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Effect of Fertilization on Slash Pine Growth and Straw Production in an Old-field Planted Site in Dodge County, Georgia

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Abstract

Many private non-industrial forest landowners (NIPFLs) in Georgia and the southeastern U.S. are interested in fertilizing their pine plantations. These landowners wonder if the benefits of fertilization with reduced pine stumpage prices since 1998 and dramatic rises in fertilizer prices in 2005 are worth the cost. Forest industry has fertilized an average of 1 million pine plantation acres per year between 1995 and 2003 on sites that have been in trees for at least one rotation. There is also an opportunity to fertilize approximately 2/3 of a million acres of cropland and pastureland planted in Georgia in the mid-1980's to early 1990's. There is very little literature available pertaining to the growth response of loblolly and slash pine to fertilization on these old-field sites. The University of Georgia WSF&NR and CEAS faculty installed three fertilizer trials on old-field sites in the Coastal Plain of Georgia in 2000-2001 to determine the benefits of adding nutrients including nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), sulfur (S), boron (B), and copper (Cu) to these relatively fertile sites. Financial support of this project comes from the Potash & Phosphate Institute – Foundation for Agronomic Research (PPI-FAR). This paper details five-year fertilization results (age 12- through 17-years-old) in a slash pine plantation planted on a former corn field in Dodge County, Georgia.

Five-year results indicate that there were negligible fertilizer benefits using a single N+P, N+P+K, or N+P+K+Mg+S+B+Cu fertilizer application. The three fertilizer treatments did not significantly increase diameter, height, volume/tree, volume acre^{-1}, or chip-n-saw volume increment over the five-year study period when compared to no fertilization. There was a significant increase in pine straw production in the first rake after fertilization but no significant differences existed with the second rake. Fertilization, in this case, on a relatively fertile site, was not cost-effective over the five-year period. Forest landowners should continue to use established fertilization diagnostic tools of leaf area (LAI) estimates, soil sampling for available P, foliar sampling, and soil series knowledge for cost-effective fertilization prescriptions.

Introduction

Between 1986 and 1992 over 645,000 acres of marginal cropland in Georgia were planted to predominantly loblolly and slash pine stands under the Conservation Reserve Program (CRP). Thousands of acres of marginal cropland were also planted to primarily loblolly pine in Alabama, Louisiana, Mississippi, North Carolina, and South Carolina during the same time period. The growth rate of these stands initially was very dramatic, in some cases approaching 3 to 4 cords acre^{-1} year^{-1}, for the first 10 to12 years. The accelerated growth rate on these old-fields can be attributed primarily to three factors: minimal competing vegetation (essentially no woody competition for the first 8 to10 years), a residual fertilizer effect, and good surface soil tilth for root development. Estimated macro- and micro-nutrient uptake rates for loblolly and slash pine stands on these old-fields may be on the order of 2 to 3 times that of cut-over sites to achieve such early dramatic growth rates. Micro-nutrients such as copper and boron, present in small amounts at time of planting, may be at critical levels as these stands develop. Foliar macro-nutrient (N, P, K, and Mg) levels in loblolly and slash pine stands are at or below sufficiency in some of these old-field stands.

Private non-industrial forest landowners are very interested in fertilization of their pine plantations. They own two-thirds of the forest land in Georgia and South Carolina. Many own tractors and spreaders and are willing to apply fertilizers themselves. Very little information exists on the magnitude and duration of response to N+P, N+P+K, or N+P+K+Mg+S+Cu+B fertilization on old-field and pasture land sites that have been planted in loblolly or slash pine. Pine pulpwood (trees with a visible defect or a diameter at 4.5 feet above groundline; dbh of <6.5” and height >25’ to a 3” top) versus superpulp (trees with a minor or no visible defect and a dbh of 6.6 to 8.5”), chip-and-saw (trees with no visible defect and a dbh of 8.6 through 12.5”), and sawtimber (trees with no visible defect and a dbh > 12.5”), have had varying price disparities over the last ten years. Pine product stumpage values per ton during 2005 through 2010 have been as follows; pine pulpwood @ no difference to ½ of superpulp, no difference to 1/5 of chip-and-saw, and 1/3 to 1/6 of sawtimber. Many NIPF landowners want to shift wood to the more valuable product classes as well as grow more wood. Annual pine straw income of $50 to $150 acre^{-1} (up to $300 to $400 in a single rake) for loblolly, longleaf, and slash pine on many old-field sites may also be significantly enhanced (by 20% to70% year^{-1} for two to five years) with fertilization. Pine straw revenues for forest landowners have increased dramatically from $15.5 million in 2000 to $23.5 million in 2002, and $80 million in 2008 and 2009 in Georgia.

