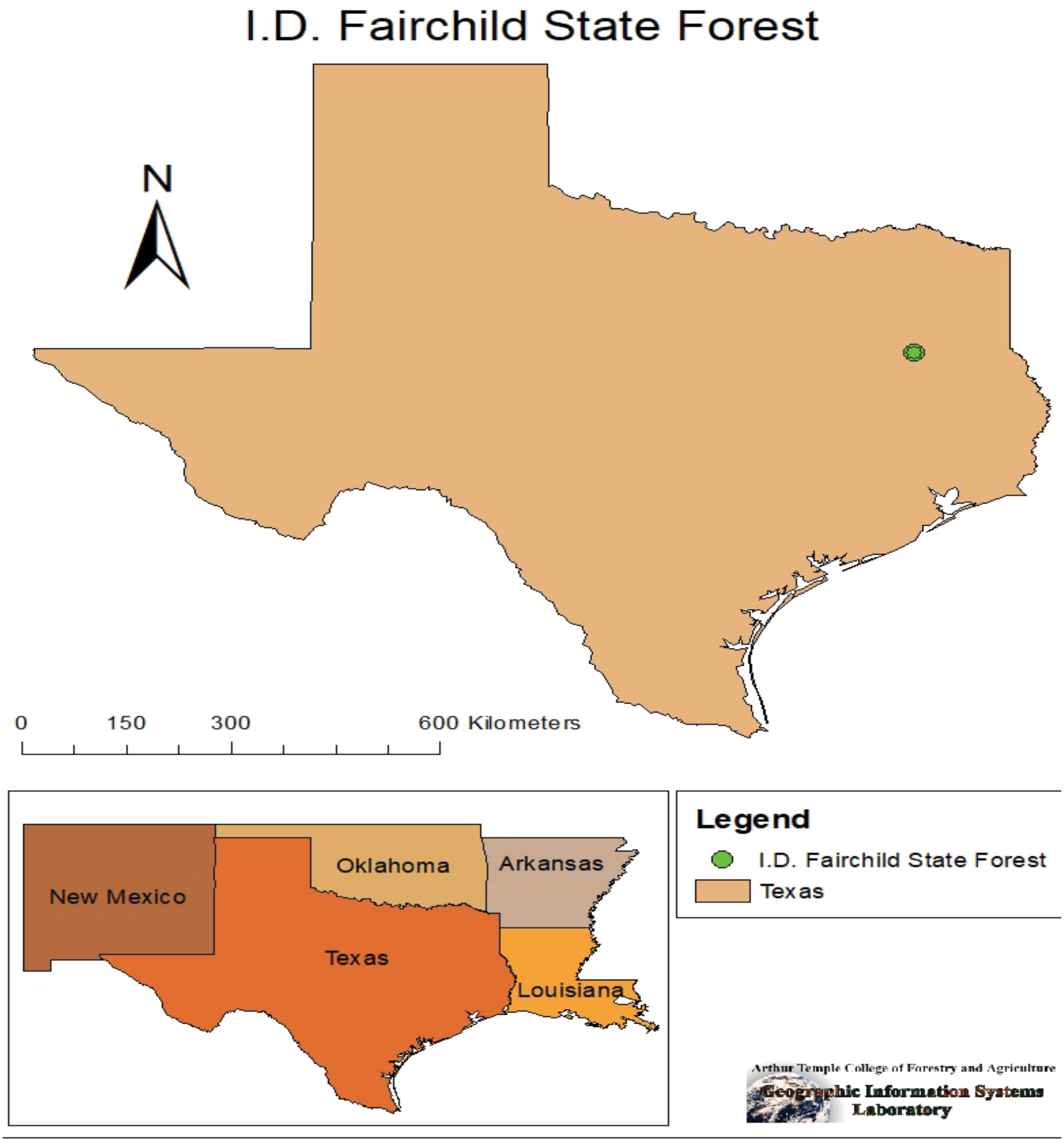

Figure 1: Location of I.D. Fairchild State Forest Research Site.

