Georgia Forest Productivity
Publication Series

Publication Number 004R - 2010 December 2010

Effect of Fertilization on Slash Pine Growth and Pine Straw Production in an Old-field Site in Toombs 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 2005 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 between the mid-1980's to early 1990's. There is 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 CAES 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 4-year fertilization results (age 8- through 12-years-old) in an unthinned slash pine plantation planted on a former Vidalia onion field in Toombs County, Georgia.

Four-year results at the old-field slash pine Toombs County site 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 superpulp volume increment over the 4-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, was not cost-effective over the 4-year period. Forest landowners should continue to use the well 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.

Many private non-industrial forest landowners are interested in fertilization of their pine plantations. They own 2/3^{rds} of the forest land in GA and SC. 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 >25' to a 3" top) versus superpulp (trees with a minor or no visible defect and a dbh of 6.6 through 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"), price disparities have been, at times large in the last ten years. Pine product stumpage prices per unit of wood from 2005 through 2010 have been as follows: pulpwood is the same as to ½ of superpulp, the same as 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 and $150 acre^{-1} or more for loblolly and slash pine on many old-field sites may also be enhanced with fertilization. Pine straw revenues for forest landowners in Georgia have increased dramatically from $15.5 million in 2000, to $23.5 million in 2002, and to over $80 million in 2008 and 2009.

Each old-field pine stand has it's own set of site characteristics, some possibly reaching a 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's duration is 5 years (1 February 2001 through 31 January 2006). Three of these old-field planted sites have been located in Georgia: a thinned 12-year-old slash pine stand in Dodge County, an unthinned 8-year-old slash pine stand in Toombs County, and a 15-year-old thinned loblolly pine plantation in Washington County. This paper summarizes the unthinned slash pine plantation in Toombs County, Georgia.

Objectives

This fertilizer trial, using macro- and macro+micro-nutrients installed in three old-field slash and loblolly stands in a randomized complete block design with 3 or 4 replications/treatment, addresses the following major objectives: (1) 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) if there is a significant growth response to fertilization then discern the magnitude and duration of wood volume response to the fertilizer combinations, (3) determine any 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 2001. Forty feet of untreated buffer is 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 index (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.

Treatments

Randomly assigned to each plot was a N+P, N+P+K, N+P+K+Mg+S+Cu+B fertilizer treatment. Untreated control plots will serve reference plots. The one-time fertilizer application levels were 155 lbs N acre^{-1} + 25 lbs elemental-P + 75 lbs elemental-K + 30 lbs Mg + 60 lbs S + 4.5 lbs Cu + 3 lbs B acre^{-1}. 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 macro-nutrient fertilizer materials were applied in February 2001 at the Toombs County site (Table 2). The dominant soil series present was Tifton (fine loamy with an argillic horizon @ 8-13", Plinthic Paleudults). Sixteen 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 2002. 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 superpulp volume acre^{-1} prior to fertilizer application (February 2001), 2-, and 4-years post-application as well as incremental growth were quantified.

A foliar active herbicide (3 quarts of 41% Glyphosate + 1% surfactant @ 18 GPA using an ATV and boom sprayer) was applied to plots 1-8 (replications one and two) of the Toombs County site in September 2001. The herbicide was estimated to be 75-85% effective on average. There were no tree or stand growth benefits to the one-time herbicide application in this case when comparing replications one and two to three and four.

Table 1. Application timing of fertilization and type/amounts of fertilizer materials used.

	App. date	**Nitrogen**	**N+P**	**Potassium**	**K+Mg+S**
		------------lbs/ac------------			
	2/26/01(N,P,K, Mg, and S)	400 NH_4NO_3	125 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)

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, P, K, Ca, Mg, S, and B were above sufficiency (Table 2) for all treatments (Table 4) prior to fertilizer application. Mean foliar 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 superpulp 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 (February 2001, Table 6).

