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Full Length Research Paper

Comparison of fertilizer amendments on pine growth and forage production in a west gulf coast loblolly pine-bahiagrass silvopasture

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Abstract

Silvopasture land-use management practices have been evaluated in the southeastern United States, providing information on integrating commercial trees, forage, and livestock within an agroforestry system. If managed properly, this concept can form a network of mutually beneficial interactions that create profitable land-use options for various landowner types. Additional data is needed regarding site productivity, timber, and forage species in combination with fertilization regimes to further validate the benefits of a silvopasture system. A study was implemented at the Hill Farm Research Station, Louisiana State University Agricultural Experiment Station near Homer, Louisiana, with the overall goal to quantify the effect of poultry litter and commercial fertilizer on timber and forage production within a silvopasture system. Forage yield was measured at five production intervals in a growing season, and significant yield differences were detected among fertilization treatments compared to control treatment, with high rate poultry litter being significantly greater than other treatments. No timber production differences were detected after two-years of fertilization treatments. Poultry litter appears to be a potentially cost-effective alternative to commercial fertilizers in silvopasture systems in this region of the United States.

Key words: Poultry litter, *Pinus taeda*, nutrients, Fertilization, Silvopasture.

INTRODUCTION

Silvopasture is an agroforestry practice integrating trees, forage, and livestock to form a structural system of mutually beneficial interactions (Clason 1998), with the strategy to combine these so that each component produces usable products, while facilitating production of other components. In the United States they are designed to produce marketable commodities (cattle and timber) while maintaining long-term land productivity. Intermittent profits can be obtained from the sale of livestock, with additional future profits from the sale of timber (Harwell and Dangerfield 1991). According to Lawrence and Hardesty (1992), Zinkhan (1996), and public land-use professionals of the southern United States, increases in financial returns and economic diversity were direct results of silvopasture practices. Dangerfield and Harwell (1990) in a simulated loblolly pine silvopasture system found that the overall net value, per unit area, of a silvopasture was up to 70% greater than a pure forestry operation.

Non-industrial private forest landowners (NIPFs) control over 58 percent of the commercial forestland in the United States, and over two-thirds of total land in the south-

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east is classified as forest (USDA Forest Service1987). By the year 2030, it has been predicted that demand for pine pulpwood and sawtimber will significantly increase (USDA Forest Service 1987), and multiple land-use systems can fit southeastern timber production patterns (Biswell and Foster 1942, Pearson and Whitaker 1973, Byington *et al*. 1983, Clason 1999, Grado et al. 2001, Burner and MacKown 2005, Michel 2007, Blazier et al. 2008, Baker and Langsdon, 2011). While economic incentives to change from agricultural cropping enterprises to timber production systems are apparent (Harwell and Dangerfield 1991), data on the correct combination of site productivity, timber and forage species, as well as management practices such as fertilization regimes is needed before such systems are more accepted.

The specific objectives of this study were to:

(1) Compare the effectiveness of poultry litter to commercial fertilizer as a soil nutrient amendment source within a silvopasture system.

(2) Determine effects of soil nutrient amendments on forage and tree foliage nutrient concentration.

(3) Evaluate the impact of soil nutrient amendments on wood production and forage yield.

MATERIAL AND METHODS

Study Area

This study was conducted at the Hill Farm Research Station, Louisiana State University Agricultural Experiment Station, located near Homer, Louisiana (Figure 1) in a 2.3 hectare loblolly pine plantation that was planted in the fall of 1986 at 1371 trees per hectare (TPH). A pre-commercial thinning in 1990 left the stand at 741 TPH and in 1990 the stand was converted to a silvopasture by thinning to 247 TPH and the trees were pruned. Soils of the study site are Wolfpen loamy fine sands (loamy, siliecous, Thermic Arenic Paleudalfs) (Clason 1999).

Field Treatments

At 12 years old, the stand was divided into 24 rectangular 0.09 hectare treatment plots (54 x 17 m or 918 m^2) oriented east to west. A randomized complete block (RCB) design consisting of four fertilizer treatments and three-nested measurement subplots within each treatment was replicated six times. Within each treatment plot, three measurement subplots were established (radius of 8.5 m) and all trees within each measurement subplot were tagged. Three, 1m^2 soil/forage sampling plots protected from grazing by wire exclosure cages were placed in each treatment plot.