Table 1: Seeding rates of forages.

Forages	kg PLS ha^{-1}*	lbs PLS ac^{-1}
Bahiagrass	33.6	30.0
Bermudagrass	4.5	4.0
Native Mix	7.2	6.8
Switchgrass	6.7	6.0
Eastern gamagrass	22.4	20.0
*PLS: Pure Live Seed		

with 2.13 kg ha^{-1} of 2, 4-D amine (2, 4-Dichlorophenoxyacetic acid) between June 20 and June 23 to reduce establishing broadleaf weeds.

Soil and light sampling

Soil samples were taken to a depth of 10 cm from each corner of each plot using a push probe sampler and a composite sample created for chemical analyses for pH, NO_3-N, extractable K, Ca, Mg, S and Na at the Stephen F. Austin State University Soil, Plant and Water Analysis Laboratory, Nacogdoches, Texas. P was determined by Melich III extraction. Soil depth to B horizon or restrictive layer was determined using an 8 cm diameter hand bucket auger. Five borings were taken per plot; one from each corner and one in the center of each plot.

Radiant light readings were taken at each corner and the center of all plots using a FieldSpec® HandHeld Spectroradiometer (model FS HH 325-1075) by ASD, Inc (2555 55th Street, Suite 100 Boulder, CO 80301) with Full Sky Irradiance Reverse Cosine Receptor (RCR) attached. Five spectrums were recorded at each sample site during each sampling period and averaged to form one reading per location. Readings were taken on cloudless days between 11:00 am and 2:00 pm. on consecutive days if all samples could not be gathered in one day and as weather permitted. Three series of light readings were conducted: August 4; between October 23-30, 2008; and January 14, 2009. Some October 23 readings were postponed due to increased cloud cover and completed October 30. Full sun readings were used as a baseline correction for each plot reading [5]. All readings for a single block were gathered within 1 hour of baseline measurements. Mean light readings were calculated for each plot from the reading taken from the five locations in each plot. A tripod was used to elevate the spectroradiometer to approximately 1.1 m, which was leveled at each reading location using an attached bubble level. Software used was RS^3 version 5.5 for Windows and ViewSpec Pro version 5.0.

Plant density

Plant density was sampled using a 1 m^2 quadrat assigned systematically at three sampling locations within each plot in October, 2008 and a mean was calculated for each plot. Each species occurring within a quadrat was counted to determine plant m^{-2}. *Stoloniferous* species, such as bahiagrass and bermudagrass, were tabulated by counting each plant crown as one plant and not counting runners which had rooted. Success rate of establishment (%) was calculated by dividing plant density by number of seeds sown, then multiplying by 100.

Data analysis

Radiant light data collected in the field and stored as digital values plotted against wavelength (nm) was converted to quantum intensity (μmol m^{-2} s^{-1}) using ViewSpec Pro 5.0.19 [18]. Data was then classified into ranges of light: wavelengths; 400-499 nm as blue (B), 500-599 nm as green (G), 600-699 nm red (R), and 700-799 nm as far red (FR). Ratios were calculated for each range in proportion to Photosynthetically Active Range plus Far Red (PARFR), and the ratios generated labeled as B/PARFR, G/PARFR, R/PARFR, and FR/PARFR. The ratio of red:far red wavelengths were calculated as R/FR. Full sun (x) was used as a correction factor for light in the silvopasture (z) and in determining light absorbed and reflected by the canopy (y). Light absorbed and reflected by the canopy (y) was determined from data collected in full sun and in the silvopasture by the equation

$$y = x - z.$$

Means of y and z for each wavelength band were calculated for each plot. Plot means for y and z of each wavelength band for August, October and January were analyzed by 3-way ANOVA. Factors of the ANOVA were wavelength band, time sampled, and block. Proportions to full sun were reported in % and were calculated by dividing z by x for readings in the silvopasture, and by dividing y by x for canopy absorbance and reflectance.

