EFFECTS OF APPLICATION OF MILL-GENERATED PRIMARY SLUDGE AND BOILER ASH ON LOBLOLLY PINE SURVIVAL AND GROWTH

Emily J. Goodwin and Andrew M. Burrow[1]

Abstract—Use of Kraft primary sludge and boiler ash in forest production systems holds promise as a cost-effective alternative to landfilling. From a soil quality perspective, particularly in coarse-textured sandy soils, increases in organic matter content from inputs of sludge/ash may improve soil chemical, biological, and physical properties. The objective of this study was to determine the impacts of a single application of sludge/ash at site preparation on loblolly pine (*Pinus taeda* L.) survival and growth. In the summer of 2002, a 2:1 sludge/ash mixture from a Kraft mill was mixed into beds during site preparation at three levels: 0, 39, and 77 tons per acre. Loblolly pine was planted in February 2004, followed by N fertilization at two levels (0 and 125 pounds per acre) in May. First-year measurements of survival (SURV), ground line diameter (GLD), total height (HT), and height to live crown (HTLC) were taken in February 2004. HT and HTLC were used to calculate vertical crown length (VCL). All sludge/ash treated plots showed greater HT and VCL than control (CTL) plots. Results showed greater HT and VCL in trees receiving 39 tons per acre with no fertilization and those receiving 77 tons per acre with fertilization. GLD was significantly greater for trees receiving 77 tons per acre with fertilization. Second year results show similar results for HT but not for VCL or GLD. VCL showed less stratification by the second year, and GLD had no significant differences. There was no difference in SURV between treatments for either year. The sludge/ash mixture showed HT growth benefit. Operational costs are somewhat prohibitive without more efficient methods of transport and application.

INTRODUCTION

The pulp and paper industry generates millions of tons of by-products in the manufacturing process. Most by-product solids are disposed of in costly private landfills or are incinerated. Land application accounts for a small fraction of by-product use but has the potential to be extremely beneficial for the mill and the forest landowner.

During the pulping process, wastewater is generated and treated to remove solids and dissolved organic material. The material left is referred to as wastewater treatment plant (WTP) residuals or mill sludge. Primary WTP residuals contain mainly wood fibers, which are derived from the clarification of raw effluent. Consequently, they have high carbon (C) content; this can pose a problem when land-applied because of the low nitrogen (N) concentrations of the material (Buckman and Brady 1969). Severe N-deficiencies can occur as microorganisms take up available soil N to balance their internal C:N ratio with a high external one (Pritchett 1979).

Secondary WTP residuals undergo a process in which N and phosphorous (P) are added to stimulate naturally occurring microorganisms. These microorganisms consume the remaining dissolved organic constituents, mainly lignin and other wood-based molecules. Secondary residuals may be more beneficial to trees and crops because of the added nutrients. When secondary sludge is land-applied, N and P rates must be monitored closely to protect water quality.

Boiler ash is a by-product of the incineration of wood and other fuels for energy. Ash is generally high in P and possibly potassium and is often used as a lime substitute in agricultural applications. Calcium and magnesium concentrations in the ash may also benefit nutrient-deficient sites. Ash may increase soil pH causing greater volatilization of N (NCASI 2003a).

All of these materials, as organic matter, may improve the physical properties of forest soils, particularly on sandy sites. Additions of organic matter may influence the cation exchange capacity and the stability of soil aggregates (Buckman and Brady 1969). Water-holding capacity of a soil may also be improved (NCASI 2000, Pritchett 1979). Since tree roots take up nutrients in solution, increasing water-holding capacity may enhance nutrient availability. Incorporating the residuals into the soil may increase decomposition rate and reduce erosion of the material off the site (NCASI 2000).

Benefits of mill sludge and ash must be tempered with environmental concerns. Much of this material is considered nonhazardous; however, levels of metals and dioxins have been controversial. Land application is regulated at the state level under laws regarding municipal sewage biosolids. Metals in WTP residuals are mainly derived from residual wood fiber and are relatively low in concentration when compared to municipal sewage biosolids. Lower metal concentrations in inks and processing chemicals have decreased the residual concentration of metals in recent years. Additionally, the last decade has seen dramatically reduced dioxin concentrations with the substitution of chlorine dioxide for chlorine in pulp bleaching. WTP residuals at mills may have accumulated for a number of years, so material stored before 1990 may have higher levels; however, these are still generally far lower than municipal sewage biosolids (NCASI 2000). Careful scrutiny of material is important to developing a land application program. Best Management Practices should also be applied for protection of water systems and environmentally sensitive areas.