Fertilizer treatment applications in April of 1998 were a commercial fertilizer blend, two rates of poultry litter, and an untreated control. Poultry litter was applied at a low rate poultry litter treatment of 2 milligrams per hectare (Mg ha^{-1}) applied in two, 1 Mg ha^{-1} increments, while the high rate poultry litter treatment was applied in two, 2 Mg ha^{-1} increments totaling 4 Mg ha^{-1}. Analytical testing was conducted to determine nutrient composition of the poultry litter (Table 1). A pasture blend commercial fertilizer, containing diammonium phosphate (DAP), ammonium nitrate (NH_4NO_3) and muriate of potash (KCL) to supply 114-39-20 kilograms per hectare (kg ha^{-1}) of nitrogen (N), phosphorus (P), and potassium (K), for each of the nutrients, respectively was applied at the same time as the poultry litter.

Two forage crops consisting of Pensacola bahiagrass (*Paspalum notatum* Fluegge) in the spring of 1997 and Mt. Barker subterranean clover (*Trifolium subterranean* L.) in the fall of 1997 were seeded on site prior to fertilizer treatment application. The bahiagrass was broadcast seeded at 11 kg ha^{-1} and subterranean clover was broadcast seeded at 11 kg ha^{-1}. Due to drought conditions in 1998, the subterranean clover failed to reseed. Excess forage was grazed rotationally at a rate of two grazing units ha^{-1} (Clason 1999).

Field Sampling

Forage sampling was conducted in 1999 at 28-day intervals from April to August (Interval 1 (April to May 7), Interval 2 (May 7 to June 4), Interval 3 (June 4 to July 3), Interval 4 (July 3 to July 29), and Interval 5 (July 29 to August 28)), with samples from the cage exclosures obtained using a motorized hedge trimmer to simulate a sickle mower. All samples were placed in paper bags, oven-dried in a forced-draft oven at 60^o C for 72 hours, and weighed to determine total dry matter yield. The samples were then ground in a Wiley Mill, passed through a 60-mesh sieve, and tested for total N using the Kjeldahl method (Horneck and Miller 1998). A 2 gram sub-sample was placed in an acid-washed crucible and ashed at 500^o C for 5 hours in a muffle furnace for macronutrient (P, K, Sulphur (S), Calcium (Ca), Magnesium (Mg)) and selected micronutrient (Boron (B), Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Aluminum (Al), Sodium (Na)) concentrations analysis.

Pine foliage sampling began in early February prior to fertilization. Three trees from each treatment plot, for a total of 72 trees, were randomly chosen from the dominant and co-dominant crown classes. Using a 12-gauge shotgun, small branches were shot from the upper and outer portions of the crown where nutrient concentrations are most representative. Foliage samples were collected from the first flush of growth from the most recent growing season, and nutrient analysis was performed as described above.

In mid-April before fertilization, soil core samples were removed from the center of each measurement subplot, collected at depths sufficient to sample the A (0-15 centimeters), E (15-68 centimeters), and B (68+centimeters)