Correlation analysis using Pearson's correlation (r), Spearman rank correlation (r_s), and Kendall rank correlation (τ) was conducted on plant density, August light readings and soil profile depth. Student's *t* test was performed on each correlation coefficient. Correlation analysis and Student's *t* was performed in SAS (SAS Institute, Inc.). The Shapiro-Wilk test for normality was used to assess normality for each of the variables used in the correlation analysis. Alpha level used was 0.05.

RESULTS

Site characterization

The recorded basal area of 12 m^2 ha^{-1} (52 ft^2 ac^{-1}) showed an increase from the approximately 9 m^2 ha^{-1} (40 ft^2 $acre^{-1}$) since the site was thinned. Mean soil depth to restrictive layer or B horizon across the site was 65.5 cm (± 19.5 cm). Field soil profile description borings were restricted at several locations due to accumulations of plinthite and ironstone (Table 2). The soils were moderately acidic and low in fertility, especially phosphorus, which may have adversely affected forage establishment, especially the Bermuda grass.

Germination rates and plant density

Germination rates of the native mix and Eastern gamagrass were both well below 50%. Switchgrass germination was the highest of the five tested species; viability of ungerminated seed was not determined (Table 3). The rate of establishment was highest in Eastern gamagrass. Bahiagrass had the greatest density of the five species evaluated; however, plant density was not significantly different among species (Table 4).

Table 2: Mean soil analysis results.

pH	NO_3-N	P	K	Ca	Mg	S	Na
5.7	1.12 mg kg^{-1}	3 mg kg^{-1}	54.0 mg kg^{-1}	591.3 mg kg^{-1}	65.6 mg kg^{-1}	6.6 mg kg^{-1}	110.3 mg kg^{-1}

Table 3: Germination rates of the five forages.

Forages	Germination (%)
Bahiagrass	50.5
Bermudagrass	61.3
Native Mix	17.3
Switchgrass	77.0
Eastern gamagrass	31.0

Table 4: Mean plant density and success establishment rate for the five forages.

Forage	Mean plant density (plants m^{-2})	Success rate (%)
Bahiagrass	7.9 (8.2)	0.38
Bermudagrass	3.9 (3.2)	1.72
Native Mix	5.1 (3.9)	0.58
Switchgrass	1.8 (1.4)	0.29
Eastern gamagrass	5.9 (1.3)	10.35

Plant density was not significantly different among species. Standard deviation is in parentheses.

Light

Mean light quality data for August, October and January varied in mean quantum intensity (µmol photons m^{2} s^{-1}) for each light quality wavelength band (Figure 2). Mean quantum intensity (QI) decreased over time as shade density in the silvopasture increased. QI was reduced by 29, 51 and 56% in the silvopasture in August, October and January, respectively. The proportion of wavelength band to PARFR was found to increase for B, G, and R over time, while proportion of FR decreased. The ratio of R:FR increased due to increasing proportions of R and decreasing proportions of FR.

There was a significant interaction between time and wavelength band (Table 5), as significant changes were found in QI of B ($p<0.001$), G ($p<0.001$), and R ($p<0.001$) bands of light over the three sampling times. FR was found to be significantly different for August ($p<0.001$), but not for October and January ($p=0.409$). A significant interaction occurred between time and band width also was found. Mean y QI was significantly different when comparing August to October and January ($p=0.005$). Quantum intensity was statistically different for B when comparing August and October ($p \leq 0.001$), August and January ($p \leq 0.001$) and October and January ($p=0.017$). The G band was found to be statistically different between August and October ($p \leq 0.001$), August and January ($p \leq 0.001$), and October and January ($p=0.003$). The R band was found to be statistically different when comparing August and October ($p \leq 0.001$), August and January ($p \leq 0.001$), and October and January ($p<0.002$). Mean FR band was statistically different for all sampling times.

