EFFECT OF BIOSOLIDS ON A LOBLOLLY PINE PLANTATION FOREST IN THE VIRGINIA PIEDMONT

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Abstract—Forests in the piedmont of VA may be a good alternative location for land application of biosolids. The objectives of this study were to quantify nutrient availability and tree growth in a loblolly pine (*Pinus taeda* L.) plantation following the application of different biosolids types, at different rates, and at two different times. The study was installed in September 2005, in a thinned loblolly pine plantation, located in Amelia County in the piedmont of VA. The study was established as a randomized complete block design with nine treatments. The treatments are three different biosolids types (lime stabilized, anaerobic digested, and pelletized), conventional fertilizer (Urea + diammonium phosphate), and seasonal applications (fall or winter). Biosolids increased soil nitrogen (N) availability and tree growth one growing season after application compared to the control treatment. Results for this study indicate that biosolids may be a good alternative to fertilizers to increase forest growth while providing additional sites for the land application of biosolids.

INTRODUCTION

Biosolids are solid or liquid materials produced during the treatment of sewage that has been sufficiently processed to allow land application of these materials (Evanylo 1999a). Approximately 5.6 million dry tons of sewage sludge are disposed of annually in the United States with approximately 60 percent used for land application (NRC 2002).

Land applications of biosolids are regulated by the US Environmental Protection Agency (EPA 2000). The EPA established regulations for the land application of biosolids, based on concentration limits and loading rates for specific chemicals. The EPA regulations are also designed to control and reduce pathogens or disease vectors.

Decreasing availability of agricultural land suitable for biosolids application in eastern VA due to urban expansion in the Washington-Richmond-Norfolk corridor may limit ongoing land application programs. Forestland in the Piedmont and Upper Coastal Plain of VA provides an alterative location for the land application of biosolids. In VA, approximately 50 percent (75 000 dry tons) of the biosolids produced annually by water treatment plants in the state are land applied (UVA 1997). In VA, the acreage permitted for biosolids land application represented approximately 2.5 percent of the 8 million acres in agricultural production in 1997 (UVA 1997).

Managed pine forests tend to grow on nutrient deficient soils and may be an effective nutrient sink. Growth of loblolly pine increases on most soils following fertilization (Fox and others 2007). In the South, the average growth response following fertilization with 200 pounds per acre of N and 25 pounds per acre of phosphorus (P) averaged around 55 cubic feet per acre per year. Similar to agricultural systems, biosolids supply plant essential nutrients that are deficient in most forest ecosystems, particularly N and P. Land application of biosolids can improve site productivity by increasing soil organic matter content. Because of the different organic forms found in biosolids, they function as slow-release fertilizers, releasing plant essential nutrients over time to the trees and crops (Evanylo 1999b). Published research shows that land application of treated municipal and industrial wastewater on forestland has been utilized successfully as source of nutrients at various locations in the United States for over 30 years (Cole and others 1986). A significant growth response frequently occurs in forests following the application of biosolids (Chapman-King and others 1986), but the growth response following biosolids applications to loblolly pine forests has been inconsistent. For example, McKee and others (1986) showed that liquid, not solid, biosolid applications increased tree growth in loblolly pine plantations. However, in young plantations, the increased competition from weeds whose growth was stimulated by the sludge application detrimentally affected the growth of the pine trees.

To ensure the sustainable application of biosolids to forested lands, we need to consider: (i) the ability of the soil to assimilate and cycle N; (ii) the cumulative effects of nutrients on the soil; and (iii) the change in bioavailability of nutrient with time. When properly managed, application of biosolids can increase tree growth due to increased mineral nutrient availability (Henry and others 1993, Kimberley and others 2002). Most of N in biosolids is organically bound N. The organic N needs to be mineralized before it becomes available for roots uptake. N mineralization of biosolids varies by sources (Kelty and others 2004), rates (Harrison and others 2002) and locations (Wang 2004). To avoid residual N, it is important to match the ability of the ecosystem to assimilate N mineralization rates. It has been reported that high application rates of biosolids could result in NO_3^- leaching from the site (Burton and others 1990). This study is a part of a larger project focusing on the effect of biosolids on nutrient cycling and tree growth. The objective of this study is to: (1) document the growth response of loblolly pine following the application of biosolids; (2) compare the growth response of loblolly pine to different types of commonly produced biosolids and conventional inorganic fertilizers; and (3) compare impact of biosolids application on N availability.

