EFFECT OF LIME STABILIZED BIOSOLIDS AND INORGANIC FERTILIZER APPLICATIONS ON A THINNED LONGLEAF STAND – TEN YEAR RESULTS

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Abstract—This project was initiated on the Sand Hills State Forest in Chesterfield County, SC in May 1995 to determine the benefits of inorganic fertilizer (NPK) and lime stabilized biosolids applications in a twice-thinned longleaf pine (*Pinus palustris* Mill.) stand planted in 1963 on an excessively well drained deep sand (Alpin soil series). Major objectives included quantifying the magnitude and duration of pine straw response, stand growth, and economics of each treatment over a ten-year period. The experimental design was randomized complete block design with three replications with treatments applied in the spring of 1995 and reapplied in the spring of 1999. Treatments were: control (no fertilizer), NPK, and lime stabilized biosolids. All living tagged trees in treatment plots were measured (d.b.h, total height) prior to the first application in March 1995 and re-measured in February-March 1997, 1999, June 2001, February 2003, and August 2005. Results indicate a significant near-term pine straw production benefit to NPK and the biosolids treatments in years 2 and 3 after the first application. Mean NPK and biosolids treatment plot basal area per acre and volume per tree increments during the periods 1999-2005 and 1995-2005 were significantly greater than the control. Mean NPK plot volume per acre increment was significantly greater than the control and biosolids plots during the period of 1995-1999. The NPK and biosolids plot volume per acre increments during 1999-2005 were significantly greater than the control. Ten year total volume per acre increment was significantly greater in NPK plots than in biosolids plots and biosolids plots were significantly greater than the control.

INTRODUCTION

The South Carolina Forestry Commission was interested in determining the benefits of two applications of inorganic fertilizer and the town of Cheraw lime stabilized biosolids in a mid-rotation thinned longleaf pine stand on the Sand Hills State Forest in Chesterfield County, SC in the spring of 1995. Major objectives included quantifying the magnitude and duration of (1) pine straw (litter layer dry weight) response, (2) soil available P and foliar N, P, and K trends over time by treatment, and (3) tree/stand growth (d.b.h., basal area (BA) per acre, height, volume per tree, volume per acre, and product class distributions; pulpwood (PW), superpulp (SP), and chip-n-saw (CNS)) response.

METHODS

The land use history of the study area was as follows. Prior to the longleaf planting, the site was a natural pine stand with a heavy turkey oak (*Quercus laevis* Walt.) understory that was clearcut in 1961. The site was mechanically cleared and planted to watermelons in 1962. The site was then planted to longleaf pine using bareroot seedlings at a 6 by 6 feet spacing in 1963. The longleaf stand was thinned twice: in 1984 from 90 square feet basal area per acre to 64 square feet BA per acre removing 3 cords per acre leaving 7.5 cords per acre, and in 1994 from 100 to 60 square feet BA per acre removing 7.6 cords per acre leaving 16 cords per acre. Stand management during the ten year study period included pine straw raking every other year from 1995 through 1999 with no understory hardwood control, then raking annually with controlling understory woody vegetation, primarily turkey oak, by stump cutting, piling, and herbicide treating the stumps from 2000 to 2005. The soil series was verified by a NRCS soil mapper as excessively well- drained deep sand (Alpin soil series; Lamellic Quartzipsamments).

The experimental design was randomized complete block design with three replications. Gross treatment plots (145 by 145 feet) were installed within the soil delineated stand. Permanent measurement plots (104.5 by 104.5 feet) were installed within each gross treated plot. Forty feet of untreated buffer separated each plot. Forest floor and surface soil samples were collected prior to fertilizer and biosolids treatments. Since spring growth had already initiated, foliage samples were not taken prior to plot treatment. All living longleaf trees in each permanent measurement plot were aluminum tagged (at 4.5 feet above groundline), numbered, and measured for d.b.h. and total height prior to plot treatment. Longleaf total and merchantable stem volume (wood+bark) was estimated using equations developed by Baldwin and Saucier (1983):

$$\text{Total Volume} = \log TV = -2.77009 + 1.04013 \log (D^2H)) \text{ and}$$
$$\text{Merchantable Volume} = MV = TV*R \qquad (1)$$
$$\text{where } R = 1- 7.1949(Dm^{2.89957})/((D^2H)^{1.04094}), \qquad (2)$$

Total Volume and Merchantable Volume in cubic feet, D=d.b.h. (inches), H=total height (feet), and Dm=top diameter (inches; 3 for PW, SP, and 6 inches for CNS)