Correlation analysis results

Soil depth to B horizon or the restrictive layer and plant density (Figure 3 and Table 6) were found to be correlated by Spearman rank correlation coefficient (r_s=0.487 ($p=0.014$)) and Kendall rank correlation (τ=0.349 ($p=0.016$)). August PARFR was not found to be significantly correlated with soil depth or plant density. Plant density data was found to be not normally distributed by the Shapiro-Wilk test for normality ($W=0.780$, $p<0.001$), and since Pearson correlation analysis assumes data is normally distributed, the Pearson coefficients for plant density have been omitted.

DISCUSSION

Reported germination rates confirmed the need for high seed rates of forages for adequate establishment, and the use of preferred planting methods for each species, rather than a single methods used in this study may increase germination and success rate of establishment of forage species. This study evaluated eastern gamagrass with the seed case still attached to the seed embryo. Establishment of eastern gamagrass from seed sown in late winter has also been shown to increase germination and overall stand development, but applications of chemical treatments such as KNO_3, gibberellic acid, sodium-hypochlorite, and carbon-dioxide to stimulate germination of eastern gamagrass are generally unsuccessful. Forages were seeded at twice the recommended rate to compensate for low germination and because seed was not drilled. Establishment appears successful during the first year of growth, suggesting that doubling the recommended seed rate may overcome limitations posed by seed dormancy and sowing

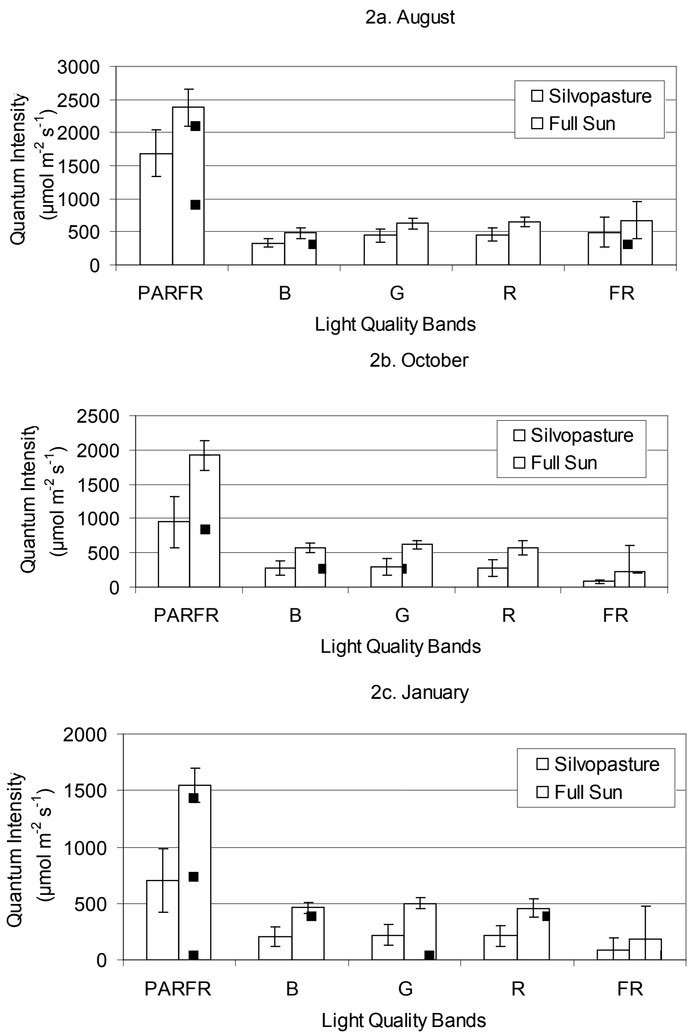

Figure 2: Light quality bands and light quantity in the silvopasture and full sun for (a) August, (b) October, and (c) January. Photosynthetically Active Radiation plus Far Red (400-800 nm) = PARFR; Blue light (400-500 nm) =B; Green light (500-600 nm) = G; Red light (600-700 nm) = R; Far Red light band (700-800 nm) = FR. Standard deviations are shown as error bars.

without drilling seed. Future studies may be needed to evaluate the establishment of Eastern gamagrass using seed pretreatment methods.