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MATERIALS AND METHODS

Study Area

The study was established in the summer of 2005 and it was conducted in Amelia County northeast of Blackstone, VA. The site supports a loblolly pine plantation that is 18-years old. The stand was thinned in 2004-2005 using a combination of fifth-row removal and low thinning between the removal rows. The soil at the site is predominantly from the Appling series (Fine, kaolinitic, thermic Typic Kanhapludults). The Appling series consists of very deep, well drained, moderately permeable soils on ridges and side slopes of the Piedmont uplands. These soils are deep to saprolite and very deep to bedrock. They formed in residuum weathered from felsic igneous and metamorphic rocks of the Piedmont uplands. Slopes at this site range from 2 to 15 percent.

Experimental Design

The experimental design was a randomized complete block design with four plots and nine treatments. Thirty-six plots of 0.25-acre (200 by 50 feet) were established in July 2005. The buffer area between each plot is approximately 100 feet. Each treatment area was approximately 1.03 acres.

Biosolid Application

Biosolids were applied in November 2005 and March 2006 using a side discharge spreader. The biosolids were not tilled into the soil. Collection trays were installed in each plot to accurately determine the amount of biosolids applied. Three different types of biosolids were used for this study from different locations (table 1). The anaerobically digested material was obtained from the Alexandria, VA and Back River, MD facilities. The lime stabilized biosolids were obtained from the Blue Plains facility (Washington, DC). The pelletized biosolids were obtained from the Baltimore, MD facility. The conventional fertilizer was based on common recommendations to loblolly pine plantations using urea + diammonium phosphate. Biosolids were applied at different target N loading rates, base on the amount of plant available N (PAN) estimated using established recommendations for VA (Evanylo 1999b). Treatment descriptions and biosolid characterization are listed in Table 1.

N Availability

In situ ion exchange membrane-N (IEM-N) was measured in all plots according to Cooperband and Logan (1994) and Huang and others (1996) procedures. Cation and anion exchange membrane sheets (Ionics Inc., Watertown, MA), were first cut into 13-square inch sheets. Cation and anion membrane squares were kept separate, washed with de-ionized water, and soaked inside plastic carboys containing 1 M NaCl solution every time they were used. Two sets of membranes were installed at random in the soil of each plot. After a 30-day incubation period individual membranes were then removed and stored at 4 °C until extraction with 1 M KCl. All extracts were analyzed colorometrically for nitrate (US EPA Method 353.2) and ammonium (US EPA Method 350.1) using a TRAACS 2000 Auto Analyzer (SEAL Analytical, Mequon, WI).

Foliage Weight Sampling

Foliage was sampled in each plot on February 1-7, 2007 following the procedure established by Colbert and Allen (1996). In each plot, five dominant or co-dominant trees were selected and marked. Then 20 fascicles from the 5 trees in each plot were composited to create a plot foliage sample of 100 fascicles. The foliage samples were dried in a forced air drying oven at 70 °C for 7 days. The oven-dried needle samples were then weighed and ground in a Wiley® mini-mill to pass through a 1 mm screen.

RESULTS AND DISCUSSION

Nitrogen availability was measured using IEM-N which is the sum of HN_4^+ and NO_3^- extracted from the membranes located at the top mineral soil and the forest floor. The total amount of N extracted was divided by the amount of days that they were buried in the field. Fall fertilization with lime stabilized and anaerobically digested biosolids increased total IEM-N from November 2005 to September 2006 in relation to the control treatment. The largest concentration of 36 mg-N/m^2/day was released by the anaerobically digested material in February. Total IEM-N concentrations for lime stabilized biosolids were elevated in May and July (fig. 1).

Spring biosolid application at different rates of anaerobically digested, lime stabilized, pelletized biosolid, and conventional fertilizer also significantly increased total IEM-N relative to the control treatment. Figure 2 shows the treatment increases in total IEM-N compared to the control treatments. There are no differences in total IEM-N among the 200 pounds per acre treatments, but N availability tended to last longer in biosolid applications than the conventional fertilization.

The main form of N in biosolids is organically bound N. This means that mineralization will play a key role in N availability (Hallett and others 1999). Given the large addition of organic N in both types of biosolids, we could expect that the N availability in the biosolids treated plots would remain higher than control plots for a longer period of time due to mineralization of organically bound N. Throughout the duration of this study biosolids applications increased soil IEM-N compared to control plots especially in the high rates biosolid treatments (fig. 2).

Trees respond to N availability by allocating more N to the foliage N. Increases in foliar N leads to increase foliar biomass, which then increase tree stem growth (Binkley and Reid 1984). Needles dry weight increased with biosolids applications, at both application times (fig. 3). The increases were not significant and not consistent with the biosolids loading rates. We may expect future significant responses since biosolids and fertilizer applications have shown to increase the tree foliage mass (Magesan and Wang 2002). Pelletized biosolids tended to have no effect on foliage weight; this could be explained due to the slower N release from the pellets.