Past studies have shown mixed results in improving survival and growth through the use of WTP residuals and ash on pine species. Georgia-Pacific applied a mixture of primary and secondary sludge (13.4 tons per acre) and ash (12.5 tons per acre). The study found an increase in loblolly pine (*Pinus taeda* L.) height when compared to a control but a decrease in survival, most likely due to increased weed competition. Another test found ash rates as high as 50 tons per acre had

[1] Research Forester and Research Forester, respectively, Temple-Inland Forest Products Corporation, Diboll, TX 75941.

Citation for proceedings: Connor, Kristina F., ed. 2006. Proceedings of the 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640 p.

positive growth effects. A Weyerhaeuser study showed a 15 percent growth increase with 12.5 tons per acre of ash on a P-deficient site. Jefferson-Smurfit examined slash pine (*Pinus elliotii* Engelm.) growth with WTP residual additions. A 6-inch layer of residuals incorporated into the soil prior to planting caused severe seedling mortality (>90 percent) presumably due to inadequate mineral soil contact with seedling root systems (NCASI 2000).

METHODS

The study site is located in Hardin County, TX (30° 19' N, 94° 12' W). Soils on the study site are deep, well-drained sands that are Fluvic in nature. Flooding occurs regularly from a nearby creek. This site was chosen because of its deep sands, its proximity to a mill, and its ability to represent a characteristic site in southeast Texas.

A 2:1 mixture of sludge/ash was applied at three levels (0, 39, and 77 tons per acre) to three replicates across the study site. This in combination with two levels of fertilization and a control comprised four treatments:

(1) 39 tons per acre with no fertilization (39N)

(2) 39 tons per acre with fertilization (39F)

(3) 77 tons per acre with no fertilization (77N)

(4) 77 tons per acre with fertilization (77F)

(5) control with normal silviculture (CTL)

The original study design called for 31 (3 truckloads) and 62 (6 truckloads) tons per acre. Available equipment dictated that the material be applied in strips and not broadcast over the entire acre. This change increased the effective treatment rate that each individual tree experienced to 39 and 77 tons per acre.

The 2:1 sludge/ash mixture was premixed and delivered in trucks averaging 10.3 tons per truck. A total of 72 truckloads were utilized. Average hauling cost per truckload was $112, totaling $8,087 for the 12 acres that were treated. A three-pass system using a shear, a manure spreader, and a Savannah plow was utilized to distribute the sludge/ash mixture: (1) A path was sheared, (2) the mixture was spread, and (3) the mixture was incorporated into a bed. Application costs were $691 per acre. Each treatment was applied across 1 acre in each of the three replicates in the summer of 2002. Loblolly pine seedlings were planted in February 2003, with urea fertilization (125 pounds per acre) following in May 2003.

Every 1-acre treatment plot was subsampled by 8 15-tree-space subplots. All trees within each subplot were labeled to track individual growth and survival (SURV) over time. Tree spaces were used to construct subplots to better represent the actual area each tree occupied. Plot level measurements of SURV were calculated from the average of the eight subplots. Individual tree measurements of total height (HT), height to live crown (HTLC), and ground line diameter (GLD) were taken on each seedling. Vertical crown length (VCL) was calculated for each tree by subtracting HTLC from HT. HTLC was defined as the height to the first live whorl of two or more branches.

The experimental design for HT, GLD, and VCL is a replicated random design with nested subsamples. The linear mixed model,

$$y_{ijkl} = \mu + A_i + B_j + [AB]_{ij} + C_{k(ij)} + e_{l(ijk)} \qquad (1)$$

where

i = 1 to 3 (replications),

j = 1 to 5 (treatments),

k = 1 to 8 (subplots), and

l = 1 to 15 (trees),

includes random terms for replication (A), replication/treatment interaction (AB), subplots (C), and a fixed term for treatments (B). The individual tree measurements comprise the error term (e).

The experimental design for SURV is a replicated random design. The linear mixed model,

$$y_{ijk} = \mu + A_i + B_j + [AB]_{ij} + e_{k(ij)} \qquad (2)$$

where

i = 1 to 3 (replications),

j = 1 to 5 (treatments), and

k = 1 to 8 (subplots),

includes random terms for replication (A) and replication/treatment interaction (AB), and a fixed term for treatments (B). The subplot level measurements of SURV comprise the error term (e).

