EFFECT OF A ONE-TIME BIOSOLIDS APPLICATION IN AN OLD-FIELD LOBLOLLY PINE PLANTATION ON DIAMETER DISTRIBUTIONS, VOLUME PER ACRE, AND VALUE PER ACRE

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Abstract—A forest land application of biosolids study was initiated in 1991 in the lower Coastal Plain of South Carolina (SC). A major objective of this project was to quantify the magnitude and duration of old-field loblolly pine (*Pinus taeda*, L.) growth response to a one-time biosolids application after canopy closure. The study area is located on Alcoa property in Berkeley County, SC. The soil series, Goldsboro (Fine-loamy, Aquic Paleudults) was delineated by a NRCS soil mapper in a 1982 planted loblolly pine stand. Gross treated and interior permanent measurement plots were installed in a randomized complete block design. Forty feet of untreated buffer was maintained between plots. All living loblolly pines were tagged, numbered, and measured for dbh and total height in February-March 1992. Berkeley County Water and Sanitation Authority (BCW&SA) biosolids (5.7 percent total-N, 15 percent solids, extended aeration treated) were applied one-time in April 1992 at 0, 650, and 1300 pounds of total-N per acre (5.7 and 11.4 dry tons/acre). The stand was operationally thinned (third row with logger select in between) in August 1993 reducing SPA from 560 to 300 (BA/ac from 120 to 65 square feet). Stand data from age 10-years-old to age 17-years-old show a dramatic growth increase in mean dbh increment (0.5 and 1.0 inch), total height increment (2.0 and 2.7 feet), volume/tree (30-35 percent), and volume/acre increment (37-38 percent) in the biosolids versus the control plots. Diameter distributions 7 years after biosolids application favored more chip and saw (8-9 cords/acre) and less pulpwood (1-3 cords/acre) in the biosolids versus control plots. Total wood value/acre was increased by $555 to $595 (at $19/cd pulpwood and $73/cd chip and saw (Timber Mart-South 2000) in the biosolids plots versus the control plots by age 17-years-old.

INTRODUCTION

Total demand for forest products is anticipated to increase substantially by the year 2030 (USDA 1988). Pulpwood is projected to show the largest rise, with demand increasing 50 percent (GFC 2001). The southeastern US is estimated to produce 50 percent or more of the world's pulp and paper 30 years from now (USDA 1988). This increased demand for wood fiber coincides with the recent interest by the US congress and EPA to promote beneficial use of biosolids. Forest land application of biosolids can save large sums of money through landfill tipping fee cost avoidance and extensions in landfill life. These savings are estimated for South Carolina to range from $50,000 to $400,000 per year per county. Loblolly pine (*Pinus taeda,* L.), a principle southeastern US crop tree, will often respond to one-time N+P fertilization on most better drained Coastal Plain soils (NCSUFNC 1999). Forest wood and fiber products are not a part of the human food chain and forest land application scheduling and management is not as complicated as in other crop alternatives. There is an abundance of forest land in South Carolina where two-thirds of 19 million acres is forested (Tansley and Hutchins 1988).

METHODOLOGY

Permanent measurement plots were established in the fall of 1991 on Alcoa property in Berkeley County, SC. The study area was on an old field 10-year-old loblolly pine planted at 6x10 feet with 14 feet between every 5th row. The soil series throughout the study area was Goldsboro. The experimental design was randomized complete block with two replications (blocks) per treatment (0, 5.7, and 11.4 dry tons biosolids/acre) in the loblolly pine stand for a total of six experimental units (plots). Gross treated plots averaged 1/4 acre and internal permanent measurement plots averaged 1/10th acre. Forty feet of untreated buffer was maintained between each plot. Plot conversion factors were used to convert from volume per tree and number of trees to wood volume per acre for each plot and biosolids treatment. All living loblolly pine trees in each plot were affixed with a numbered aluminum tree tag at 4.5 feet above groundline then measured for diameter (Dbh with a d-tape) and total height (height pole except the last measurement was with a clinometer) in February-March 1992 prior to biosolids application and two (1/94), four (1/96), five (3/97), and seven (3/99) growing seasons after biosolids application. Extended aeration biosolids (80 percent domestic and 20 percent industry input, 15 percent solids, 5.7 percent total-N, table 1) were applied on 9-15 April 1992 at 0, 5.7 dry tons (200 PAN) and 11.4 dry tons

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Table 1—Concentrations and application levels for the BCW&SA biosolids applied to an old-field loblolly pine plantation in Berkeley County, SC on a Goldsboro soil