Table 1—Treatment application rates and selected characteristics of the different biosolids

Treatments	Dry Weight (tons per acre)	Carbon (tons per acre) (pounds per acre)	Total N (tons per acre)	Effective PAN (pounds per acre)	pH
Fall Application					
Lime Stabilized 800	42.3	14.8	1.5	880	12.4
Anaer. Digested 800	31.5	9.8	1.57	935	8.2
Spring Application					
Lime Stabilized 200	10.3	3.6	3.8	220	12.2
Pellets 200	1.08	-	-	230	-
Urea + DAP 200	-	-	-	209	-
Anaer. Digested 200	7.7	2.4	0.4	223	8.5
Anaer. Digested 800	33.5	10.4	1.7	943	8.5
Anaer. Digested 1600	62.6	19.4	3.1	1820	8.5

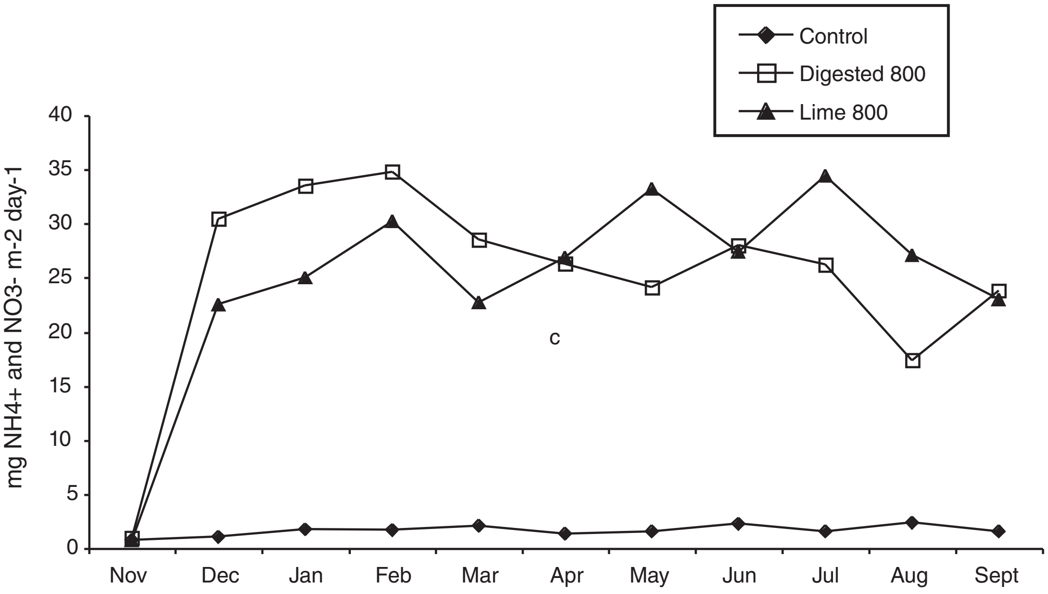

Figure 1—Total ion exchange membrane-NH4+ and NO3- from the forest floor and the upper 6 inches of mineral soil in a loblolly pine plantation in the Virginia Piedmont. Treatments are anaerobically digested and lime stabilized biosolids applied during November 2005 at a rate of 800 pounds per acre of plant available nitrogen (PAN), and reported in units of mg-N/m^2 of ion exchange membrane surface.