Plots were randomly assigned a treatment. Treatments were as follows: control (no fertilizer), 10-10-10 at 1500 pounds per acre, lime stabilized biosolids (8 wet tons per acre; 40 percent solids, 4.5 wet tons = 1 ton agricultural lime, 210 pounds total-N, 80 pounds plant available-N, 110 pounds P_2O_5, 11 pounds K_2O, 1900 pounds Ca, and 6.4 pounds Mg per acre) first applied in May - June 1995. Plots were treated a second time in May - June 1999. The treatments were: control=no treatment, 10-10-10 at 1500 pounds per acre, and lime stabilized biosolids at 12 wet tons per acre

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Citation for proceedings: Stanturf, John A., ed. 2010. Proceedings of the 14th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 614 p.

(310 pounds total-N, 367 pounds P_2O_5, and 72 pounds K_2O per acre). All living tagged trees were re-measured (d.b.h. and total height) in February-March 1997, 1999, June 2001, March 2003, and August 2005. Surface soil (0-6 inches) and foliage samples were taken each January-February starting in 1996 through 2003 and 2005. Surface soil was analyzed for available phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) using the Mehlich I extract procedure and soil pH (AS-3000 pH analyzer 1:1 ratio of soil to deionized water). Foliage was analyzed for N (Dumas procedure), P, K, Ca, Mg, B, and Cu (HNO_3 + 30 percent H_2O_2 wet ashing). Six 144-square inch grids of forest floor litter layer (fresh brown needles representing straw that would be harvested) samples were taken per plot prior to the lime stabilized biosolids and inorganic fertilizer application in May-June 1995 and then each January-February after fertilizer application through February 1999. The stand was raked twice during the first four years of the study period then annually starting in 2000 making litter layer collection and analysis impractical. All litter layer samples were oven dried at 70 °C for 48 hours and weighed to determine dry weights per acre by treatment. A bale of longleaf pine straw was assumed to be 19 pounds of litter layer by dry weight (Morris and others 1992). Pine straw, soil, foliage, and tree/stand parameter means were tested by year for significant differences using Duncan's Multiple Range Test at the 5 percent alpha level.

RESULTS

Pine Straw Estimates

There were no significant pine straw (litter layer) gains with NPK or biosolids fertilization 9 months after initial application (table 1). This is to be expected as pine needles tend to stay on the tree for an average of 18 months (range of 1 to 2 years) (Gholz and others 1985). The second year post-NPK and biosolids application there were significant pine straw gains over the control of 1 812 and 1 292 pounds per acre, respectively (table 1). The plots that were fertilized with NPK or lime stabilized biosolids had significantly greater pine straw values in the third and fourth year after initial application (table 1). The control plots produced 4.82 tons per acre, the NPK treated plot produced 7.09 tons per acre, and the biosolids treated plots produced 6.52 tons per acre from May 1995 through February 1999. The NPK treated plots produced 2.27 extra tons per acre and the biosolids treated plots produced an extra 1.70 tons per acre over the control during this period. This equates to and extra $89 to $120 per acre (at $0.50 per bale and 19 pounds per bale dry weight) (Morris and others 1992) in pine straw revenues for the biosolids and NPK treatment, respectively during this period.

Soil Available Phosphorus

Surface soil (0-6 inches) available P (SA-P) prior to the first treatments (May 1995) means ranged from 0.33 to 3.5 ppm (table 2), concentrations considered to be below sufficiency for longleaf pine (Blevins and others 1986). Soil available P concentrations from the NPK plots in July 1995, September 1996, and February 1996 were significantly greater than SA-P in the control and biosolids plots. There were no significant SA-P treatment differences in 1997 (control; 3.5, NPK; 7.5 and biosolids; 11 ppm), 1999 (control and biosolids; 0 ppm and NPK; 6 ppm), and 2001 (control; 0.5, NPK 25, and biosolids; 3.3 ppm). SA-P was significantly greater in the NPK plots (8 ppm) than the biosolids (1.8 ppm) and control plots (0.5 ppm) in 1998, 2000 (control; 0.33, NPK; 21, and biosolids; 1.5 ppm), 2002 (control; 3.0, NPK; 21, and biosolids; 7.7 ppm), 2003 (control; 2.5, NPK; 32, and biosolids; 11 ppm), and 2005 (control; 3.5, NPK; 18, and biosolids; 7.0 ppm, table 2).