Results over the 4-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 more (by 0.67 units) than the unfertilized plots (0.30 units) during the study period. These two events are to be expected in a forested environment and where these common fertilizer materials are applied. The soil pH for the unfertilized control plots decreased from 6.0 to 5.8, 5.7, and 5.5 one, three, and four years into the study period (Table 3 and 5). Soil pH in the NP plots declined from 6.0 to 5.4, 5.3, and 5.1 one, three, and four years after fertilizer application. Soil pH in the NPK plots declined from 6.1 to 5.5, 5.4, and 5.1 one, three, and four years after fertilizer application. Soil pH in the NPKMgSBCu plots declined from 6.1 to 5.7, 5.5, and 5.2 one, three, and four years after fertilizer application (Table 3 and 5). Soil pH in the NP and NPK plots were significantly less than the control during the post-application portion of the study period. Soil available P was 17 to 28 and 7 to 16 lbs acre^{-1} greater in the fertilizer plots one year and three years after application, respectively when compared to the control plots (Table 5). Soil available P was significantly greater in the NP plots than in the control one, three, and four years post-application. Control plot mean soil available P levels were 41 and 35 lbs acre^{-1} one and three years into the study or 29 and 23 lbs acre^{-1} above the generally accepted soil available P minimum. Soil available K was 34 to 48 and 5 to 8 lbs acre^{-1} greater in the NPK and NPKMgSBCu plots one year and three years after application, respectively when compared to the control plots (Table 5). Soil available K levels in the NPK plots were significantly greater than the control one and four years after application (Table 5). Control plot mean soil available K levels of 66, 75, and 54 lbs acre^{-1} one, three, and four years into the study were greater than the NP plot means by 8, 6, and 9 lbs acre^{-1}, respectively. Soil available Mg ranged from 68 lbs acre^{-1} (NPKMgSBCu plot mean) to 75 lbs acre^{-1} (control plot mean) prior to fertilizer treatment (Table 3). Mean soil available Mg was 2, 20, and 26 lbs acre^{-1} greater in the control plots one year after treatment compared to the NPKMgSBCu, NPK, and NP plot means respectively (Table 5). Mean soil available Mg level was greatest in the NPKMgSBCu plots three years after fertilizer application (89 lbs acre^{-1}), followed by the control (77 lbs acre^{-1}), NPK (59 lbs acre^{-1}), and NP (52 lbs acre^{-1}).

Foliar nutrient status

Mean slash pine foliar N (≥1.23 %), P (≥0.10), K (≥ 0.42%), Ca (≥ 0.16%), Mg (≥ 0.08%) and B (≥ 10 ppm, Table 4) were above the minimum guidelines for slash pine (Table 2) prior to treatment across all fertilizer plots. Only mean copper (Cu) levels were at or below the minimum guideline prior to treatment (Table 4). Foliar N concentration was greater one year after treatment in the NP (1.49%), NPK (1.55%), and NPKMgSBCu (1.37%) plots compared to the control (1.07%, Table 5). Foliar N in the fertilized plots (0.99% to 1.29%) was not significantly different than the control (1.08%) three years after treatment. Foliar P, K, Mg, S, B, and Cu levels from the fertilized plot trees were similar to the control one and three years after fertilization. Foliar N, P, K, Mg, Ca, and S concentrations from the control plots in February 2005 were at or above sufficiency.

Leaf area index estimates

Leaf area index (LAI) was first estimated in July 2002, and subsequently in July 2004 (Figure 1), and July 2005. Mean LAI for the NP, NPK, and NPKMgSBCu plots were significantly greater (3.0 – 3.1 and 3.2 – 3.3) than the control (2.5 and 2.6) in mid-summer 2002 and 2004 but not significantly different in 2005 (3.0 – 3.2, Table 7).

Tree and stand growth

Dbh, basal area, total height, volume/tree, and volume acre^{-1} means, and two- and four-year growth increment treatment means were not significantly different (Table 8 and 9). The unfertilized plots mean dbh (1.75"), basal area (58.7 ft^2 acre^{-1}), height (15.1'), and volume per acre (1690 ft^3 acre^{-1}) four-year increment were large in this case (Table 8). The mean annual increment for total volume in the first eight, ten, and twelve years without fertilization was 145, 199, and 237 ft^3 acre^{-1} year^{-1}, respectively. The mean periodic annual increment (PAI) between ages 8- and 12-year-old in the unfertilized plots was 423 ft^3 acre^{-1} year^{-1} (13.3 tons acre^{-1} year^{-1}). The fertilized plots, when averaged, had a PAI of 408 ft^3 acre^{-1} year^{-1} (12.8 tons acre^{-1} year^{-1}) during this same period. It is hard to improve on a growth rate of 423 ft^3 acre^{-1} year^{-1} (13.3 tons acre^{-1} year^{-1}) for slash pine between ages 8- and 12-years-old. The NP fertilizer treatment four-year volume/tree growth increment was 5% greater than the control (3.36 versus 3.54 ft^3 acre^{-1}). Superpulp volume per acre four-year growth increments were essentially the same for the control, NP, and NPKMgSBCu treatments (Table 9).