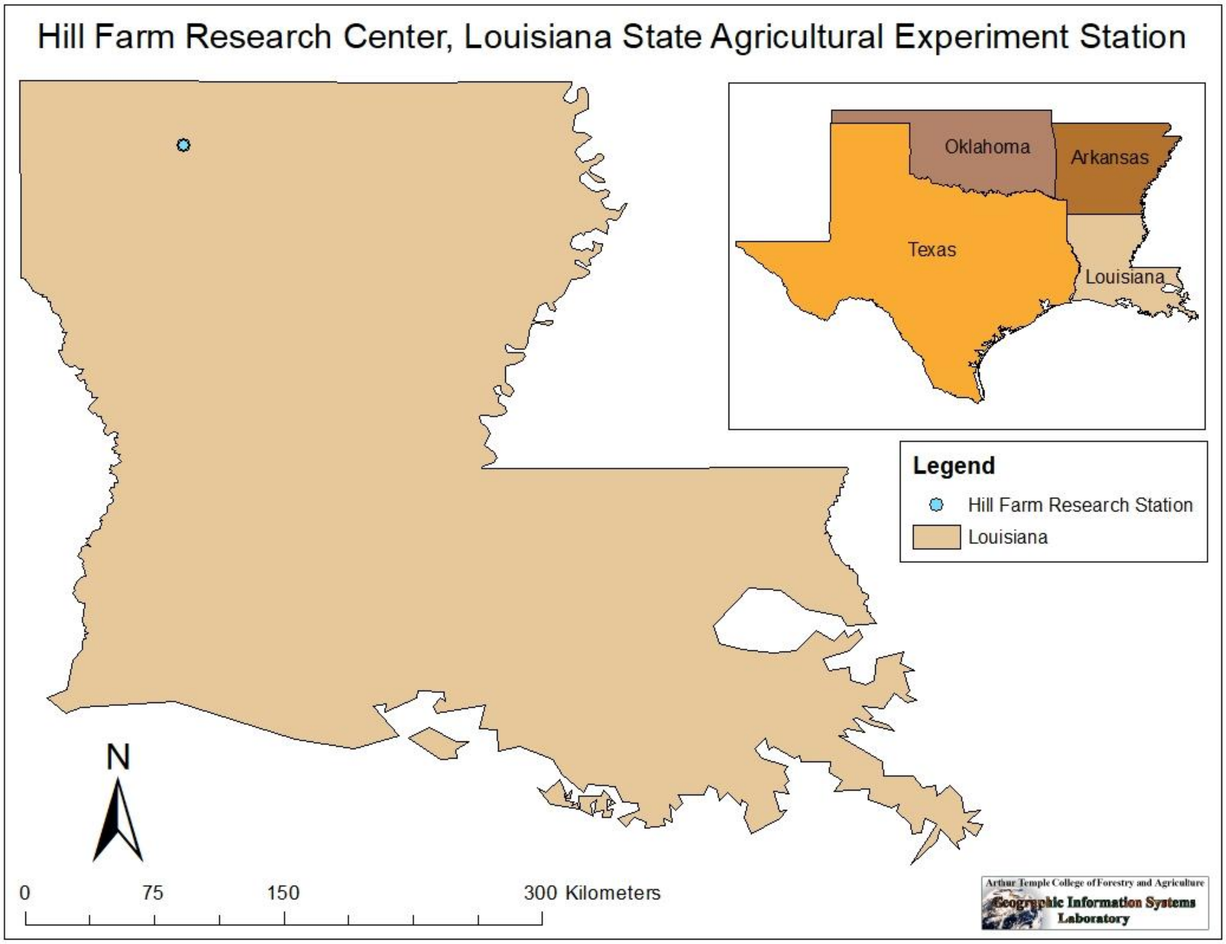

Figure 1. Location of Hill Farm Research Center, Louisiana State Agricultural Experiment Station.

soil horizons using a tractor mounted hydraulic soil sampling probe. Soil samples were analyzed for total N and extractable P using the Bray P method (Bray and Kurtz 1945). Forage, foliage, and soil samples were analyzed at the Stephen F Austin State University Soil Testing Laboratory.

Tree growth of individual trees was assessed from three nested subplots established within each treatment, each having a radius of 8.5 meters. Tree diameter (dbh), at 1.2 meters, was measured to the nearest millimeter using a tree caliper using tree tags as a reference point to ensure consistency with previous measurements. Total tree height to nearest meter was measured to the tip of the live crown with a clinometer. Trees were measured prior to fertilization treatments, and again two years after fertilization.

Total pine volume per tree among treatments was calculated using a volume equation [1] developed by Avery and Burkhart (1994) and validated by Tasissa *et al*. (1997).

The total volume equation used was:

$V_1 = B_1 + B_2 D^2 H$ [1]

Where

V_1 = total inside bark volume per tree in a thinned loblolly pine plantation
B_1 = (intercept) -0.13431
B_2 = (slope) 0.00203
D = diameter at breast height
H = total tree height

This equation is an extension of the combined variable equation of Avery and Burkhart (1994) and regional volume equations of Amateis and Burkhart (1987). For the purpose of this study, only total volume per tree was determined. Cubic-foot volumes were inside bark volume (i.b.) for individual trees.

Data Analysis

Analysis of variance (ANOVA, general linear model using Duncan's Multiple Range Test) for a randomized complete block design with four fertilizer treatments and six sampling replications compared tree foliage variables, forage variables and yields and soils data. Since drought conditions resulted in the subterranean clover failing to

Table 1. Nutrient contribution of two rates of poultry litter treatments.