Plant density and success rate of establishment

Bahiagrass and eastern gamagrass were found to have the highest plant densities of the five species evaluated and appeared to be well established. Eastern gamagrass showed an higher success rate of establishment compared to the other species. Eastern gamagrass density of 1 plant m^{-2} may be considered established because plants may reach over 1 m in diameter [19] and these results found plant density for Eastern gamagrass to be 5.9 plants m^{-2}.

The native mix produced a plant density of 5.1 plants m^{-2}, the second lowest observed. Plant densities of 20 to 30 plants m^{-2} for native grasses have been reported [20], including switchgrass and big bluestem, appropriate for grazing. Bermudagrass and switchgrass produced low plant densities in the silvopasture and did not appear well established and were well below recommended densities. An evaluation of establishment after the second growing season may allow for viable, dormant seed to germinate.

Table 5: Mean light readings for August, October and January in the silvopasture, for full sun, and for the calculated values of light reflected or absorbed by the canopy.

		Wavelength Band					
Variables		B	G	R	FR	R:FR	Total PARFR QI
Month	**Source**		Proportion to PARFR				µmol m^{-2} s^{-1}
August	Silvopasture	0.20	0.26	0.27	0.29	0.93	1689.3
	Full Sun	0.20	0.26	0.28	0.28	0.97	2376.9
	Canopy	0.20	0.27	0.29	0.25	1.16	687.6
October	Silvopasture	0.29	0.31	0.30	0.09	3.44	948.4
	Full Sun	0.30	0.32	0.30	0.12	2.45	1918.6
	Canopy	0.29	0.33	0.29	0.11	2.71	994.0
January	Silvopasture	0.29	0.31	0.30	0.12	2.44	700.3
	Full Sun	0.30	0.32	0.30	0.12	2.51	1545.2
	Canopy	0.30	0.33	0.29	0.12	2.39	839.2

Blue light band (400-500 nm)=B; Green light band (500-600 nm)=G; Red light band (600-700 nm) =R; Far Red light band (700-800 nm) =FR; Photosynthetically Active Radiation plus Far Red band (400-800 nm)=PARFR.

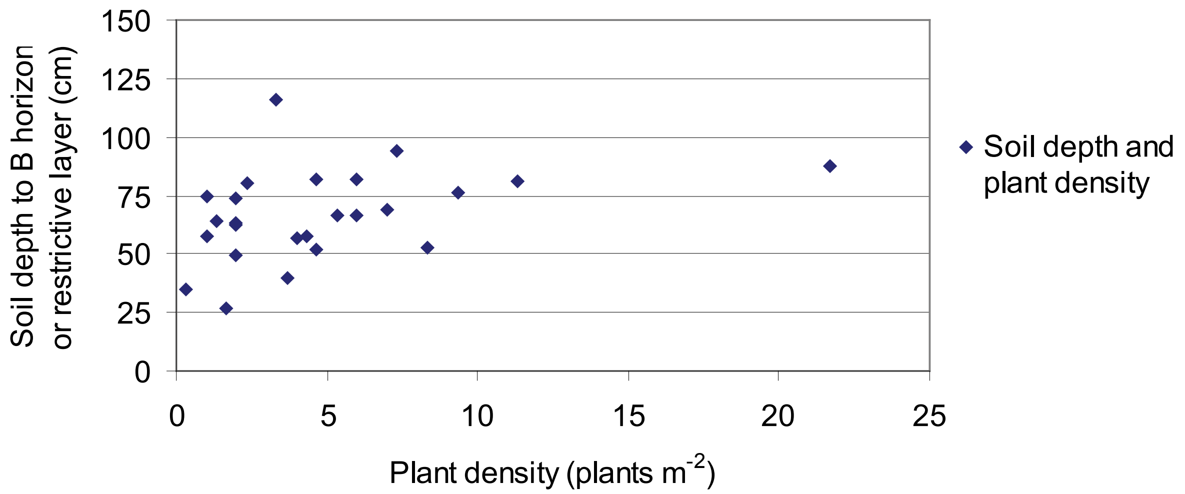

Figure 3: Scatter plot of soil depth to B horizon or restrictive layer and plant density (rs = 0.487, τ = 0.349).