There were two growth parameter significant differences; superpulp (trees with a dbh of 6.6 to 8.6" to a 3" top) volume acre^{-1} and live crown ratio means at age 12-years for the NPK plots were significantly less than the control and NP plot means (Table 8). Control plot tree mortality (10 TPA) was 2.5- to over 4-fold less than the fertilizer treatments (25, 40 or 43 TPA) contributing to the control having largest basal area and volume growth over the four year period (Table 9).

Pine straw production

The first pine straw raking occurred 17 months after fertilization (July 2002). The NPK fertilized plots (356 bales acre^{-1}) had significantly greater pine straw production than the unfertilized plots (267 bales acre^{-1}) from the first rake (Table 10). The NP (299 bales acre^{-1}) and NPKMgSBCu (311 bales acre^{-1}) treatment pine straw bales per acre were not significantly greater than the control from the first rake. The second rake occurred in January 2004. 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; 230 for the control and NPK, 232 for the NP, and 243 for the NPKMgSBCu treatments. This pine straw scenario may be explained in part by (1) a larger foliar N concentration one year after fertilizer treatment in the NP (1.49%), NPK (1.55%), and NPKMgSBCu (1.37%) plots compared to the control (1.07%, Table 5) but a subsequent drop in foliar N in the fertilized plots to 0.99% to 1.29% compared to the control (1.08%) three years after treatment and (2) a significantly greater LAI in the fertilized plots one and two years after treatment but no significant difference four years after treatment when compared to the control plot mean LAI.

Summary

This study area is located on an excellent soil (Tifton) to grow most crops or tree species, the hardwood component was negligible, and site fertility was more than adequate for slash pine. A land manager would find it hard to improve on a growth rate of 423 ft^3 $acre^{-1}$ $year^{-1}$ (13.3 tons $acre^{-1}$ $year^{-1}$) for slash pine between ages 8- and 12-years-old. In this case NPK fertilization did improve the first pine straw rake production by 89 bales $acre^{-1}$ over the control. 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: (1) leaf area index (LAI) estimates, (2) soil sampling for available P, and (3) foliar sampling as well as soil series and land use history knowledge for cost-effective fertilization prescriptions. Fertilization, in this case, was not cost-effective over the 4-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 (2/10/01) mean surface (0-6") soil pH, available macro-, and micro-nutrient levels (range) by fertilizer treatment in the old-field unthinned 8-year-old slash stand at the Toombs County, Georgia site (Tifton Soil).

Treatment	pH	P	K	Ca	Mg	Zn	Mn
		lbs/acre					
Control	6.0 (5.8-6.4)	42 (25-61)	74 (58-94)	638 (560-716)	75 (64-94)	1 (1)	17 (11-18)
NP	6.0 (5.9-6.2)	47 (35-62)	62 (48-77)	593 (478-690)	61 (54-73)	1 (1)	12 (10-15)
NPK	6.1 (6.0-6.3)	38 (23-44)	76 (55-99)	636 (489-852)	74 (55-117)	1 (1)	17 (12-21)
NPKMgSBCu	6.1 (5.9-6.3)	40 (29-61)	65 (43-83)	619 (417-722)	68 (41-88)	1 (1)	13 (10-16)

Soil available-P minimum guideline value is 12lbs/ac using Mehlich I (soil extractable procedure used at UGA). There were no statistically significant differences at the 5% level.

Table 4. Pre-application (2/10/01) mean (range) foliar macro-, and micro-nutrient concentrations in the old-field unthinned 8-year-old pine stand at the Toombs County, Georgia site (Tifton soil).

Treatment	N	P	K	Ca	Mg	S	Mn	B	Cu[a]
	percent						ppm		
Control	1.23 (1.12-1.30)	0.10 (0.10-0.11)	0.42 (0.36-0.50)	0.22 (0.16-0.32)	0.11 (0.08-0.14)	0.13 (0.11-0.14)	95 (71-136)	12 (10-14)	1.5 (1-2)
NP	1.28 (1.10-1.55)	0.10 (0.09-0.11)	0.45 (0.40-0.47)	0.22 (0.19-0.27)	0.10 (0.08-0.13)	0.13 (0.12-0.15)	128 (87-167)	12 (7-13)	1.8 (1-2)
NPK	1.28 (1.21-1.38)	0.10 (0.09-0.11)	0.43 (0.35-0.49)	0.20 (0.15-0.23)	0.10 (0.08-0.11)	0.14 (0.12-0.16)	106 (88-143)	10 (10-11)	2.0 (2-2)
NPKMgSBCu	1.23 (1.16-1.30)	0.10 (0.09-0.11)	0.49 (0.29-0.70)	0.16 (0.09-0.20)	0.08 (0.04-0.11)	0.13 (0.11-0.15)	98 (34-168)	12 (10-15)	2.5 (2-4)

[a] Mean foliar Cu for all fertilizer treatments were at or below minimum guidelines for slash pine (Table 2). There were no statistically significant differences at the 5% level.