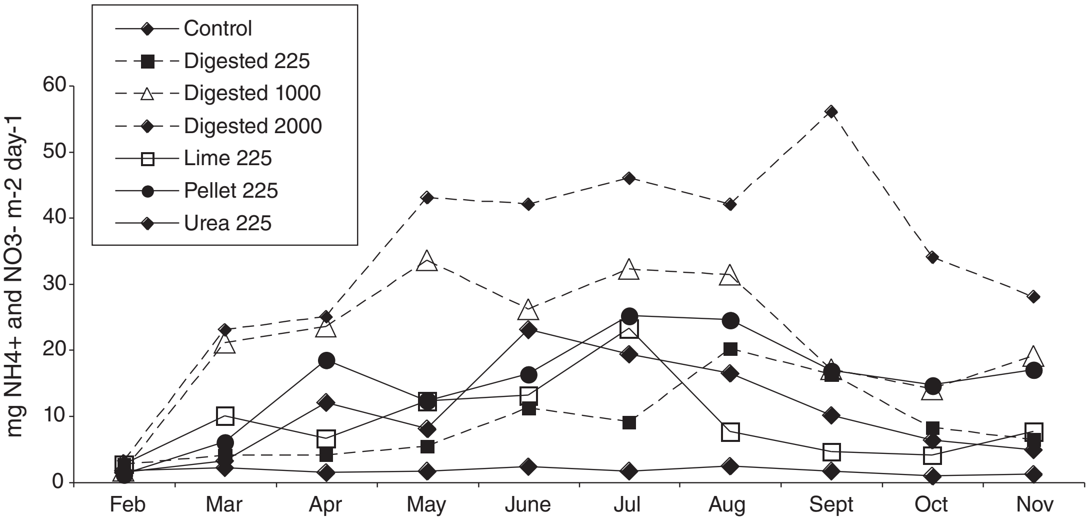

Figure 2—Total ion exchange membrane-NH4+ and NO3- from the forest floor and the upper 6 inches of mineral soil in a loblolly pine plantation in the Virginia Piedmont. Treatments are three rates of Anaerobically Digested biosolid (200, 800, and 1600 PAN), Lime Stabilized (200 PAN), pelletized biosolids (200 PAN), and conventional 200 pounds per acre of urea and DAP applied during March 2006, and reported in units of mg-N/m^2 of ion exchange membrane surface.

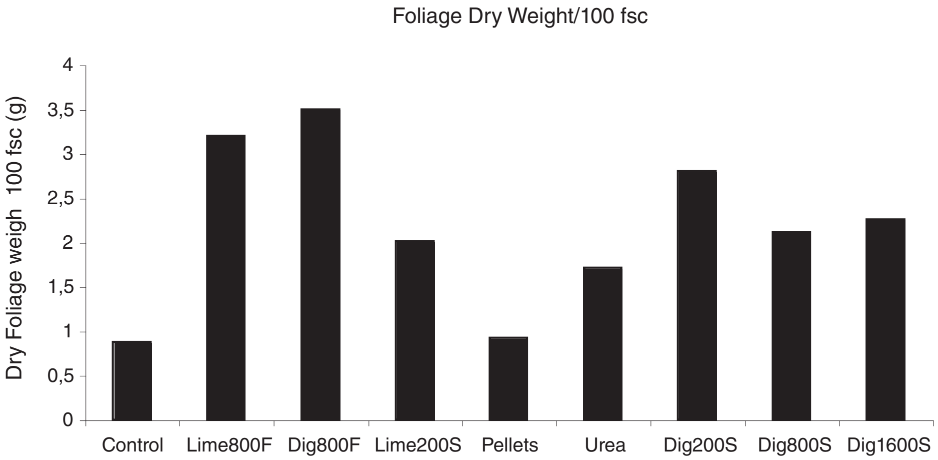

Figure 3—Total foliage dry mass of 100 needles sampled from a loblolly pine plantation in the Virginia Piedmont following treatment applications during November 2005 and March 2006. The first treatment applications were at one rate of anaerobically digested and lime stabilized biosolids (800 pounds per acre of PAN). The second treatment applications were at three different rates of anaerobically digested biosolid (200, 800, and 1600 pounds per acre PAN) and one application rate (200 pounds per acre PAN) of lime stabilized, pelletized biosolids, and a conventional urea + DAP treatment. Results are reported in mg/100 fascicles.

CONCLUSION

Preliminary results from this study indicate that biosolids additions increased soil nitrogen availability. Soil nitrogen availability following biosolids applications were greater than in the control plots. This occurred following both fall and spring treatment applications. Soil nutrient availability following biosolids was similar to that following application of inorganic fertilizer. Foliage mass increased in response to biosolids and fertilizer applications indicating there will likely be a positive effect on tree growth. Because the application of biosolids increased N availability in the soil, it also has the potential to increase N leaching. Several studies indicate that high application rates of biosolids increase the potential for nutrient leaching (Wells and others 1986, Ferrier and others 1996, and Jordan and others 1997). Additional work is underway to determine the leaching of N from these treatments.

The findings reported here and in other studies show that the characteristics of the biosolids being applied to land are as important as the site characteristics. Organic N forms, moisture content, and other soil chemical and physical properties could affect nutrient cycling and should be considered when applying biosolids.

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LITERATURE CITED

Binkley, D.; Reid, P. 1984. Long-term responses of stem growth and leaf area to thinning and fertilization in a Douglas-fir plantation. Canadian Journal of Forest Research. 14: 656-660.

Burton, A.J.; Hart, J.B.; Urie, D.H. 1990. Nitrification in sludge-amended Michigan forest soils. Journal of Environmental Quality. 19: 609-616.