Element	Nutrient Concentration		Rate		Commercial
	25% Moisture	as spread	4 Mg ha^{-1}	9 Mg ha^{-1}	Fertilizer
	%		kg ha^{-1}		Kg ha^{-1}
N	3.0	2.25	101	202	114
P	2.5	1.85	84	168	39
K	2.5	1.85	84	168	20

reseed, analysis determined that no significant difference occurred between blocks containing a mixture of subterranean clover and bahiagrass, and blocks containing bahiagrass only treatment. Tree and stand data were analyzed using Statistical Analysis System (SAS®) and General Linear Model Procedures with the replication x treatment interaction (14 df) as the error term to test Type III mean squares. Significance level for all analyses was set at the 0.05 alpha level.

RESULTS

Forage Production and Nutrient Content

Total dry matter forage yields over the five production intervals ranged from 2011 to 3713 kilograms per hectare. Yields were highest with the high rate poultry litter and lowest in the control. All fertilizer treatments had forage yields that were significantly different from the control (Table 2). Mean dry matter forage yield for the intervals ranged from 307 to 1365 kilograms per hectare; in general, yields increased between production intervals 1 to 3, and then decreased during intervals 4 and 5, with interval 3 being significantly greater. Daily dry matter yields were highest in the high rate poultry litter treatment throughout all production intervals. Production interval three had the highest daily dry matter yields for all treatments.

Macronutrient concentrations in bahiagrass forage differed significantly among fertilization treatments for nitrogen, phosphorus, potassium, and magnesium. Potassium concentration was significantly lower in the control compared to all other treatments. Significant differences were also detected for manganese, zinc, and copper in the high poultry litter treatment (Table 3).

Tree Foliar and Soil Nutrient Content

Concentrations of N, P, Ca, and Mg in foliage samples (Table 4) did not differ significantly among treatments, but K did. While the commercial fertilizer and high rate of poultry litter treatments did not affect foliar K concentrations, trees fertilized with low rate poultry litter were significantly higher than those in the control. Micronutrient concentrations of B and Cu differed significantly among treatments, while no differences were detected for Fe, Mn, and Zn. Boron differed between the control and high poultry litter treatments, with concentration lower in the high poultry litter treatment. Concentrations of boron ranged from 57.7 milligrams per hectare for the control and 39.8 milligrams per hectare for high poultry litter. Differences for copper were detected among low poultry litter and commercial fertilizer treatments (Table 4).

No significant differences in mean total soil N concentrations at any of the three depths were detected. Mean Bray – P concentrations differed significantly only among treatments at Depth 1 (0 to15 centimeters) (Table 5).

Timber Production

Tree growth attributes (Table 6) were measured prior to fertilization and following two years of fertilization applications, and were used to calculate growth rates. Mean tree height, dbh increment, total volume, and total cubic meter volume per tree increment from 1997 to 1999 were nonsignificant among treatments. Tree height increment ranged from 1.5 to 1.8 meters, and dbh increment over 2 years and ranged from 3.3 to 3.5 centimeters. Silvopasture management practices did not affect total volume growth (inside bark) among treatments. The volume equation produced an R^2 value of 0.96 and a standard error of 0.9425. Non-significant differences were found for total cubic meter volume per tree among treatments or for 2-year cumulative mean tree total cubic volume increment (Tables 7, 8, and 9).

DISCUSSION

The high rate poultry litter proved to be significantly different in regard to forage production from all other treatments, and can be attributed to higher nitrogen, phosphorus, and potassium amounts supplied by the poultry litter, and perhaps to its slower release compared to the commercial fertilizer. The low rate poultry litter and commercial fertilizer had comparable yields (Table 2), suggesting a potential savings for landowners where poultry litter is available, as well as less carbon-based fertilizer source. Moreover, fertilization in addition with adequate precipitation seemed to increase the forage production of bahiagrass under a pine canopy,comparable

Table 2. Forage yield by treatment and production intervals on the Hill Farm Research Station in northwest Louisiana, USA. Within column means with the same letter are not significantly different at the 0.05 level, determined by Duncan's multiple range test.