Table 5. Mean surface (0-6") soil pH, available macro-, and micro-nutrient levels one (2002), three (2004), and four (2005) years after fertilizer application in the old-field unthinned slash pine stand in Toombs County, Georgia (Tifton soil).

Treatment	Year	pH#	P	K	Ca	Mg	Zn	Mn
			--(lbs acre-1)---					
	2002							
Control		5.8 a	41 b	66 bc	550	67	0.6	14 b
NP		5.4 b	69 a	58 c	465	41	0.9	17 b
NPK		5.5 b	60 a	106 a	488	47	2.3	24 a
NPKMgSBCu		5.7ab	58ab	92 ab	469	65	0.6	14 b
	2004							
Control		5.7 a	30 b	75	702	77ab	2.6	24
NP		5.3 b	51 a	69	565	52 b	3.7	20
NPK		5.4 b	42 a	83	566	59 b	2.6	22
NPKMgSBCu		5.5ab	50 a	80	559	89 a	5.5	20
	2005							
Control		5.5 a	30 b	54 b	621 a	67 a	2.1 b	15
NP		5.1 a	43 a	45 b	420 b	36 b	2.4 b	13
NPK		5.1 a	39 b	68 a	463 b	48ab	2.4 b	14
NPKMgSBCu		5.2 b	42 b	53 b	425 b	54ab	3.1 a	10

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

Table 6. Foliar nutrient concentrations one (2002), three (2004) and four (2005) years after fertilization in an unthinned old-field site slash pine plantation in Toombs County, Georgia (Tifton soil).

Treatment	Year	N	P	K	Ca	Mg	S	B	Cu[a]
		--percent-------------------------------						---------ppm---------	
	2002								
Control		1.07	0.10	0.49	0.17	0.11	0.10	10	*1.5*
NP		1.49	0.11	0.60	0.25	0.12	0.13	12	*2.0*
NPK		1.55	0.12	0.50	0.28	0.13	0.13	9	*1.3*
NPKMgSBCu		1.37	0.10	0.47	0.20	0.13	0.13	11	*0.9*
	2004								
Control		1.08	0.10	0.46	0.24	0.14	0.10	14	*2.8*
NP		1.01	0.10	0.42	0.20	0.12	0.12	12	*2.3*
NPK		0.99	0.11	0.56	0.20	0.11	0.11	16	*2.2*
NPKMgSBCu		1.29	0.11	0.51	0.21	0.10	0.12	24	*2.3*
	2005								
Control		1.04	*0.09*	0.49	0.16	0.11	0.10	13	*1.9*
NP		1.19	.10	0.47	0.18	0.09	0.12	10	3.1
NPK		1.32	.10	0.46	0.23	0.12	0.11	13	*2*
NPKMgSBCu		1.24	.10	0.49	0.24	0.14	0.12	20	*2.3*

[a] Foliar nutrients in italics are at or below sufficiency level for slash pine.
[#] Means followed by a different letter within a measurement period are significantly different using Duncan's Multiple Range Procedure at the 5% alpha level (foliar N concentrations were significantly different at the 10% level in 2002 and 2005).

Table 7. Leaf area index (LAI) estimates one (2002), three (2004), and four (2005) years post fertilization in an unthinned old-field site slash pine plantation in Toombs County, Georgia (Tifton soil)

Treatment	LAI 2002 #	LAI 2004	LAI 2005
Control	2.5 b	2.7 b	3.0
NP	3.1 a	3.3 a	3.1
NPK	3.1 a	3.3 a	3.2
NPKMgSBCu	3.0 a	3.2 a	3.0

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

Table 8. Growth parameter means at fertilization (age 8-years-old), two, and four years post application in an unthinned old-field slash pine plantation in Toombs County, Georgia (Tifton soil).