Component	Concentration	Application Level Low		Application Level High	
	--mg/kg dry basis--	kg/ha	(lb/ac) dry basis	kg/ha	(lb/ac) dry basis
Biosolids		2800	(11400)	25,500	(22800)
Kjeldahl-N	57000	728	(650)	1460	(1300)
NH_4-N	1660	21.1	(18.9)	42.3	(37.8)
NO_3-N	53	0.67	(.60)	1.3	(1.2)
elemental-P	11500	147	(131)	293	(262)
elemental-K	3770	48.2	(43)	96	(86)
Ca	18600	237	(212)	475	(424)
Mg	6400	81.8	(73)	164	(146)
As	3.0	0.038	(.034)	0.076	(.068)
Cr	10.0	0.128	(.114)	0.260	(.230)
Cu	380	4.85	(4.33)	9.70	(8.66)
Pb	33	0.421	(.376)	0.842	(.752)
Ni	38	0.476	(.433)	0.970	(.866)
Se	1.7	0.022	(.020)	0.045	(.400)
Zn	500	6.4	(5.7)	12.8	(11.4)

(400 PAN) per acre to randomly assigned plots. Plant available nitrogen (PAN) was estimated to be 30 percent of organic-N (TKN - NH_4-N), 50 percent of NH_4-N, and 100 percent of NO_3-N (SC-DHEC 1996). The low biosolids level (5.7 dry tons/acre or 38 wet tons/acre) was achieved by one pass with a tractor and pull behind side port spreader at a known speed with the port door set to a marked opening height and the PTO RPMs set at 540. Two passes achieved an average of 11.4 dry tons/acre (76 wet tons/acre). Fourteen feet between every fifth row allowed for ground access into the plots. The stand was operationally thinned (third row with logger select in between) in August 1993 from an average of 560 stems/acre (120 ft^2 BA/ac) to 300 SPA (65 ft^2 BA/ac). Winter prescribe backing fires were performed in the entire study area in February 1994, 1996, and 1998.

An analysis of covariance (SAS 1988) was run on 1994 data to ensure that a "common" starting point among the treatment levels after the thinning. Per acre basal area was used as the co-variate but it was not significant nor was the treatment effect. There were no significant treatment differences (5 percent alpha level) for mean dbh, total height, total volume/tree and total volume/acre the 1994 data. The number of stems in each diameter class was multiplied by the plot conversion factor to obtain the number of trees/acre by dbh class. Pre-thinning and pre-treatment (3/94) average stems/acre were 589 for the control, 555 for the low biosolids (200 PAN/ac) and 527 for the high biosolids (400 PAN/ac). Post thinning (1/94) stems/acre averages were 310 for the control, 300 for the low biosolids (200 PAN/ac) and 286 for the high biosolids (400 PAN/ac). Age 17-years-old average stems/acre were 297 for the control, 295 for the low biosolids (200 PAN/ac) and 271 for the high biosolids (400 PAN/ac). Diameter distributions at age 17-years-old were discerned by individual measured stems in one inch dbh classes from 4.0 - 4.9 to 12.0 and greater. The stem volume equations used (Pienaar and Grider 1984, Bailey and others, 1985) were:

$$TV_{(ib)} = 0.0014793\ D^{1.821}H^{1.1629}$$
$$MV_{(ib)} = TV_{(ib)}(1 - 0.4482\ D_m^{3.4580}D^{-3.1947})$$

where

$TV_{(ib)}$ = inside bark, total stem volume in cubic feet
$MV_{(ib)}$ = inside bark, merchantable stem volume in cubic feet
D = dbh in inches
H = total stem height in feet
D_m = outside bark, merchantable diameter in inches.

It was assumed that 100 percent of the tagged loblolly pines were pulpwood after biosolids application (age 10-years-old) and after the thinning (age 12-years-old). Product class distribution (either pulpwood or chip and saw) at age 17-years-old was estimated in the following manner. All living tagged loblolly pines in each plot that were 9.0 inches dbh and over were considered to be chip and saw trees. All living tagged trees that were 4.0 through 8.9 inches dbh were considered to be pulpwood trees. Where dbh was greater than or equal to 9.0 inches then D_m was 4.0 inches. Where dbh was less than 9.0 inches then D_m was 2.0 inches. Each individual measured living stem was therefore "merchandised" into either a "pulpwood" or "chip and saw" tree at age 17-years-old. Seventy-six cubic feet (ib) per cord was used as the conversion factor. A price of $19/cord for pulpwood and $73/cord for chip and saw