Chapman-King, R.; Hinkley, T.M.; Grier, C.C. 1986. Growth response of forest trees to wastewater and sludge application. In: Cole, D.W.; Hendry, C.L.; Nutter, W.L. (eds). The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes. University of Washington Press, Seattle.

Colbert, S.R.; Allen, H.L. 1996. Factors contributing to variability in loblolly pine foliar nutrient concentrations. Southern Journal of Applied Forestry. 20: 45-52.

Cole, D.W.; Hendry, C.L.; Nutter, W.L. (eds.). 1986. The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes. University of Washington Press, Seattle: 582 p.

Cooperband, L.R.; Logan, T.J. 1994. Measuring in situ changes in labile soil phosphorus with anion-exchange membranes. Soil Science Society of America Journal. 58: 105-114.

EPA. 2000. Biosolids Technology Fact Sheet. Land Application of Biosolids. EPA 832-F-00-064. US Environmental Protection Agency. Washington, DC.

Evanylo, G.K. 1999a. Agricultural land application of biosolids in Virginia: production and characteristics of biosolids. Crop and Soil Environmental Sciences Publication 452-301. Virginia Cooperative Extension Service, Blacksburg, VA.

Evanylo, G.K. 1999b. Agricultural land application of biosolids in Virginia: managing biosolids for agricultural use. Crop and Soil Environmental Sciences Publication 452-303. Virginia Cooperative Extension Service, Blacksburg, VA.

Ferrier, R.C.; Edwards, A.C.; Dutch, J.; Wolstenholme, R.; Mitchell, D.S. 1996. Sewage sludge as a fertilizer of pole stage forests: short-term hydrochemical fluxes and foliar response. Soil Use and Management. 12: 1-7.

Fox, T.R.; Allen, H.L.; Albaugh, T.J. [and others]. 2007. Tree nutrition and forest fertilization of pine plantations in the southern United States. Southern Journal of Applied Forestry. 31: 5-11.

Harrison, R., Rutnblom, E.; Henry, C. [and others]. 2002. Response of three young Douglas-fir plantations to forest fertilization with low rates of municipal biosolids. Journal of Sustainable Forestry. 14: 21-29.

Hallett, R.A.; Bowden, W.B.; Smith, C.T. 1999. Nitrogen dynamics in forest soils after municipal sludge additions. Water, Air, and Soil Pollution. 112: 259-278.

Henry, C.L.; Cole, D.W.; Hinckley, T.M. [and others].1993. The use of municipal and pulp and paper sludges to increase production in forestry. Journal of Sustainable Forestry. 1: 41-55.

Huang, W.Z.; Schoenau, J. 1996. Microsite assessment of forest soil nitrogen, phosphorus, and potassium supply rates in-field using ion exchange membranes. Communications in Soil Science and Plant Analysis. 27: 2895-2908.

Jordan, M.L.; Nadelhoffer, K.J.; Fry, B. 1997. Nitrogen cycling in forest and grass ecosystems irrigated with 15N-enriched wastewater. Ecological Applications. 7: 864-881.

Kelty, M.; Menalled, F.; Carlton,M.M. 2004. Nitrogen dynamics on red pine growth following application of palletized biosolids in Massachusetts, USA. Canadian Journal Forest Research. 24: 1477-1487.

Magesan, G. N.; Wang, H. 2003. Application of municipal and industrial residuals in New Zealand forests: an overview. Australian Journal of Soil Research. 41: 557-569.

McKee, W.H., Jr.; McLeod, K.W.; Davis, C.E. [and others]. 1986. Growth response of loblolly pine applied to municipal and industrial sewage sludge applied at four ages on Upper Coastal Plain sites. In: Cole, D.W.; Hendry, C.L.; Nutter, W.L. (eds.). 1986. The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes. University of Washington Press, Seattle.

NRC. 2002. Biosolids Applied to Land. Advancing Standards and Practices. National Research Council. The National Academies Press. Washington, DC: 346 p.

UVA. 1997. Land application of biosolids in Virginia. A study prepared for the Virginia Department of Health. UVA Institute for Environmental Negotiations, Charlottesville, VA: 47 p.

Wang, H.; Magesen, G.N.; Kimberley, M. [and others]. 2004. Environmental and nutritional response of *Pinus radiata* plantation to biosolids application. Plant and Soil. 267: 255-262.

Wells, C.G.; Carey, D.; McNeil R.C. 1986. Nitrification and leaching of forest soil in relation to application of sewage sludge treated with sulfuric acid and nitrification inhibitor. In: Cole, D.W.; Hendry, C.L.; Nutter, W.L. (eds.). 1986. The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes. University of Washington Press, Seattle: 582 p.