Foliar N, P, and K

Longleaf pine foliar N, P, and K concentrations were not significantly different by treatment in February 1996, but foliar N was below sufficiency (Blevins and others 1986) from the control plot trees (0.85 percent) and above sufficiency from the biosolids (1.1 percent) and the NPK plot trees (1.3 percent) nine months after the first treatment (table 2). Mean foliar N from the NPK plot trees (0.97 percent) was significantly greater than the biosolids (0.82 percent) and control plot trees (0.70 percent) in February 1997. Foliar P and K were not significantly different between treatments in 1997. Foliar N and P were not significantly different between treatments in February 1998 and 1999. Foliar K was significantly greater from the NPK plot trees (0.46 percent) than the biosolids (0.32 percent) and control (0.26 percent) in 1998. There were no significant treatment differences in February 1999 (table 2). Longleaf pine foliar N, P, and K

Table 1—Pine straw production estimates by treatment and measurement year from a 1963 planted longleaf stand (Alpin soil series) on the Sand Hill State Forest in Chesterfield County, SC

Treatment	Pinestraw production by year				
	1995	1996	1997	1998	1999
	---------------- *pounds per acre* ----------------				
Control	2390	1647	2000b	2191b	1417b
NPK	2123	1468	3812a	4035a	2745a
Biosolids	2123	1751	3202a	3555a	2400a

Table 2—Foliar nitrogen (N), phosphorus (P), potassium (K), and surface (0-6 inches) soil available P by treatment and measurement year from a 1963 planted longleaf stand (Alpin soil series) on the Sand Hill State Forest in Chesterfield County, SC

	Year									
Treatment	1995	1996	1997	1998	1999	2000	2001	2002	2003	2005
	---------- Foliar N (%) ----------									
Control		0.85	0.70c	0.82	0.88	0.88b	0.88	0.86	0.98b	
NPK		1.10	0.97a	0.96	0.87	1.58a	0.92	0.89	1.18a	
Biosolids		1.30	0.82b	0.88	0.82	0.89b	0.96	0.83	0.88b	
	---------- Foliar P (%) ----------									
Control		0.08	0.05	0.07	0.07	0.07b	0.07	0.08	0.09b	
NPK		0.08	0.08	0.09	0.07	0.11a	0.07	0.08	0.10a	
Biosolids		0.08	0.07	0.09	0.08	0.08b	0.08	0.14	0.09b	
	---------- Foliar K (%) ----------									
Control		0.32	0.20	0.26b	0.26	0.25b	0.28b	0.29	0.32b	
NPK		0.36	0.42	0.46a	0.43	0.54a	0.46a	0.40	0.47a	
Biosolids		0.58	0.28	0.32b	0.28	0.29b	0.32b	0.27	0.27b	
	---------- Soil P (ppm) ----------									
Control	0.3	0.0b	3.5	0.5b	0.0	0.3b	0.5	3.0b	2.5b	3.5b
NPK	3.6	16.0a	7.5	8.0a	6.0	21.0a	25.0	21.0a	32.0a	18.0a
Biosolids	1.8	0.0b	11.0	1.8b	0.0	1.5b	3.3	7.7b	11.5b	7.0b

Minimum sufficiency longleaf pine guidelines; foliage N=0.95 percent, P=0.08 percent, K=0.30 percent and soil available P=5 ppm (Blevins and others 1986).

Treatment means within a measurement year followed by a different letter are significantly different using Duncan's Multiple Range Test at the 5 percent alpha level.

concentrations from the NPK treatment (1.6 percent N, 0.11 percent P, and 0.54 percent K) were significantly greater than the biosolids (0.89 percent N, 0.08 percent P, and 0.29 percent K) and control (0.88 percent N, 0.07 percent P, and 0.25 percent K) in February 2000, nine months after the second biosolids and NPK treatment (table 2). Foliar N and P were not significantly different between treatments in 2001, but mean foliar K concentration from the NPK treatment (0.46 percent) was significantly greater than the biosolids (0.32 percent) and control (0.28 percent). Foliar N, P, and K were not significantly different between treatments in 2002. Foliar N, P, and K concentrations from the NPK treatment trees were significantly greater than the biosolids and control trees from the last year of foliage collection in February 2003 (table 2).

Tree and Stand Growth

Treatment means by year—There were not significant treatment mean differences for trees per acre, d.b.h., total height, total volume per acre, pulpwood (PW; 4.5 inches < d.b.h. <6.6 inches) volume per acre, and superpulp (SP; 6.6 inches ≤ d.b.h. < 8.6 inches) volume per acre during the ten year study period (tables 3 and 4). There was a significant chip and saw (CNS; d.b.h. ≥ 8.6 inches) volume per acre difference in 2005 with the NPK treatment producing more CNS volume (1,560 cubic feet per acre) than the control (1,199 cubic feet per acre) and the biosolids treatment (1,437 cubic feet per acre) not being significantly different than the NPK or control treatment (table 4).