Table 2—Mean diameter (at 4.5 feet above groundline), total height, volume/tree (ib), and volume/acre in a 1982 planted old-field loblolly pine plantation where biosolids were applied (4/92) in Berkeley County, SC on the Goldsboro soil series

Year	Trt[a]	Dbh (in)	Tot Ht (ft)	Vol/tree (ft^3)	Vol/acre (ft^3)
1992	Control	5.05	26.7	1.29	760
	Low	5.33	27.2	1.45	805
	High	4.88	26.6	1.20	632
1994	Control	6.44	39.2	3.13	970
	Low	6.74	39.0	3.38	1014
	High	6.45	38.0	3.11	889
1996	Control	7.22	43.8	4.39	1317
	Low	7.69	45.4	5.13	1513
	High	7.54	43.8	4.75	1287
1997	Control	7.63	48.5	5.47	1625
	Low	8.17	49.5	6.34	1870
	High	8.12	49.2	6.22	1686
1999	Control	8.01	51.8	6.44	1913
	Low	8.82	54.3	8.12	2395
	High	8.83	54.4	8.15	2209
Culm.	Control	2.96	25.1	5.15	1153
grow	Low	3.49	27.1	6.67	1590
92-99	High	3.95	27.8	6.95	1577

[a]Treatments = biosolids treatments: control (no treatment), low (200 lb PAN/acre), and high (400 lb PAN/acre). The stand was operationally 3[rd] row thinned with select in between in August 1993 from 120 BA/acre to 65 ft^2 BA/acre.

(Timber Mart-South 2000) was used to determine value/ace by product class and total value/acre by treatment.

RESULTS

Loblolly pine mean diameters in the 1982 established stand were 4.88 inches (400 lb PAN/ac), 5.05 inches (control), and 5.33 inches (200 lb PAN/ac) in March 1992 prior to biosolids application and 8.01, 8.82, and 8.83 inches, respectively by March 1999 (table 2). Control plots mean diameter increased 2.96 inches, the 200 lb PAN/acre plots mean diameter increased 3.49 inches, and the 400 lb PAN/acre mean diameter increased 3.95 inches during the seven year measurement period. Average seven year diameter increment was increased by .07 and .14 inches/year in the biosolids plot trees compared to the control plot trees (table 2). Five year (94-99 post thin) average loblolly pine dbh increment was 0.314"/yr for the control, 0.416"/yr for the 200 PAN/acre, and 0.476"/yr for the 400 PAN/acre treatment.

Average loblolly pine tree heights prior to biosolids application were 26.7, 27.2, and 26.6 feet for the control, 200, and 400 lb PAN/acre plots, respectively at age 10-years-old (table 2). Average total heights seven years after biosolids application (3/99) were 51.8, 54.3, and 54.4 feet for the control, 200, and 400 lb PAN/acre plots, respectively. Average tree height growth during this seven year period since biosolids application was 25.1, 27.1, and 27.8 feet for the control, 200, and 400 lb PAN/acre plots, respectively. Biosolids plots height increment was 8 percent and 11 percent above the control seven years since biosolids application (table 2). Five year (94-99 post thin) average loblolly pine height increment was 2.52'/yr for the control, 3.06'/yr for the 200 PAN/acre, and 3.28'/yr for the 400 PAN/acre treatment.

Total inside bark wood volume per tree means prior to biosolids application (age 10-years-old) were 1.29, 145, and 1.20 cubic feet (inside bark) for the control, 200, and 400 lb PAN/acre plots, respectively (table 2). Wood volume per tree averages seven years after application (3/99) were 6.44 (control), 8.12 (200 lb PAN/acre), and 8.15 (400 lb PAN/acre) cubic feet. Wood volume per tree growth between 1992 and 1999 was 5.15 (control), 6.67 (200 lb PAN/acre), and 6.95 (400 lb PAN/acre) cubic feet. The biosolids plots mean wood volume per tree growth during the seven years since biosolids application was 30 percent (200 lb PAN/acre) and 35 percent (400 lb PAN/acre) greater than the control's. Five year (94-99 post thin) average loblolly pine volume/tree increment for the 200 and 400 PAN/acre biosolids treatments were 43 percent and 52 percent greater than the control, respectively. Post thin average annual volume/tree increment was 0.662 ft^3/yr for the control, 0.948 ft^3/yr for the 200 PAN/acre, and 1.01 ft^3/yr for the 400 PAN/acre treatment.