Each old-field pine stand has its own set of site characteristics, some possibly reaching macro- or micro-nutrient deficiency(ies) much sooner than others. Generally, these stands have been thought to have sufficient nutrients to last for a portion to all of a rotation. This may not necessarily be the case for some of these plantations.

The project duration was five years (1 February 2001 through 31 January 2006). Three old-field planted sites were installed: a thinned 12-yearold slash pine stand in Dodge County, an unthinned 8-yearold slash pine stand in Toombs County, and a 15-yearold thinned loblolly pine plantation in Washington County. This paper summarizes the thinned slash pine plantation in Dodge County, Georgia.

Objectives

This fertilizer trial using macro- and macro+micro-nutrients was installed in an old-field slash stand with 4 treatments and three replications in a randomized complete block design. The following objectives are: (1) to quantify diameter, height, live crown ratio, wood volume/tree, and wood volume/acre growth from the fertilizer treatments compared to unfertilized pine stand parameters, (2) determine if there is a significant growth response to fertilization then discern the magnitude and duration of wood volume response to the fertilizer combinations, (3) quantify changes in product class distributions (volume of pulpwood, superpulp, chip-n-saw, or sawtimber) and (4) estimate the economic benefit of fertilization where there may be a significant pine straw and/or wood volume response, and (5) discern if/when fertilizers are to re-applied to maintain increased volume gain.

Methods

The soil series on all sites were delineated by a NRCS soil mapper. Gross treated plots and internal permanent measurement plots were installed in the delineated soil series area in January 2000. Forty feet of untreated buffer was between each gross treated plot. Replications (blocks) were laid out on the contour to minimize soil moisture differences. Baseline soil (10/plot @ 0-6") samples were taken in each plot prior to treatment at all three sites. Plot leaf area indexes (LAI) were estimated using the NC State University Forest Nutrition Cooperative (NCSUFNC) protocol in midsummer. Three digital photos per plot of multiple tree crowns were also taken during the study period from fixed points to estimate crown and leaf area changes. Foliage samples (3 dominants/plot, upper 1/3 crown, south side, first flush of previous year's growth) were taken each dormant season. Soil and foliage analysis including N (foliage only), P, K, Ca, Mg, S, Cu, Mn, Zn, and B. Baseline foliage and/or soil analysis from the three sites are at or below sufficiency levels of either N, P, K, Mg, B or Cu. Soil pH for each plot was also determined. All living crop trees in each plot have been aluminum tree tagged, numbered and measured for dbh and total height prior to treatment.

Treatments

The one-time fertilizer application levels were 160 lbs N $acre^{-1}$ + 40 lbs elemental-P + 75 lbs elemental-K + 30 lbs Mg + 60 lbs S + 4.5 lbs Cu + 3 lbs B $acre^{-1}$ or no fertilizers at the Dodge County site. Fertilization application timing was targeted for late winter to early spring (February-April, Table 1) to minimize N losses and maximize N use. Urea was used as the dominant N source at the Dodge County site while ammonium nitrate was used as the dominant N source at the Toombs and Washington County sites.

Project Background

The urea and DAP fertilizer materials were applied in March 2000 while the K-mag and MOP were applied in April 2000 at the Dodge County site (Table 2). The soils present are as follows: Dodge county: Wagram (loamy sand w/ Bt @ 28-34", Arenic Paleudults) for replication one, Troup (loamy sand w/ Bt @ 41-45", Grossarenic Paleudults) for replication two, and Ailey (loamy sand w/ Bt @ 21-30", Arenic Hapludults) for replication three. Toombs county is Tifton (fine loamy w/ Bt @ 8-13", Plinthic Paleudults). Washington county is Orangeburg (fine-loamy w/ Bt @ 8-15", Typic Paleudults).