Forage Treatment	Production Interval 1	Production Interval 2	Production Interval 3	Production Interval 4	Production Interval 5	Total	Mean Daily Yields
	Dry Matter Yields kg ha^{-1}						
Control	420	230	703	351	307	2011[c]	14.4
Commercial Fertilizer	443	522	942	403	418	2728[b]	19.5
Low Poultry Litter	531	486	1012	398	342	2769[b]	19.8
High Poultry Litter	679	724	1365	498	447	3713[a]	26.5

Table 3. Mean bahiagrass forage macronutrient and micronutrient concentration by fertilizer treatments on the Hill Farm Research Station in northwest Louisiana, USA. Within column means with the same letter are not significantly different at the 0.05 level, determined by Duncan's multiple range test.

	mg kg^{-1}				
Treatment	**N**	**P**	**K**	**Ca**	**Mg**
Control	15157[b*]	2445[bc]	19688[b]	3653[a]	2408[a]
Commercial Fertilizer	19263[a]	2313[c]	23624[a]	3594[a]	2374[a]
Low Poultry Litter	17729[a]	2693[ab]	22770[a]	3690[a]	2538[a]
High Poultry Litter	18099[a]	2876[a]	24192[a]	4185[a]	2809[b]
	B	**Fe**	**Mn**	**Zn**	**Cu**
Control	4.53[a*]	485[a]	385[b]	57[b]	7.21[bc]
Commercial Fertilizer	4.69[a]	522[a]	503[a]	65[ab]	6.59[c]
Low Poultry Litter	4.67[a]	445[a]	363[bc]	60[b]	8.24[ab]
High Poultry Litter	4.64[a]	567[a]	343[c]	72[a]	9.32[a]

Table 4. Mean foliage macronutrient and micronutrient content of trees sampled during the month of February, on the Hill Farm Research Station in northwestern Louisiana, USA. Within column means with the same letter are not significantly different at the 0.05 level, determined by Duncan's multiple range test.

	mg kg^{-1}						
Treatment	**N**	**P**	**K**		**Ca**		**Mg**
Control	15145[a*]	1431[a]	4902[b]		1899[a]		982[a]
Commercial Fertilizer	16047[a]	1493[a]	5076[ab]		1905[a]		1033[a]
Low Poultry Litter	15351[a]	1501[a]	5516[a]		1894[a]		1017[a]
High Poultry Litter	15646[a]	1435[a]	5162[ab]		1865[a]		1050[a]
	B	**Fe**	**Mn**	**Zn**	**Cu**	**Al**	**Na**
Control	57.7[a*]	52.8[a*]	382[a]	681[a]	2.29[bc]	26.0[a]	29.8[a]
Commercial Fertilizer	45.5[bc]	53.7[a]	387[a]	584[a]	2.14[c]	28.6[a]	21.5[a]
Low Poultry Litter	50.3[ab]	50.7[a]	414[a]	633[a]	2.82[a]	29.9[a]	32.1[a]
High Poultry Litter	39.8[c]	49.8[a]	384[a]	623[a]	2.55[ab]	27.2[a]	29.3[a]

to the results found by Hart *et al*. (1970) and Lewis *et al*. (1985a) under slash and longleaf pine.

Mean dry matter forage yields among production intervals were greatly influenced by precipitation. The highest mean forage yield (interval 3) coincided with the greatest amount of precipitation from June 4 to July 3. In contrast, the lowest mean forage yield was produced during interval 5 (July 29 to August 28), in which the lowest amount, 1.65 cm, of precipitation occurred (Table 10). The factor affecting forage growth the most was low precipitation. During the summer of data collection, there were only five days in which more than 0.635 cm of precipitation were recorded from July 1 to November 30. Total precipitation for the summer amounted to approximately 12.7 cm of rain. However, the mean rainfall at the research station from July to October since 1950 was over 35.6 cm. Due to the below normal precipitation, mean productivity of bahiagrass should increase in the future given more normal precipitation amounts.