Total inside bark wood volume/acre means were 760, 805, and 632 cubic feet for the control, 200 PAN/ac, and 400 PAN/ac plots, respectively, prior to biosolids application

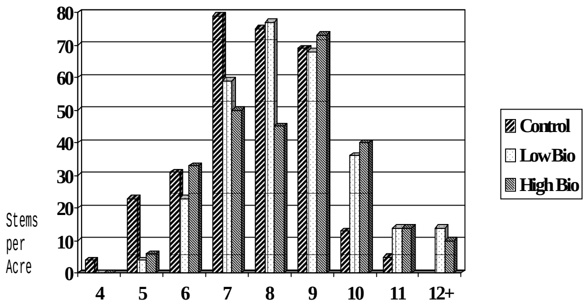

Figure 1—Old-field thinned loblolly pine plantation diameter distributions by treatment seven years after a one-time biosolids application in Berkeley County, SC on a Goldsboro soil series.

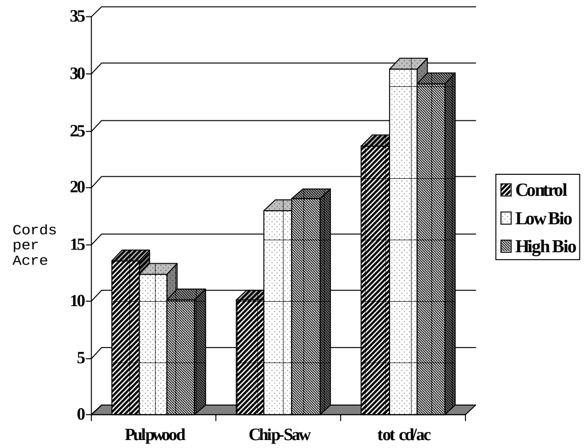

Figure 2—Old-field thinned loblolly pine plantation mean cords per acre production by treatment seven years after a one-time biosolids application in Berkeley County, SC on a Goldsboro soil series.

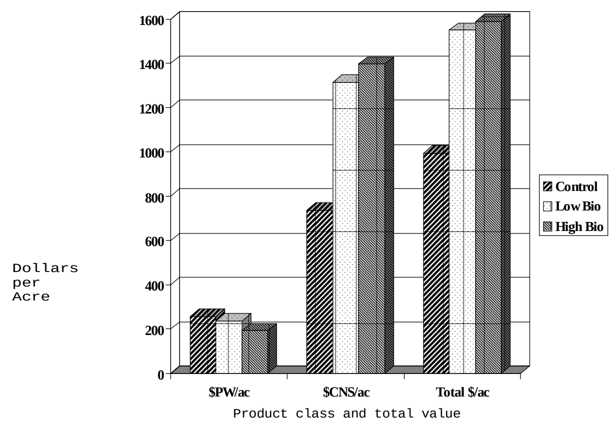

Figure 3—Old-field thinned loblolly pine plantation mean value by product class and per acre by treatment seven years after a one-time biosolids application in Berkeley County, SC on a Goldsboro soil series.

(3/92). Total inside bark wood volume means were 1913, 2395, and 2209 cubic feet for the control, 200 PAN/ac and 400 PAN/ac, respectively, seven years after the one-time biosolids application and five years after the thinning. Total wood volume(ib)/acre growth was 1153 (control), 1590 (200 PAN/ac), and 1577 (400 PAN/ac) seven years after biosolids application or 37-38 percent more wood volume increment in the biosolids plots. Five year (94-99 post thin) average loblolly pine volume/acre.year increment was 189 ft^3/yr for the control, 276 ft^3/yr for the 200 PAN/acre, and 264 ft^3/yr for the 400 PAN/acre treatment. Post thin average loblolly pine volume/acre for the 200 and 400 PAN/acre biosolids treatments were 46 percent and 40 percent greater than the control, respectively.