Table 6: Pearson, Spearman, and Kendall correlation analysis for soil moisture, soil profile depth, plant density and August PARFR.

	Pearson (r)	p value	Spearman (rs)	p value	Kendall (τ)	p value
Soil profile depth	**1.000**	-	**1.000**	-	**1.000**	-
Plant density	-	-	**0.487**	0.014	**0.349**	0.016
August PARFR	0.015	0.942	0.023	0.913	0.013	0.926
Plant density†	-	-	1.000	-	1.000	-
Soil profile depth	-	-	**0.487**	0.014	**0.349**	0.016
August PARFR	-	-	0.175	0.402	0.098	0.497
August PARFR	1.000	-	1.000	-	1.000	-
Soil profile depth	0.015	0.942	0.023	0.913	0.013	0.926
Plant density	-	-	0.175	0.402	0.098	0.497

Values in parentheses are negative.
P values are given for each coefficient (α=0.05).
†Plant density was not normally distributed so the Pearson correlation coefficient was not reported.
Bold values are significant at α=0.05.

Soil depth and plant density

Official soil description for the Bowie soil series reports ironstone pebbles in all horizons varying in size from 2-8 mm and in occurrence from 2-4% by volume in the upper 78 cm of the soil profile. Ironstone layers limited soil depth sampling in several plots. Correlation analysis found soil depth to B horizon or restrictive layer and plant density to be positively related. The relationship between these two parameters may be caused by the decreased rooting depth in the soils. A restrictive layer may have a negative effect upon plant root growth and development, whereas B horizons are generally thought to act as moisture reservoirs and are therefore beneficial to plant growth. The official soil profile description for the Bowie series notes the presence of brittle masses, concretions and ironstone throughout the profile. Plant growth may be negatively affected by the increased bulk density of the soil, impedance of root growth and decreased water holding capacity of the soil as a result of concretions and ironstone in the soil.

The relationship between soil depth and plant density is species dependent. *Sideoats grama* has been shown to colonize soils with depths between 0 and 20 cm more often than soils with depth greater than 20cm, suggesting a preference for shallow soils [21], in contrast to [22] who found native tall grass prairie species to be most productive in deep soils during the first 2 years after establishment. Little bluestem production has been reported to increase with increasing soil depth [23], while 87% of bermudagrass roots were found to occur in the upper 0.3m of the soil and 12% of roots occurred in the 0.3 to 0.9 m range [24]. Our results indicate that bermudagrass may not have been negatively affected by shallow soils, but little bluestem, eastern gamagrass and switchgrass establishment could have been impeded by shallow soils. Tall grass prairie species such as little bluestem, switchgrass and Eastern gamagrass show characteristics of adaptation to the deep soils present in the prairie ecoregions of the United States. The success of *Sideoats grama* on shallow soils may in part be a competitive response to limited soil moisture, nutrients, and volume for root development.

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]. Light in the silvopasture was above the mean light compensation point of 25 μmol photons m^{-2} s^{-1} reported for C_4 grasses [27]. The lowest irradiance observed was 167 μmol photons m^{-2} s^{-1} in January. Mean quantum intensity data indicated that the light saturation point was not reached for bahiagrass, switchgrass or big bluestem during any of the 3 light reading events. However, the lowest irradiance found in the silvopasture coincides with the winter dormancy of the warm season species evaluated in this study.