The high rate poultry litter treatment consistently produced the highest yields with the control treatment producing the lowest (Table 2). Similar results were reported by Clason (1993), Morris and Clason (1997), and Clason (1999) under pine canopies, who also emphasized the impact of weather. Fribourg *et al*. (1989) also reported weather as being a major limiting factor in forage production. Based on this study, Pensacola bahiagrass seems to have the ability to produce quality yields under partially shaded and droughty conditions. While no direct comparisons were made to forage yields in an open field for this study, Hart *et al*. (1970) reported bahiagrass and coastal bermudagrass yields under trees as being similar to forage yields grown in an open pasture. Clason and Oliver (1984) indicated that an acceptable silvopasture practice is to thin loblolly pine trees to a basal area of 20 square meters per hectare 20 to 25 years of age, and Wolters (1981) suggested thinning trees to a basal area of 12 to 20 square meters per hectare to sustain forage yields under the tree canopy. The loblolly pine stand used in this study meets this criterion. While reduction in forage yields was not a problem in this study, a thinning regime that maintains these relatively low basal areas will be necessary to maintain adequate forage yields. Fertilizer treatments and precipitation directly affected daily dry matter yields. Yields were consistently higher on high rate poultry litter treatments and lower on the control treatments. According to the National Research Council (1984), daily dry matter yields would have to average 9.2 kilograms per hectare to support a 160 kilogram steer growing at 0.75 kilogram per day. In this study all treatments produced adequate daily dry matter to support one animal unit per hectare.

The stage of growth and nutritive value when forage is grazed is more important than total forage production (Campbell and Cassady 1951). Early spring growth is important to cattle because this is when cattle are in poorest physical condition. Information concerning the nutrient requirements of bahiagrass is lacking despite its popularity as a pasture grass in the Southeast. According to Payne *et al*. (1990), very little consideration has been given to fertilizer recommendations for bahiagrass, especially regarding micronutrients.

Nitrogen concentration in the forage was significantly less on the control compared to the other treatments (Table 3). The correlation between nitrogen and crude protein suggests that crude protein levels would be adequate (>8%) for cattle nutrition among treatments, including the control treatment. Lewis *et al*. (1985b) found crude protein of Pensacola bahiagrass generally increases with fertilizer applications. Phosphorus content levels of bahiagrass for all treatments (Table 3) were well above the 0.18% minimum recommended for cattle nutrition (National Academy of Sciences 1963 and National Research Council 1984) and highest in the two poultry litter treatments. Campbell and Cassady (1951) stated that nursing or pregnant cows and young animals need 0.18 to 0.21% phosphorus in their feed for milk production, and the proper development of bones, blood, and body tissues. Calcium content levels for all treatments were well above the recommended 0.24% for cattle (National Research Council 1984). Nursing cows and most growing animals need 0.20 to 0.25% calcium content to ensure proper bone structure and good body growth (Campbell and Cassady 1951). No assessment of nutrient concentration levels was made for B, Fe, Mn, Zn, Cu, Al, Na, K and Mg due to a lack of published studies. Varying rates of fertilizer applications and soil conditions may have contributed to differences among manganese, zinc, and copper.

Foliar N concentration differences were not detected among first flush of growth from the previous growing season needle samples, but concentrations were higher than those of Lea and Ballard (1982), McNeil *et al*. (1988), and Zhang and Allen (1996), in which nitrogen was a limiting nutrient. Nitrogen concentrations for all treatments were well above the critical level of 1.10% (Allen 1987a) (Table 4), suggesting that nitrogen was not a limiting nutrient for tree growth among treatments. However, Lea and Ballard (1982) reported that tissue N concentrations may be an unreliable predictor for N fertilization.

Positive and negative foliar P responses can occur following fertilization. Foliar P concentrations have been reported to increase following P fertilization alone or as N + P (Adams and Allen 1985, Gent *et al*. 1986, Adams *et al*. 1987, Valentine and Allen 1990). Wells *et al*. (1986) reported that fertilization with 40 to 60 kg P ha^{-1} increased mean foliar P from 1.00 to 1.20 grams per hectare in the Coastal Plain. In contrast, fertilization with N alone had no effect on P concentrations (Adams *et al*. 1987, Valentine and Allen 1990). According to Adams and Allen (1985), the optimum P:N ratio for loblolly pine foliage is between 0.095 and 0.105. Below a ratio of 0.085, a strong P response can be expected. Between 0.085 and the optimum range, a P or N + P response is possible and above 0.105 response would be primarily limited to N (Adams and Allen 1985). The control plots for this study had a P:N ratio of 0.1431 and 1.514, which suggest that tree growth in response to fertilization was

Table 5. Mean Total-N and Bray-P concentrations at various soil depths on the Hill Farm Research Station in northwest Louisiana, USA. Within column means with the same letter are not significantly different at the 0.05 level, determined by Duncan's multiple range test.