Year 1 and year 2 measurements of HT, HTLC, and GLD were taken in February 2004 and 2005, respectively. SURV for each year was assessed as the percentage of live trees in each subplot.

RESULTS AND DISCUSSION

The main objective of this study was to determine if 39 or 77 tons per acre of a sludge/ash mixture could be applied without detriment to the crop trees. With this in mind, it must be noted that although significant differences were found between treatments, the magnitude between growth responses may be considered minimal. Table 1 summarizes results for HT, GLD, VCL, and SURV.

Total Height Comparisons

All sludge/ash treated plots yielded greater HT growth than the CTL for both the first and second years with best HT growth from 77F. For year 1, all treatments were significantly > the CTL, and 39N and 77F were significantly > 39F and 77N. For year 2, 77F was significantly > all other treatments; 39N, 39F, and 77N comprised a second homogeneous group, with 39N and 39F showing significant difference from the CTL. There was no change in the HT growth pattern between treatments from year 1 to year 2.

Interactions between the P in the sludge/ash mixture and N fertilization are apparent in the HT growth comparisons. At 39 tons per acre, N fertilization showed a decrease in HT growth. At this rate, P supplied by the sludge/ash may not be sufficient to allow full utilization of available N. Also, N fertilization often results in an increase in leaf area (Colbert and others 1990, Jokela and Martin 2000, Kozlowski and Pallardy 1997, Samuelson 1998, Vose and Allen 1988) and reduced allocation to fine root production (Albaugh and others 1998,

Table 1—First and second year total height, ground line diameter, vertical crown length, and survival for each treatment

Variable	Year	39N	39F	77N	77F	CTL
TH[a]	1	2.02a	1.88b	1.84b	2.07a	1.69c
(*feet*)	2	5.51AB	5.42AB	5.06BC	5.77A	4.87C
GLD	1	0.459ab	0.433b	0.443ab	0.470a	0.460ab
(*inches*)	2	1.23A	1.44A	1.13A	1.27A	1.12A
VCL	1	1.42ab	1.34b	1.32b	1.48a	1.16c
(*feet*)	2	4.55A	4.35A	4.23AB	4.64A	3.70B
SURV	1	97.1ab	98.3ab	98.9a	94.6b	97.8ab
(*percent*)	2	96.8AB	98.2AB	98.9A	94.6B	97.8AB

[a] Lowercase letters represent homogenous groups (α=0.05) within each variable for year 1; capital letters represent homogenous groups (α=0.05) within each variable for year 2.

Samuelson 2000). Greater maintenance respiration of these N fertilized trees may have caused greater water stress during the growing season, especially on this sandy, bedded site. Additionally, research has shown greater relative declines for photosynthesis and stomatal conductance at high N levels than at low N levels for trees experiencing water stress (Kozlowski and Pallardy 1997, Walters and Reich 1989).

At 77 tons per acre, N fertilization showed an increase in HT growth. Differences in response at this level of sludge/ash may be caused by an N deficiency. The sludge/ash mixture had a C:N ratio of 10,000:1, far above normal levels of 200:1 to 300:1 (NCASI 2003b) and recommended levels of 20:1 to 30:1 (NCASI 2000). Soil microorganisms immobilize inorganic N from the soil matrix to offset the imbalance between their internal C:N ratio and the external one affected by the sludge/ash mixture.

N may have been lost due to significant volatilization caused by the alkaline nature of the ash. Urea also raises the pH of the soil creating greater potential for loss of N. Although timing of the treatments were staggered with sludge/ash application taking place the season before the urea application, this high level of sludge/ash may have caused more alkaline conditions.

Ground Line Diameter Comparisons

Although year 1 measurements yielded significant differences in GLD, the differences are ≤ 0.01 inches, a level that would scarcely impact overall seedling volume growth. It is more likely that the differences are a product of minute variations in average seedling size at planting than any real differences in treatments. Unfortunately, year 0 measurements were not taken to validate this theory.

Year 2 measurements of GLD yielded no significant differences. Excluding an inexplicable shift in 39F, GLD growth patterns were fairly stable from year 1 to year 2.