Observations made while conducting light readings showed a decrease in solar angle from August to October to January. Although light readings were performed between 11:00 am and 2:00 pm on cloudless days, quantum intensity decreased with decreasing solar angle. This is in agreement with the assumption that irradiance decreases as the growing season comes to an end. Solar angle of incidence tables supported this observation. Solar angle from the horizon at 12:00 pm decreased from approximately 75° in August to 45° in October and 36° in January [28]. Decreasing solar angle also causes increased interception of light by the silvopasture canopy. Lower solar angle means light must pass through more of the silvopasture canopy and therefore has a higher likelihood of being intercepted or absorbed.

Proportion of B in the PARFR spectrum in the silvopasture was found to increase in all plots over time; however, mean QI for B decreased over time. This is most likely attributed to the decreasing solar angle of incidence coupled with decreasing total PARFR QI, explaining an increase in the proportion of B while PARFR QI decreased. Light in the B wavelength band assumed a larger proportion of the total PARFR spectrum in the silvopasture as the growing season transitioned to autumn and winter. Quantum intensity readings for G and R in the silvopasture decreased, while the proportions of G and R in the silvopasture increased over time. Proportions of B, G and R appear to increase equally in the silvopasture and in full sun over time. Light quality of the PAR did not appear to be altered by the silvopasture canopy.

Decreased QI of FR coincided with decreased proportion of FR. The FR band examined here, with wavelengths from 700 to 800 nm, overlaps the thermal range known as near infrared light (approximately 700 nm to 1400 nm). Seasonal changes in temperature may have affected results of FR in the silvopasture over time due to this overlap of two spectral ranges. Ratios of R:FR increased from August to January in the silvopasture, in full sun, and for light reflected and absorbed by the canopy. Increased R:FR has also been correlated with cloud cover, however readings in this study were taken on cloudless days. While vegetation absorbed high amounts of R while FR increased beneath vegetation shade [29], light readings in this study do not support the findings of Bell et al. [29] because FR decreased in the silvopasture. Light data showed a consistent proportion of R for all light readings over time, while FR decreased significantly from August to January.

Quantum intensity of wavelength bands of B, G and R trended upward from August to January for light reflected and absorbed by the canopy. Decreasing heat radiation between August and January may explain the decreasing quantum intensity for FR reflected and absorbed by the canopy from August to January. These changes in quality of light reflected or absorbed by the canopy may be a sign of physiological and morphological changes within the loblolly pine canopy along with seasonal decreases of these bands. Autumn needle drop of loblolly pine may explain the observed changes in light reflected or absorbed by the silvopasture canopy from August to October. Similar to the filtration of the UV-B band (280 to 320 nm) by certain conifers, the wavelength bands examined in this study may be preferentially absorbed or reflected by the loblolly pine silvopasture canopy [30].

Full sun light quality appears to have followed similar trends as light quality in the silvopasture. Proportion of the far red band decreased dramatically from August to October, while proportions of bands B, G and R remained similar between the three readings. PARFR also decreased with seasonal changes and explains decreases in total PARFR in the silvopasture.

CONCLUSION

Soil depth may have been a contributing factor effecting plant establishment during the first growing season. Bahiagrass and Eastern gamagrass produced high plant densities; however, plant density was not significantly different among species. Biomass production beneath shade is also significant as an indirect measurement of biological productivity and may be used to evaluate the success of establishment. Bahiagrass produced the greatest density in the study, indicating that establishment as successful. Eastern gamagrass produced mean plant densities greater than the densities recommended for grazing or hay harvesting. Mean quantum intensity decreased and shade density increased over time.

The proportion of each band to PARFR was similar for B, G and R, and FR decreased from summer to winter. Light reflected or absorbed by the silvopasture canopy significantly decreased for the wavelength bands B and G over time, and light quality did not appear to differ from quality of full sun with the exception of FR. Light quality beneath a vegetation canopy is known to be dependent upon many factors. Aside from factors known to influence the physical characteristics of light, the vegetation canopy of silvopastures creates additional factors which may influence light conditions beneath the canopy. However, plants may also modify growth characteristic such as leaf size to compensate for differing light quality measures: While plant density was assessed under the silvopasture light conditions, specific foliage measurements were not measured. Future studies might evaluate such plant characteristics.

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