Incremental means between measurement years—The NPK treatment basal area per acre increment (13.4 square feet per acre) during the first four years (March 1995 to March 1999) was significantly greater than the control (8.1 square feet per acre, table 5). The NPK total volume per acre increment (399 cubic feet per acre) was significantly greater than the biosolids (285 cubic feet per acre) and control (245 cubic feet per acre) between 1995 and 1999 (table 6). The NPK and biosolids d.b.h., basal area, volume per tree, and total volume per acre increment means during the second six year period were significantly greater than the control. Ten year (1995-2005) d.b.h, basal area, and CNS volume increment means from the NPK and biosolids treatments were significantly greater than the control (table 6). The NPK volume per tree increment (6.22 cubic feet) during the ten year period was significantly greater than the control (3.63 cubic feet) but not significantly greater than the biosolids (5.21 cubic feet). The NPK treatment produced significantly greater total volume per acre (1,059 cubic feet per acre)

Table 3—Trees per acre, d.b.h., total height, and volume per tree by treatment and measurement year from a 1963 planted longleaf stand (Alpin soil series) on the Sand Hill State Forest in Chesterfield County, SC

Year	Treatment	Trees per acre	d.b.h.	Total height	Tree volume
			in	*ft*	*ft³*
1995	Control	196	7.5	50.1	6.85
	NPK	177	7.3	49.7	6.52
	Biosolids	192	7.3	50.5	6.70
1997	Control	195	7.7	51.6	7.61
	NPK	175	7.8	51.5	7.75
	Biosolids	188	7.7	50.3	7.49
1999	Control	195	8.0	51.6	8.14
	NPK	175	8.2	52.7	8.50
	Biosolids	187	8.1	52.0	8.91
2001	Control	195	8.4	52.8	9.29
	NPK	175	8.9	53.6	10.50
	Biosolids	185	8.7	53.4	9.99
2003	Control	195	8.5	54.0	9.77
	NPK	175	9.1	56.0	11.60
	Biosolids	185	8.9	54.9	10.70
2005	Control	195	8.7	55.2	10.50
	NPK	175	9.4	57.6	12.70
	Biosolids	185	9.2	56.5	11.90

There were no significant treatment differences within each measurement year using Duncan's Multiple Range Test at the 5 percent alpha level.

than the biosolids (903 cubic feet per acre) and the biosolids produced significantly greater total volume than the control (699 cubic feet per acre) during the ten-year study period (table 6). There were no significant treatment differences for total height, PW, or SP volume increment during the study period (tables 5 and 6).

DISCUSSION

Prior to the first treatments, soil available P in the surface 6 inches (0 to 3.6 ppm, table 2) was below sufficiency for longleaf pine (Blevins and others 1986), making this site a good candidate for fertilization. Longleaf pine foliar N (0.85 percent) was below sufficiency, foliar P (0.08 percent) was at sufficiency, and foliar K (0.32 percent) was slightly above sufficiency from the control plot trees in the first sampling year (1996, table 2). Foliar N, P, and K concentrations from the control plot trees were at or below sufficiency from 1997 through 2002, indicating that this stand would respond to an NPK fertilizer treatment. The near-term (1995 through 1999) straw production rate was increased by an average 52 bales per acre per year with the first NPK application and 37 bales per acre per year with the first biosolids application. Ten year diameter increment for the NPK and biosolids plot trees were 0.9 (75 percent gain) and 0.7 inches (58 percent gain) greater than the control (1.2 inches, table 5). Basal area ten year increment for the NPK (32.5 square feet per acre) and the biosolids (28.9 square feet per acre) were 52 and 35 percent greater than the control (21.4 square feet per acre). The NPK and biosolids volume per tree increments (6.22 and 5.21 cubic feet) were 71 and 44 percent greater than the control (3.63 cubic feet) during the ten year study period (table 5). Total volume per acre was improved over the control by 84 and 29 percent or 0.42 cords per acre per year (1.1 tons per acre per year) and 0.24 cords per acre per year (0.64 tons per acre per year) with the two NPK and biosolids treatments, respectively (table 6). Chip and saw volume per acre production was improved by 47 and 33 percent with the two NPK and biosolids treatments, respectively compared to the control (table 6). Using Timber Mart-South (1995, 2005), SC pine stumpage prices, the NPK treatments improved wood value over the control by $342 per acre and the biosolids improved wood value by $209 per acre over the control. Adding in the increased pine straw revenues during 1997, 1998, and 1999 (at $0.50 per bale), the NPK wood plus pine straw revenues were $473 per acre greater than the control and the biosolids wood plus pine straw revenues were $303 per acre greater than the control.