Vertical Crown Length Comparisons

Significant differences were found for VCL between treatments for both year 1 and year 2, but again the magnitude was rather small. For both years, differences between the greatest and least VCL were only 10 to 20 percent of HT for those treatments. Comparative growth patterns for both years were unchanged. The relationship between HT and HTLC controls VCL. Trees with greater HT tended to have greater HTLC, possibly due to a reallocation of resources to the top of the tree.

Survival Comparisons

An asrcsin square root transformation was employed to approximate normality for the percentage response variable. Patterns in SURV were similar from year 1 to year 2. None of the treatments were significantly different from the CTL, and all survival rates were above 94 percent. Interestingly enough, the only difference in treatments lie between 77N, which had the highest survival, and 77F, which had the lowest survival. Survival rates for slower-growing trees could possibly be > faster-growing trees.

CONCLUSIONS

Growth responses over the CTL are predominantly responses to the P supplied by the sludge/ash mixture. Interactions with the N fertilization may increase or decrease the P growth response as more N supplied lowers the C:N ratio. At 39 tons per acre, N fertilization may not be beneficial. At 77 tons per acre, P may not be limiting, so N fertilization may improve growth. At either level, survival was not adversely affected.

Well-drained sandy sites that may flood frequently typically have too much water during the wet season and too little water during the dry season. Bedding helps to control water during the wet months, but during droughty periods, beds may cause excessive drainage resulting in low survival and growth. Sludge/ash amendments incorporated into the beds may increase the water holding capacity, thus increasing survival and growth.

Currently, the high cost of transport and application may be the greatest limitation for sludge/ash application at an operational scale. Refinement of the application technique and strategic selection of near-to-mill sites could help to lower the cost. However, if stockpiling of sludge or ash receives stricter regulations or if the mill runs out of landfill space, higher associated costs may transform the tasks of transport and application into cost-effective ones.

LITERATURE CITED

Albaugh, T.J.; Allen, H.L.; Dougherty, P.M. [and others]. 1998. Leaf area and above- and belowground growth responses of loblolly pine to nutrient and water additions. Forest Science. 44: 317-328.

Buckman, H.O.; Brady, N.C. 1969. The nature and properties of soils. London: The MacMillan Company. 653 p.

Colbert, S.R.; Jokela, E.J.; Neary, D.G. 1990. Effects of annual fertilization and sustained weed control on dry matter partitioning, leaf area, and growth efficiency of juvenile loblolly and slash pine. Forest Science. 36: 995-1014.

Jokela, E.J.; Martin, T.A. 2000. Effects of ontogeny and soil nutrient supply on production, allocation, and leaf area efficiency in loblolly and slash pine stands. Canadian Journal of Forest Research. 30: 1511-1524.

Kozlowski, T.T.; Pallardy, S.G. 1997. Physiology of woody plants. San Diego, CA: Academic Press. 411 p.

National Council for Air and Stream Improvement (NCASI). 2000. Utilizing paper mill by-products as forest soil amendments: forest responses, recommendations, and industry case studies. Technical Bulletin No. 798. Research Triangle Park, NC: National Council for Air and Stream Improvement. 31 p.

National Council for Air and Stream Improvement (NCASI). 2003a. Planning guide and state regulation summary for land application of mill by-product solids. Technical Bulletin No. 863. Research Triangle Park, NC: National Council for Air and Stream Improvement. 22 p.

National Council for Air and Stream Improvement (NCASI). 2003b. Land application of forest industry mill by-product solids. Research Brief No. 9. Research Triangle Park, NC: National Council for Air and Stream Improvement. 8 p.

Pritchett, W.L. 1979. Properties and management of forest soils. New York, NY: John Wiley & Sons. 500 p.

Samuelson, L.J. 1998. Influence of intensive culture on leaf net photosynthesis and growth of sweetgum and loblolly pine seedlings. Forest Science. 44: 308-316.

Samuelson, L.J. 2000. Effects of nitrogen on leaf physiology and growth of different families of loblolly and slash pine. New Forests. 19: 98-107.

Vose, J.M.; Allen, H.L. 1988. Leaf area, stemwood growth, and nutrition relationships in loblolly pine. Forest Science. 34: 547-563.

Walters, M.B.; Reich, P.B. 1989. Response of *Ulmus americana* seedlings to varying nitrogen and water status. I. Photosynthesis and growth. Tree Physiology. 5: 159-172.