Twelve gross treated plots (105x105 feet) and internal measurement plots (66x66 feet) were installed. Soil available-P was compared to the sufficiency threshold of 10 lbs

acre^{-1}. Foliar macro- and micro-nutrient status prior to fertilizer application and after fertilizer application was compared to established slash pine foliar nutrient sufficiency guidelines (Table 2). Baseline soil pH and available P, K, Ca, Mg, Zn and Mn by treatment are found in Table 3. Baseline slash pine foliar N, P, K, Ca, Mg, S, Mn, B, Cu, and Zn are found in Table 4. Plot leaf area index (LAI) was estimated using the NCSU protocol starting in midsummer 2001. Digital pictures (3/plot) were also taken during the study period for record keeping and LAI comparison. All living crop trees in each plot were aluminum tree tagged, numbered, and measured for dbh, total height, and height to a defect (canker, sweep, or fork), if present, prior to treatment (February 2001). Mean dbh, basal area, height, live crown ratio (post application only), volume/tree, volume acre^{-1}, pulpwood and chip-n-saw volume acre^{-1} prior to fertilizer application (March 2000), 1-, 3-, and 5-years post-application as well as incremental growth were quantified.

Randomly assigned to each plot was an N+P, N+P+K, or N+P+K+Mg+S+Cu+B fertilizer treatment. Untreated control plots served reference plots. Each tree in each plot was merchandised based on form, presence/height to a defect, dbh, and total height.

The old-field slash pine stand was 5th row + logger select thinned in February 2001 (11 months after fertilizer application) due to a black turpentine beetle outbreak on the southwestern and northern edges of the 20-acre stand. The 2000, 2001, and 2002 growing season rains were below normal on the well drained Coastal Plain soils (Ailey, Troup, and Wagram series) found in this stand. There were spotty continued black turpentine beetle activities in the stand one year after the thinning.

Pre-application soil, foliage, and tree/stand data

Soil available-P was above the 10 lbs acre^{-1} sufficiency level in the control, NP, NPK, and NPKMgSBCu plots prior to fertilizer treatments (Table 3). Mean foliar N and K were at or below sufficiency (Table 2) for at least one of the treatments (Table 4) prior to fertilizer application. Mean foliar P and Cu levels were at or below sufficiency for all treatments prior to fertilization (Table 4).

Mean dbh (diameter at 4.5 feet above groundline), basal area, total height, live crown ratio, volume/tree, volume acre^{-1}, pulpwood, and chip-n-saw volume acre^{-1} were tested for statistical significant differences (using Duncan's Multiple Range Procedure @ the 5% alpha level) during the 4-year study period. Mean dbh (diameter at 4.5 feet above groundline), basal area, total height, volume/tree, and volume acre^{-1} were not statistically different prior to fertilizer treatment.

Table 1. Application timing of fertilization and type/amounts of fertilizer materials used on the Dodge County slash pine site.

App. date	**Nitrogen**	**N+P**	**Potassium**	**K+Mg+S**
	----------lbs/ac----------			
	3/24/00 (N+P) 4/20/00(K,Mg,S)	268 Urea	200 DAP	150 muriate of potash	50 muriate of potash + 240 K-mag
Micro-nutrients			**Boron (B)**	**Copper (Cu)**
	5/20/02 (10%B, 15% Cu) @ 30 lbs/ac		B as Sodium Calcium Borate(3#/ac)	Cu as Cu-sulfate and Cu-oxide (4.5#/ac)