	mg kg^{-1}		
Treatment	**Depth 1 (0 to 15 cm)**	**Depth 2 (15 to 30 cm)**	**Depth 3 (30 to 150 cm)**
		Total N	
Control	420[a]	186[a]	246[a]
Commercial Fertilizer	427[a]	214[a]	237[a]
Low Rate Poultry Litter	399[a]	155[a]	267[a]
High Rate Poultry Litter	430[a]	195[a]	233[a]
		Bray-P	
Control	21.9[bc]	6.9[a]	1.1[a]
Commercial Fertilizer	20.6[c]	6.9[a]	5.6[a]
Low Rate Poultry Litter	36.1[a]	4.5[a]	0.5[a]
High Rate Poultry Litter	34.4[ab]	3.8[a]	1.5[a]

Table 6. Distribution of trees by dbh (2.54 cm classes) and total height (1.52 m classes) on the study site in northwest Louisiana, USA. *Two trees were lost due to mortality.

			Total Height (m)				
			1997				
DBH (cm)	10.6	12.2	13.7	15.2	16.7	18.3	Total
20.3	-	9	13	-	-	-	22
22.9	2	17	49	8	-	-	76
25.4	-	22	84	19	-	-	125
27.9	-	14	76	17	-	-	107
30.5	-	8	19	5	-	-	32
33.0	-	-	4	-	-	-	4
Total	2	70	245	49	0	0	366
			1999				
22.9	2	-	1	10	-	-	13
25.4	-	3	12	15	2	-	32
27.9	-	3	27	69	12	-	111
30.5	-	3	20	68	16	-	107
33.0	-	2	6	41	13	-	62
35.6	-	-	5	14	12	1	32
38.1	-	-	-	6	1	-	7
Total	2	11	71	223	56	1	364*

Table 7. Mean tree height and diameter increments per tree on the Hill Farm Research Station in northwest Louisiana, USA. Within row means with the same letter are not significantly different at the 0.05 level, determined by Duncan's multiple range test.

Tree Parameters	Treatments			
	Control	Commercial Fertilizer	Low Rate Poultry Litter	High Rate Poultry Litter
Mean Height Increment (m)	1.7[a]	1.5[a]	1.8[a]	1.8[a]
Mean DBH Increment (cm)	3.5[a]	3.5[a]	3.4[a]	3.4[a]

unlikely. Phosphorus concentrations for all treatments in the current study were also above the critical level of 0.10% (Wells *et a*l. 1973 and Allen 1987a) (Table 4), indicating that phosphorus was not a limiting nutrient, and that luxury uptake of P has occurred.

Zhang and Allen (1996), found that N fertilization did not affect foliar K concentration in 1-year-old foliage, but did significantly increase K content of current year foliage. In contrast, when N and K were applied together, foliar K content decreased (Carter and Lyle 1966). Foliar Kconcen-

Table 8. Mean total cubic volume per tree on the Hill Farm Research Station in northwest Louisiana, USA. For a particular year, values with same letters indicate no significant differences at $p = 0.05$ level.

Treatment	1997	1999
	m^3i.b.	
Control	10.06[a]	14.20[a]
Commercial Fertilizer	10.28[a]	14.71[a]
Low Poultry Litter	9.60[a]	13.83[a]
High Poultry Litter	9.62[a]	14.00[a]

Table 9. Mean two-year cumulative total cubic volume increment per tree on the Hill Farm Research Station in northwest Louisiana, USA. Volume values with same letters indicate no significant difference at $p = 0.05$ level.

Treatment			
Control	Commercial Fertilizer	Low Poultry Litter	High Poultry Litter
m^3i.b.			
4.14[a]	4.43[a]	4.22[a]	4.38[a]

Table 10. Monthly precipitation (cm) on the Hill Farm Research Station in northwest Louisiana from 1997 to 1999.

Month	1997	1998	1999
January	14.65	16.89	38.63
February	20.82	13.74	2.41
March	24.94	14.10	13.03
April	26.00	6.40	16.89
May	12.32	2.29	14.32
June	8.66	3.96	21.51
July	6.12	7.69	5.76
August	7.19	22.15	1.65
September	2.84	17.55	2.33
October	15.75	9.39	3.09
November	9.73	15.77	2.48
December	4.39	21.36	8.61
Yearly Totals	152.98	151.30	130.60

trations for all treatments were well above the critical level of 0.402% (Colbert and Allen 1996) (Table 4).