Diameter distributions in the low and high biosolids plots favored more chip and saw sized trees (9.0 inch dbh or greater) and less pulpwood sized trees (< 9.0 inch dbh) by age 17-years-old compared to the control plot diameter distribution (figure 1). Product class merchantable volumes in the biosolids plots had 8-9 more cords/acre in the chip and saw category and 1-3 cords/acre less pulpwood by age 17-years-old (figure 2). The pulpwood dollar value was greater in the control plots by $22 and $65 per acre compared to the low and high biosolids plots by age 17-years-old (figure 3). Chip and saw dollar value was $577 and $660 greater in the low and high biosolids plots, respectively, compared to the control seven years after treatment (figure 3). The net total revenue increase in the biosolids plots was $555 and $595 compared the the control plot mean (@ $19/cord for pulpwood and $73/cord for chip and saw) for the extra wood grown by product class. The internal rate of return ($(\text{Return/cost})^{1/7}-1$) for the extra wood grown over seven years at a cost of $90/acre for one pass (the low biosolids level) and $180/acre for two passes (the high biosolids level) is 29.7 percent and 18.6 percent for the low and high biosolids treatment.

DISCUSSION

The literature is scarce documenting the magnitude and duration of response to biosolids when applied to old-field planted loblolly pine stands. Loblolly pine dbh, total height, volume per tree, and volume per acre biosolids plots means were greater than the control seven years after the one-time biosolids application (table 2). Biosolids plots wood volume per tree and volume/acre seven year increments were 30-35 percent and 37-38 percent greater than the control, respectively. Diameter distributions in the biosolids plots favored 8-9 cords more chip and saw and 1-3 cords less pulpwood by age 17-years-old. In this old-field trial the extra wood volume gain due to biosolids application was greater than 5 cords/acre. Dollar revenues were increased by an average of $575/acre in the biosolids plots seven years after application and five years after a thinning in the 1982 planted loblolly pine stand. Using a typical DAP+Urea fertilizer plus application cost of $90/acre for the one pass to achieve the 200 PAN/acre biosolids level and the extra $555 in wood grown over 7 years, the calculated rate of return was 29.7 percent. Assuming a cost of $180/acre for two passes to achieve the 400 PAN/acre biosolids level and the $595/acre extra wood grown, the calculated rate of return is 18.6 percent. The incremental growth gain (4 percent wood volume seven year increment increase over the low biosolids) and $40 extra dollars/acre generated in wood value from the high biosolids (two passes to achieve 76 wet tons/acre) in this case does not appear to be worth the extra time, cost, and labor compared the one pass low biosolids one-time application level.

The 200 pounds of plant available nitrogen (PAN) per acre biosolids application level is in line with the current nitrogen prescription (200 N+ 25-50 lbs P/acre) for loblolly pine stands after canopy closure (NCSUFNC 1999). This 200 PAN/acre application level includes 131 lbs elemental-P, 43 lbs elemental-K, 212 lbs Ca, 73 lbs Mg, 4.33 lbs Cu/acre and organic matter. Loblolly pine foliar N, P, and K were above sufficiency (1.2 percent N, 0.12 percent P, and 0.35 percent K) in all plots prior to biosolids (1992) application. Foliar levels of N and P by 1996 in the control plots were below sufficiency while the biosolids plot foliar levels were still above sufficiency. Top soil (0-2") soil organic matter was 2.5 percent in the control plots, 4.1 percent to 5.7 percent in the biosolids plots in 1997. Mehlich I soil P (0-6") was < 8 ppm in the control plots and 20-95 ppm in the biosolids plots in 1997.

Berkeley County, SC is over 77 percent forested with approximately 550,000 acres wooded (Tansley and Hutchins 1988). Thousands of acres of privately owned loblolly pine plantations are in close proximity to the Berkeley County Water and Sanitation Authority treatment plant. Using 1992 BCW&SA biosolids generation figures and the low application level (5.7 dry tons/acre) approximately 500 acres of land would be needed per year. If the biosolids are to be applied once every 7-10 years (in conjunction with a thinning regime) then 3,500 to 5,000 acres are needed for a seven to ten year cycle in near-by loblolly pine stands after canopy closure (with access) or just after a thinning.

CONCLUSIONS

Land application of BCW&SA biosolids in established loblolly pine plantations in Berkeley County, SC proved beneficial, increasing wood volume growth increment by 37-38 percent and value by $555 to $595 per acre seven years after application. A second objective in this study area was to determine the effect of the one-time biosolids application on local groundwater quality. Four year data showed no adverse effect of the one-time biosolids application on groundwater quality (Dickens and others 1997, Dickens 1999). Realistically, the low biosolids level (5.7 dry tons/acre or an estimated 200 lbs PAN/acre) achieved in one pass proved almost as beneficial in seven year wood volume growth, dollar acre increased revenue, and may be the closer to the amount of N needed for loblolly pine growth at this age class compared to the two pass high biosolids level (11.4 dry tons/acre or an estimated 400 lbs PAN/acre).

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