Results over the 5-year study period

Soil pH and nutrient status

Surface soil pH (0-6") decreased during the study period. Soil pH in the fertilized plots declined by a similar amount (by 0.4 to 0.5 units) as the unfertilized plots (0.4 units) between 2001 and 2005 Table 5). Soil available P was 11-28, 16-32, and 15-37 lbs acre^{-1} greater in the fertilized plots one, three and five years after application, respectively when compared to the control plots (Table 5). Control plot mean soil available P levels were 28, 32, and 38 lbs acre^{-1} one, three, and five years into the study or 16, 20, and 26 lbs acre^{-1} above the generally accepted soil available P minimum. Soil available K was 3-17, 4-8, and 0-3 lbs acre^{-1} greater in the NPK and NPKMgSBCu plots one, three, and five years after application, when compared to the control plots (Table 5). Control plot mean soil available K levels of 27, 20, and 29 lbs acre^{-1} one, three, and five years into the study were essentially the same as the NP plot means. Soil available Mg ranged from 13 lbs acre^{-1} (NPKMgSBCu plot mean) to 23 lbs acre^{-1} (NP plot mean) prior to fertilizer treatment (Table 3). Mean soil available Mg in the control plots were 4, 9, and 4 lbs acre^{-1} less than the NPKMgSBCu plot means, one three, and five-years after fertilization, respectively (Table 5). Mean soil available Mg level peaked and was greatest in the NPKMgSBCu plots four years after fertilizer application (32 lbs acre^{-1}, Table 5). Statistically significant differences existed post-fertilization for two nutrients; P and Mg. Mean soil available P levels in the control plots were significantly less than the NP and NPKMgSBCu plot means four years after fertilization (2004) and significantly less than the NPKMgSBCu plot mean five years after fertilization (2005). Mean soil available Mg levels in the NPKMgSBCu plots were significantly greater than the control, NP, and NPK plot means three years after fertilization (2003, Table 5).

Foliar nutrient status

Mean slash pine foliar N (0.93% control treatment), P (0.08% for all treatments), K (0.28% NPK treatment), and Cu (1.0 to 1.7 ppm, for all treatments, Table 4) were at or below the minimum guidelines for slash pine (Table 2) prior to treatment. Foliar N concentration was significantly greater one year after fertilizer treatment in the NP (1.17%), NPK (1.22%), and NPKMgSBCu (1.37%) plots compared to the control (0.98%, Table 6). Foliar N concentrations in the fertilized plots (1.00% to 1.09%) were similar to the control (1.06%) four years after treatment. Mean foliar K was significantly greater in the NP, NPK, and NPKMgSBCu plots (0.43 through 0.48%) than the control one year after fertilization. The mean foliar boron (B) level from the NPKMgSBCu plot trees were significantly greater than the control, NP, and NPK treatments in 2004 and 2005 (1.5 and 2.5 years after the B and Cu were applied, Table 6).

Leaf area index estimates

Leaf area index (LAI) was first estimated in August 2001, and subsequently in August 2003, and July 2004 (Table 7). Mean LAI for the NP, NPK, and NPKMgSBCu plots were significantly greater (2.75 – 3.17 and 2.30 – 2.50) than the control (2.25 and 2.00) in 2001 and 2003.

Tree and stand growth

Mortality was highest in the N+P plot #1 next to the edge of the largest beetle outbreak in the stand. This high mortality in plot #1 greatly influenced the mean N+P fertilizer treatment mortality of 21% from February 2001 through February 2005 (Table 8). The NPK treatment had the second highest four-year post thin mortality of 14%. The complete fertilizer treatment had a four-year post thin mortality of 9%, while the control had a four-year post thin mortality of 6% (Table 8).

There were no significant differences in any of the growth parameter means one-, three-, or five years after fertilization (Table 8). Four-year diameter (measured at 4.5 feet above groundline or dbh) increment was greatest for the NP treatment (1.62”), followed by the NPK treatment (1.55”), the NPKMgSBCu treatment (1.41”) and lastly the control treatment (1.27”; Table 9). There were no significant four-year diameter growth differences. The NPK treatment basal are growth (30 ft^2 per acre) was 43% greater than the control basal area growth (21 ft^2 per acre) from age-13 through 17-years (Table 9). The mean volume per tree increment for the NP and NPK treatments (4.9 ft^3/tree) were 19.5% greater than the control (4.1 ft^3/tree) from age 13- though 17-years (Table 9), a significant difference at the 10% alpha level but not at the 5% level.

There were no significant differences in total volume and chip and saw volume (dbh 8.6 through 11.5 inches) per acre growth increment (Table 9) two years post thinning between the control and fertilizer treatments. This is essentially due to higher mortality (9 to 21 percent) in the fertilized compared to the control treatment mortality (6 percent). Control treatment value per acre growth from age 13- ($517.53) through age 17-years ($1254.81) was $737.28. The NPK treatment value per acre growth during this same period was $797.25 ($628.80 at age 13- and $1426.05 at age 17-years). This is a difference of approximately $60 per acre, which would not pay for the fertilizer materials using 2006-2010 fertilizer prices.