Treatment	Age	Trees per acre	Dbh	Basal area	Height	Live Crown ratio#	Volume per tree	Total volume	pulpwood volume[a]	superpulp volume[b]
	(Years)		(in)	(ft^2 ac^{-1})	(ft)	(%)	(ft^3)	--------------(ft^3 ac^{-1})*--------------		
	8									
Control		510	5.4	82	25.4	NA	2.20	1158	980	10
NP		523	5.5	86	25.7	NA	2.31	1231	1015	54
NPK		535	5.3	85	25.4	NA	2.15	1191	995	27
NPKMgSBCu		518	5.5	86	25.9	NA	2.32	1219	1043	41
	10									
Control		505	6.4	115	33.0	50	3.83	1985	766	1101
NP		513	6.5	119	33.3	49	3.95	2072	744	1210
NPK		515	6.4	115	32.6	48	3.75	1966	875	978
NPKMgSBCu		515	6.4	120	33.4	49	3.98	2087	830	1142
	12									
Control		500	7.1	141	40.8	44 a	5.56	2848	414	2135a
NP		480	7.3	141	40.9	44 a	5.84	2869	294	2173a
NPK		495	7.1	138	39.8	42 b	5.44	2749	452	1995b
NPKMgSBCu		493	7.3	143	40.5	43ab	5.79	2917	355	2188a

[a] Volume of trees with a dbh of 4.6 through 6.5 inches to a 3 inch top outside bark diameter. Pulpwood trees.
[b] Volume of trees with a dbh of 6.6 through 8.5 inches to a 3 inch top outside bark diameter. Superpulp trees.
* ft^3 ac^{-1} = cubic feet per acre; 88 ft^3 = 1 cord of wood and bark, and 100 $ft^3 \approx$ 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.

Table 9. Growth parameter increment means between at fertilization and two years post-fertilization (age 8- through 10-years-old), between two and four years post-fertilization (age 10- through 12-years-old), and between at fertilization and four years later (ages 8- through 12-years-old) in an unthinned old-field slash pine plantation in Toombs County, Georgia (Tifton soil).

Treatment	Age	Trees per acre	Dbh	Basal area	Height	Volume per tree	Total volume	pulpwood volume[a]	superpulp volume[b]
	(Years)		(in)	(ft^2 ac^{-1})	(ft)	(ft^3)	--------------(ft^3 ac^{-1})*--------------		
	8-10								
Control		-5	1.03	32.6	7.6	1.63	828	-214	1091
NP		-10	1.00	32.5	7.6	1.65	842	-271	1156
NPK		-20	1.04	30.4	7.2	1.66	775	-120	951
NPKMgSBCu		-3	1.02	34.3	7.6	1.60	868	-213	1101
	10-12								
Control		-5	0.72	26.1	7.5	1.72	863	-352	1034
NP		-33	0.80	21.8	7.5	1.89	797	-450	964
NPK		-20	0.73	22.6	7.2	1.69	784	-423	1017
NPKMgSBCu		-22	0.76	23.5	7.4	1.81	830	-475	1047
	8-12								
Control		-10	1.75	58.7	15.1	3.36	1690	-566	2125
NP		-43	1.80	54.2	15.1	3.54	1639	-721	2120
NPK		-40	1.78	53.0	14.4	3.29	1558	-543	1968
NPKMgSBCu		-25	1.78	57.7	14.9	3.47	1698	-689	2148

[a] Volume of trees with a dbh of 4.6 through 6.5 inches to a 3 inch top outside bark diameter. Pulpwood trees.
[b] Volume of trees with a dbh of 6.6 through 8.5 inches to a 3 inch top outside bark diameter. Superpulp trees.
* ft^3 ac^{-1} = cubic feet per acre; 88 ft^3 = 1 cord of wood and bark, and 100 $ft^3 \approx$ 3 tons.

Table 10. Pine straw production by fertilizer treatment in an unthinned slash pine plantation in Toombs County, Georgia (Tifton soil).

Treatment	Bales per acre July 2002 #	Bales per acre Jan 2004
Control	267 b	230
NP	299ab	232
NPK	356 a	230
NPKMgSBCu	311ab	243

growth parameter 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 (oven dry wt)

Figure 1. Leaf area index (LAI) photos in an unthinned, old-field slash pine stand in Toombs County, Georgia (photos taken July 2004, forty-one months after treatment). Top left=control, top right= NP, bottom left=NPK, and bottom right=NPKMgSBCu.

CITATION

Dickens, E.D., D.J. Moorhead, B.C. McElvany, D.S. Curry, and J. Edenfield. 2010. Effect of Fertilization on Slash Pine Growth and Pine Straw Production in an Old-field Site in Toombs County, Georgia. Georgia Forest Productivity Series No. 004R-2010. www.bugwood.org/productivity. 12 p.

Keywords: slash pine, old-field, fertilization, pine straw, growth and yield, soil nutrients, foliar nutrients

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