ACKNOWLEDGMENTS

The authors would like to thank the SC Forestry Commission and the Sand Hills State Forest for funding this project during the ten year period.

Table 4—Total volume, pulpwood, superpulp, and chip-n-saw volume per acre means by treatment and measurement year from a 1963 planted longleaf stand (Alpin soil series) on the Sand Hill State Forest in Chesterfield County, SC

Year	Treatment	Total volume	Pulpwood[1] volume	Superpulp[2] volume	Chip-n-saw[3] volume
		------------	ft^3 *acre*$^{-1}$	------------	
1995	Control	1338	146	761	308
	NPK	1144	149	638	251
	Biosolids	1303	145	784	256
1997	Control	1485	105	782	449
	NPK	1345	114	609	477
	Biosolids	1412	66	785	416
1999	Control	1583	74	759	579
	NPK	1543	93	592	683
	Biosolids	1588	63	650	679
2001	Control	1800	69	576	924
	NPK	1823	58	394	1122
	Biosolids	1837	47	568	991
2003	Control	1883	69	554	1020
	NPK	2003	38	381	1320
	Biosolids	1976	30	503	1181
2005	Control	2037	68	506	1199b
	NPK	2203	30	330	1560a
	Biosolids	2205	26	455	1437ab

[1]Pulpwood volume = 4.6 ≤ d.b.h. ≤ 6.5 inches to a 3 inch top.
[2]Superpulp volume = 6.6 ≤ d.b.h. ≤ 8.5 inches to a 3 inch top.
[3]Chip-n-saw volume = d.b.h. > 8.5 inches to a 6 inch top.
Treatment means within a measurement year followed by a different letter are significantly different using Duncan's Multiple Range Test at the 5 percent alpha level.

Table 5—D.b.h., basal area, total height, and volume per tree growth increments by treatment and measurement period from a 1963 planted longleaf stand (Alpin soil series) on the Sand Hill State Forest in Chesterfield County, SC

Year	Treatment	d.b.h.	Basal area	Total height	Tree volume
		in	ft^2 *acre*$^{-1}$	*ft*	ft^3
1995-1999	Control	0.5	8.1b	1.6	1.29
	NPK	0.9	13.4a	3.0	2.39
	Biosolids	0.8	10.6ab	1.5	1.80
1999-2005	Control	0.7b	13.3b	3.6	2.34b
	NPK	1.1a	19.1a	4.9	3.84a
	Biosolids	1.1a	18.1a	4.5	3.41a
1995-2005	Control	1.2b	21.4b	5.2	3.63b
	NPK	2.1a	32.5a	7.9	6.22a
	Biosolids	1.9a	28.9a	6.0	5.21ab

Treatment means within a measurement period followed by a different letter are significantly different using Duncan's Multiple Range Test at the 5 percent alpha level.

Table 6—Total volume, pulpwood, superpulp, and chip-n-saw volume per acre growth increments by treatment and measurement year from a 1963 planted longleaf stand (Alpin soil series) on the Sand Hill State Forest in Chesterfield County, SC

Period	Treatment	Total volume	Pulpwood[1] volume	Superpulp[2] volume	Chip-n-saw[3] volume
		------------------------------ft^3 $acre^{-1}$--------------------------			
1995-1999	Control	245b	-72	-2	271
	NPK	399a	-58	-45	432
	Biosolids	285b	-81	-134	424
1999-2005	Control	454b	-6	-253	620
	NPK	660a	-63	-262	877
	Biosolids	618a	-38	-195	758
1995-2005	Control	699c	-78	-255	891b
	NPK	1059a	-120	-308	1309a
	Biosolids	903b	-119	-329	1182a

[1]Pulpwood volume = 4.6 ≤ d.b.h. ≤ 6.5 inches to a 3 inch top.
[2]Superpulp volume = 6.6 ≤ d.b.h. ≤ 8.5 inches to a 3 inch top.
[3]Chip-n-saw volume = d.b.h. > 8.5 inches to a 6 inch top.
Treatment means within a measurement period followed by a different letter are significantly different using Duncan's Multiple Range Test at the 5 percent alpha level.

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