Pine straw production

The first pine straw raking occurred 23 months after fertilization (February 2002). All fertilizer treatments had significantly greater pine straw (134-140 bales $acre^{-1}$) than the unfertilized plots (96 bales $acre^{-1}$) from the first rake (Table 10). The second pine straw collection occurred in February 2003. There were no significant differences between the unfertilized and fertilized plot bale production from the second rake. The second rake bale count range was narrow, between 112 (NPK) and 120 (NPKMgSBCu) pr acre. This pine straw scenario may be explained in part by (1) significantly higher foliar N concentrations one year after fertilizer treatment in the NP (1.17%), NPK (1.22%), and NPKMgSBCu (1.37%) plots compared to the control (0.98%, Table 6) but a subsequent drop in foliar N in the fertilized plots two and four years after fertilization and (2) a 31% larger LAI in the fertilized plots one year after fertilization (2001), but a subsequent drop in LAI differences between the control and fertilized plots (Table 7).

Summary

This site was initially thought to possibly respond to fertilization. This study area was on Ailey, Wagram, and Troup soils with a sandy surface texture and depth to an argillic layer of > 20 to 80 inches. This study area was not intensively farmed and had low nutrient inputs. However, the hardwood component was negligible, there was no plow pan detected, and slash pine growth from age 13- through 17-years was 807 ft^3 per acre

(2.35 cds/ac/yr or 6.35 tons/ac/yr) without fertilization. The rate of growth from the unfertilized plots during this period was essentially the same as the NPK treatment; 781 ft^3 per acre (2.27 cds/ac/yr or 6.13 tons/ac/yr) and the NPKMgSBCu treatment; 844 ft^3 per acre (2.45 cds/ac/yr or 6.62 tons/ac/yr). In this case, like the Toombs County slash pine study area, fertilization (NPK) did improve the first pine straw rake bales per acre production. Fertilization did not improve pine straw production during the second rake when compared to the control.

Forest landowners should continue to use established fertilization diagnostic tools of leaf area (LAI) estimates, soil sampling for available P, foliar sampling, and soil series knowledge for cost-effective fertilization prescriptions. Fertilization, in this case on an old-field site with moderate to high residual fertility, was not cost-effective over the 5-year period.

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Table 2. Foliar nutrient sufficiency (minimums) guidelines for loblolly, longleaf, and slash pine.

Nutrient	Loblolly pine[a]	Longleaf pine[b]	Slash pine[a]
	----------percent (%)----------		
Nitrogen (N)	1.20	0.95	1.00
Phosphorus (P)	0.12	0.08	0.09
Potassium (K)	0.30	0.30	0.25-0.30
Calcium (Ca)	0.15	0.10	0.08-0.12
Magnesium (Mg)	0.08	0.06	0.06
Sulfur (S)	0.10	--	0.08
	----------parts per million (ppm)----------		
Boron (B)	10-12	--	4-8
Copper (Cu)	2-3	--	1.5-3.0
Manganese (Mn)	20-40	--	20-40
Zinc (Zn)	10-20	--	10-20

[a] Allen (1987); Jokela (2004); Pritchett and Comerford (1983); Wells, Crutchfield, Berenyi and Davey (1973).
[b] Blevins, Allen, Colbert, and Gardner (1996) for N, P, K, Ca, and Mg.

Table 3. Pre-application (2/10/00) mean surface (0-6") soil pH, available macro-, and micro-nutrient levels (range) by fertilizer treatment in a 1988 planted, thinned (February 2001) slash stand at the Dodge County, Georgia site (Ailey, Wagram, and Troup soils).

Treatment	pH	P	K	Ca	Mg	Zn	Mn
		----------lbsacre-1----------					
Control	5.5 (5.3-6.0)	31 (20-38)	34 (26-43)	219 (105-355)	16 (8-26)	1 (1)	11 (6-18)
NP	5.5 (5.4-5.7)	30 (20-36)	37 (30-42)	242 (203-307)	23 (12-34)	1 (1)	9 (4-12)
NPK	5.1 (4.8-5.4)	40 (13-57)	34 (31-39)	194 (165-284)	20 (15-25)	1 (1)	10 (5-16)
NPKMgSBCu	5.4 (5.3-5.5)	38 (26-45)	29 (25-32)	150 (127-166)	13 (9-17)	1 (1)	7 (6-8)

Soil available-P minimum guideline value is 12lbs/ac using Mehlich I (soil extractable procedure used at UGA).