Zhang and Allen (1996) reported highest Ca concentrations in the lower crown positions and significantly lower concentrations as crown height increases; foliar samples for this study were collected from the upper midcrown position. Calcium concentrations for all treatments exceeded the critical level of 0.174% (Table 4) (Allen 1987a). Magnesium foliar concentrations are similar to those of Ca in that foliar concentration varies with crown position. It has been reported that nitrogen fertilization has the potential to decrease foliar Mg concentration (Zhang and Allen 1996). All treatments with exception of the control met the foliar Mg concentration critical level of 0.100% (Table 4) (Allen 1987a).

Foliar nutrient concentrations are highly variable in loblolly pine and have the tendency to fluctuate from year to year in response to weather conditions (Bickelhaupt 1979). For the purpose of determining nutrient deficiency, results from the current study suggest that foliage samples should be collected from the first flush of growth from previous growing season, in the mid-crown position, during February or winter months. However, foliar analyses are less suitable for predicting growth and fertilizer response where a single nutrient marginally influences growth and interacts with other nutrients or growth limiting factors, such as moisture (Allen 1987b).

Total N concentrations were highest in the surface 0 to 15 centimeters of the soil and decreased in 15 to 30 centimeter depth; however, an increase of N occurred at the 30 to 150 centimeter depth (Table 5), likely attributed to humus and ammonium accumulations. While not significant among treatments, all fertilizer treatments with the exception of low poultry litter, tended to have higher total N concentrations than the control at 0 to 15 centimeters. In comparison, Jackson *et al*. (1977) and Sharpley *et al*. (1993) found total N concentrations of the surface 10 centimeters of soil treated with poultry litter was consistently greater than untreated soil. Sharpley and Smith (1995) found various manure applications had the tendency to increase total N contents of the soil.

Bray – P concentrations of soil treated with poultry litter were greater than untreated soil above 15 centimeters (Table 5). Poultry litter often has greater accumulations in the upper 15 cm of soil opposed to the commercial fertilizer due to its slow release, which prolongs its availability. The soil with commercial fertilizer had a concentration similar to the control, which may be attributed to no significant accumulations of phosphorus in the upper 15 cm of soil due to leaching. No differences in Bray – P concentrations were detected below 15 centimeters, similar to results reported by Sharpley *et al*. (1993). Bray-P concentration levels for all treatments, including the control, were above the optimum range for productive tree growth based on the Bray-P classification system. Thus, no tree response can be attributed to P (Table 5).

One problem associated with the application of poultry litter as a fertilizer is the tendency for excess phosphorus accumulation in the soil (Sharpley *et al*. 1993). Treated and untreated soils below 30 centimeters generally have similar phosphorus adsorption capacities for further additions of phosphorus. According to Sharpley and Smith (1995), animal manure N and P contents will vary with type of feed, number and length of exposure of animal and bedding material, and dilution by cleaning water and soil material.

No statistical difference was found among tree attributes (i.e. height growth, diameter growth, and volume increment). While growth rates were good compared to unmanaged pine plantations, in spite of the droughty conditions which occurred during the experimental period, the more than adequate nutrient content of the soils and pine foliage indicate that it is unlikely that a positive growth response on the amendment treated plots will occur even in years with greater precipitation.

CONCLUSION

Forage production under the pine canopy was affected by amendment treatments and summer precipitation. Fertilization increased yields and improved nutritional quality of the forage. Pensacola bahiagrass seemed to efficiently utilize the additional soil amendment nutrients resulting in significant yield differences among treatments. Droughty conditions and below average rainfall during the sampling summer contributed to lower forage yields; therefore, mean forage yield productivity of bahiagrass should increase with normal to above normal precipitation. Based on pine foliar nutrient data, nutrients were not a limiting factor for pine growth. Thus, luxury consumption is occurring which results in high foliar nutrient concentrations among treatments. Growth data indicate that treatment attributes (i.e. height, dbh, total volume) are similar. The non-significant response to fertilization treatments is more than likely attributed to an adequate supply of nutrients on the site.

Timber and forage management practices used in this loblolly pine silvopasture has the potential to achieve profitable land utilization. This integrated approach of commercial timber and cattle may be useful to industrial and non-industrial private landowners willing to implement a multiple land use system. In addition, with further successful research and increased knowledge, the implementation of silvopastures will continue to gain acceptance throughout the southeast.

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