Table 4. Pre-application (2/10/00) mean (range) foliar macro-, and micro-nutrient concentrations in a 1988 planted, fertilized (March 2000), and thinned (February 2001) slash stand at the Dodge County, Georgia site (Ailey, Wagram, and Troup soils).

Treatment	N [#]	P [a]	K	Ca	Mg	S	Mn	B	Cu [a]
	----------percent----------						----------ppm----------		
Control	*0.93* b (0.89-1.07)	*0.08* (0.08-0.10)	0.33 (0.27-0.38)	0.18 (0.17-0.19)	0.10 (0.06-0.13)	0.14 (0.12-0.17)	130 (80-168)	8 (4-12)	*1.2* (0.5-2)
NP	1.05 a (0.97-1.10)	*0.08* (0.08-0.09)	0.31 (0.27-0.40)	0.24 (0.16-0.28)	0.09 (0.06-0.11)	0.13 (0.14-0.18)	126 (92-146)	7 (5-9)	*1.0* (1)
NPK	1.03 a (1.0-1.08)	*0.08* (0.08-0.09)	*0.28* (0.27-0.29)	0.20 (0.19-0.21)	0.07 (0.06-0.08)	0.15 (0.13-0.18)	113 (91-157)	10 (8-12)	*1.7* (1-2)
NPKMgSBCu	1.11 a (1.1-1.2)	*0.08* (0.08)	0.32 (0.26-0.38)	0.18 (0.13-0.21)	0.09 (0.07-0.11)	0.15 (0.11-0.18)	149 (92-187)	10 (8-12)	*1.7* (1-2)

[a] Mean foliar P and Cu for all fertilizer treatments were at or below minimum guidelines for slash pine (Table 2).
[#] Nutrient means followed by a different letter within a year are significantly different using Duncan's Multiple Range Procedure at the 5% alpha level.

Table 5. Mean surface (0-6") soil pH, available macro-, and micro-nutrient levels one (2001), three (2003), four (2004), and five (2005) years after fertilizer application in a 1988 planted, fertilized (March 2000), and thinned (February 2001) slash stand at the Dodge County, Georgia site (Ailey, Wagram, and Troup soils).

Treatment	Year	pH	P	K [#]	Ca	Mg	Zn	Mn
			----------(lbs per acre)----------					
	2001							
Control		5.5	28	27 b	221	17	0.4	11
NP		5.4	50	28 b	226	20	0.5	8
NPK		5.3	39	44 a	168	13	0.6	9
NPKMgSBCu		5.1	56	30 b	134	21	0.4	7
	2003							
Control		5.7	32	20	215	18 b	0.7	9
NP		5.6	50	22	200	20 b	0.6	8
NPK		5.3	48	28	176	16 b	0.7	9
NPKMgSBCu		5.3	64	24	140	27 a	1.9	7
	2004							
Control		5.1	32 c	39	214	27	0.8	13
NP		5.0	59 ab	37	249	31	0.8	12
NPK		4.7	46 bc	35	169	30	0.9	9
NPKMgSBCu		4.9	78 a	32	159	32	1.4	9
	2005							
Control		5.1	38 b	29	232	23	2.2	13
NP		4.9	53 ab	29	223	26	2.2	13
NPK		4.9	53 ab	32	216	27	2.4	11
NPKMgSBCu		4.7	75 a	29	143	27	3.0	11

[#] Nutrient means followed by a different letter within a year are significantly different using Duncan's Multiple Range Procedure at the 5% alpha level. Significant differences at the 10% alpha level existed between soil P for the control and NPKMgSBCu and for K between the NPK and control treatments in 2003.

Table 6. Foliar nutrient concentrations one (2001), two (2002), four (2004), and five (2005) years after fertilization in a 1988 planted, fertilized (March 2000), and thinned (February 2001) slash stand at the Dodge County, Georgia site (Ailey, Wagram, and Troup soils).

Treatment	Year	N [#a]	P [a]	K	Ca	Mg	S	B	Cu [a]
		----------percent----------						---------ppm--------	
	2001								
Control		*0.98*c	*0.09*	0.35 b	0.18	0.08	0.13	10	*1.3*
NP		1.17b	0.10	0.43 a	0.24	0.11	0.15	15	*1.0*
NPK		1.22ab	0.10	0.46 a	0.21	0.09	0.15	12	*0.8*
NPKMgSBCu		1.37a	0.11	0.48 a	0.25	0.08	0.14	8	5
	2002								
Control		1.12ab	0.10	0.39	0.21	0.08	0.11	10	*2.7*
NP		1.25a	0.11	0.37	0.21	0.10	0.12	9	*2.0*
NPK		1.03b	*0.09*	0.35	0.17	0.07	0.10	7	*1.8*
NPKMgSBCu		1.19a	0.10	0.38	0.18	0.09	0.12	7	*1.3*
	2004								
Control		1.06	0.10	0.51	0.22	0.10 b	0.11	11 b	*2.5*
NP		1.00	*0.09*	0.38	0.19	0.10 b	0.11	9 b	*2.0*
NPK		1.08	0.12	0.48	0.31	0.09 b	0.11	8 b	*2.2*
NPKMgSBCu		1.09	0.10	0.46	0.23	0.12 a	0.11	32 a	7.5
	2005								
Control		*0.92*	0.11	0.40	0.22	0.09	0.13	10 b	*2.5*
NP		1.07	0.11	0.39	0.18	0.09	0.11	9 b	*1.7*
NPK		1.07	0.10	0.38	0.21	0.11	0.10	9 b	*2.9*
NPKMgSBCu		1.02	0.10	0.41	0.19	0.09	0.12	26 a	*1.9*

[a] Foliar nutrients in italics are at or below sufficiency level for slash pine.

[#] Nutrient means followed by a different letter within a year are significantly different using Duncan's Multiple Range Procedure at the 5% alpha level.

Table 7. Leaf area index (LAI) estimate means (range) one (2001), three (2003), and four (2004) years post fertilization in a 1988 planted, fertilized (March 2001), and thinned (February 2001) slash stand at the Dodge County, Georgia site (Ailey, Wagram, and Troup soils).

Treatment	LAI 2001 [#‡]	LAI 2003	LAI 2004
Control	2.25 (2.00-2.50) c	2.00 (1.75-2.25) c	2.00 (1.75-2.25) c
NP	2.92 (2.50-3.25) ab	2.42 (2.00-3.00) ab	2.25 (2.00-2.50) b
NPK	2.75 (2.50-3.00) b	2.30 (2.00-2.75) b	2.17 (2.00-2.25) bc
NPKMgSBCu	3.17 (2.75-3.25) a	2.50 (2.25-3.00) a	2.46 (2.25-2.75) a

[#] LAI estimates were taken during August 2001 and August 2003 from 3 sample points/plot.
[‡] LAI means followed by a different letter within a year are significantly different using Duncan's Multiple Range Procedure at the 5% alpha level.

Table 8. Growth parameter means at fertilization (age 12-years-old), one, three, and five years post application in a 1988 planted, thinned (February 2001) slash stand at the Dodge County, Georgia site (Ailey, Wagram, and Troup soils).

Treatment	Stand age	Trees per acre	Dbh	Basal area	Height	Live Crown ratio	Volume per tree	Total volume	Pulp-wood volume[a]	Super-pulp volume[b]	Chip-n-saw volume[c]
	(Yrs)		(in)	(ft^2 ac^{-1})	(ft)	(%)	(ft^3)	---------- ft^3 ac^{-1} ----------			
	12										
Control		443	6.9	118	38.7	51	5.2	2305	2015	NA	149
NP		410	6.9	109	37.9	52	5.1	2095	1921	NA	66
NPK		480	6.9	127	39.2	50	5.3	2542	2013	NA	313
NPKMgSBCu		443	6.8	115	37.8	53	5.0	2234	1865	NA	200
	13										
Control		227	7.5	70	42.5	46	6.4	1465	103	1186	104
NP		227	7.5	70	41.6	48	6.2	1446	147	1075	141
NPK		230	7.6	62	43.7	48	6.8	1580	81	1099	283
NPKMgSBCu		223	7.5	69	41.7	46	6.3	1438	72	981	264
	15										
Control		220	8.1	80	48.0	46	8.3	1843	13	1055	591
NP		183	8.2	68	46.2	40	8.3	1538	44	718	603
NPK		200	8.4	78	49.7	48	9.1	1859	0	953	725
NPKMgSBCu		203	8.1	75	47.6	46	8.2	1736	28	863	637
	17										
Control		213	8.8	91	53.4	45	10.5	2272	0	779	1209
NP		180	9.1	84	52.9	48	11.1	2116	0	391	1431
NPK		197	9.2	92	55.1	49	11.7	2361	0	511	1533
NPKMgSBCu		203	8.9	89	54.2	48	10.8	2282	27	504	1443

[a] Volume of trees with a dbh of 4.6 through 6.5 inches to a 3 inch top outside bark diameter are pulpwood trees.
[b] Volume of trees with a dbh of 6.6 through 8.5 inches to a 3 inch top outside bark diameter are superpulp trees.
[c] Volume of trees with a dbh of ≥ 8.6 to a 6 inch top outside bark diameter are chip-n-saw trees.
* ft^3 ac^{-1} = cubic feet per acre; 88 ft^3 = 1 cord of wood and bark, and 100 ft^3 ≈ 3 tons.
[#] Growth parameter means followed by a different letter within a year are significantly different using Duncan's Multiple Range Procedure at the 5% alpha level. There were no significant mean growth parameter differences during the study period.

Table 9. Growth parameter increment means between at thinning (one year post-fertilization) and two years post-thinning (age 13- through 15-years-old), between two and four years post-thinning (age 15- through 17-years-old), and between at thinning and four years later (ages 13- through 17-years-old) in a 1988 planted, thinned (February 2001) slash stand at the Dodge County, Georgia site (Ailey, Wagram, and Troup soils).

Treatment	Stand age	Trees per acre	Dbh	Basal area	Height	Volume per tree	Total volume	pulpwood volume[a]	superpulp volume[b]	Chip-n-saw volume[c]
	(Yrs)		(in)	(ft^2 ac^{-1})	(ft)	(ft^3)	---------- ft^3 ac^{-1} ----------			
	13 -15									
Control		-7	0.63	10	5.5	1.9	379	-91	-131	487
NP		-44	0.78	-2	4.6	2.1	92	-103	-357	462
NPK		-30	0.80	16	6.0	2.3	279	-81	-146	442
NPKMgSBCu		-20	0.64	6	5.9	1.9	298	-44	-118	372
	15-17									
Control		-6	0.64	11	5.4	2.2	428	-13	-276	618
NP		-3	0.84	16	6.7	2.8	578	-44	-328	828
NPK		-3	0.75	13	5.4	2.6	502	0	-442	808
NPKMgSBCu		0	0.77	14	6.5	2.6	546	0	-359	807
	13-17									
Control		-13	1.27	21	10.9	4.1	807	-104	-407	1105
NP		-47	1.62	14	11.3	4.9	670	-147	-684	1290
NPK		-33	1.55	30	11.4	4.9	781	-81	-589	1250
NPKMgSBCu		-20	1.41	20	12.4	4.5	844	-44	-477	1179

[a] Volume of trees with a dbh of 4.6 through 6.5 inches to a 3 inch top outside bark diameter are pulpwood trees.
[b] Volume of trees with a dbh of 6.6 through 8.5 inches to a 3 inch top outside bark diameter are superpulp trees.
[c] Volume of trees with a dbh of > 8.5 inches to a 6 inch top outside bark diameter are chip-n-saw trees.
* ft^3 ac^{-1} = cubic feet per acre; 88 ft^3 = 1 cord of wood and bark, and 100 ft^3≈ 3 tons.
[#] Growth parameter means followed by a different letter within a year are significantly different using Duncan's Multiple Range Procedure at the 5% alpha level. There were no significant mean growth parameter differences during the study period.

Table 10. Pine straw production by fertilizer treatment in a 1988 planted, thinned (February 2001) slash stand at the Dodge County, Georgia site (Ailey, Wagram, and Troup soils).

Treatment	Bales per acre February 2002 [#]	Bales per acre February 2003
Control	96 b	113
NP	137 a	117
NPK	134 a	112
NPKMgSBCu	140 a	120

Pine straw bales per acre means followed by a different letter within a measurement period are significantly different within a year using Duncan's Multiple Range Procedure at the 5% alpha level.
Assumes a bale of slash pine straw (14x14x28 inches) weighs 17.7 lbs dry weight (20-21 lbs field weight)

CITATION

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