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# Use of Deep-Row Biosolid Applications to Grow Forest Trees:A Case Study

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**Summary** - Deep-row application of biosolids on reclamation sites is a unique alternative land application method that solves many of the problems associated with surface application techniques. When combined with the growth of nitrogen demanding hybrid poplar trees, it provides a natural recycling system that utilizes nutrients on-site, produces forest products, generates wildlife habitat, and reduces erosion while reclaiming abandoned, biologically dead soils created by sand and gravel surface mining operations.

## Introduction

In the Washington, D.C./Maryland area, environmentally sound, cost-efficient utilization of biosolids has created constant challenges since the passage of the Clean Water Act of 1972. Presently, biosolids are surface-applied on farmland, marketed for compost, and incinerated; however, the most cost-effective methods of biosolids management are either by application to agricultural land or burial in landfills.

Biosolids production for 1995 in Maryland (MDE, 1997) was 857,355 Mg (945,077 wet tons) of which 672,129 (740,899 wet tons) were utilized in-state as follows: agricultural land (59 percent), landfill disposal (5 percent), distributed and marketed (21 percent), incinerated (10 percent), and marginal land applications (5 percent). The data fails to acknowledge the fate of the remaining 190,653 Mg (210,160 wet tons) (22 percent) of the total which was hauled out of state, most likely a portion going to large landfills. Also, the District of Columbia produces an average of 362,872 Mg (400,000 wet tons) per year, a large percentage of which is currently disposed of out-of-Maryland. More current figures to show the fate of biosolids are not available; however, the percentage sent to landfills versus other land application methods is known to increase with excess landfill capacity in a region and associated lower tipping fees (ENR, 1997).

Difficulty in siting new landfills and possible future restrictions on out of state hauling may result in restriction and/or increased cost of landfill disposal of biosolids. Current agricultural land application of municipal biosolids can boost soil productivity for both field crops and improves soil textural characteristics. However, regular broadcast applications once every one to three years necessary to provide crop nutrient requirements can cause logistical, safety, and economic problems due to transportation cost, poor weather, frozen soils, availability of labor, and other problems. Resentment by rural landowners and offensive odors in developing areas has resulted in many local application restrictions. There are also developing concerns over phosphorus pollution in receiving waters from repeated applications. The developing drawbacks of landfill and agricultural land application point to the need for alternative disposal technologies (Sikora and Calacicco, 1979(a), 1980).

The land application of biosolids on native forests, reclamation sites, and plantations through regular broadcast applications has been used in other parts of the country, with significant growth responses documented (Cole et al., 1986; Heilman et al., 1995; Sopper, 1993; Aschmann, 1988; Purkable, 1988). Burying biosolids in deep-rows covered by a soil overburden, known as deep-row application is a promising disposal technology that was researched in the early 1970's (Sikora and Colacicco, 1980; Taylor et al., 1978). While the production of annual corn crops on treated areas was researched (Sikora et al., 1980), no research is available for producing forest products and/or wildlife habitat. Deep-row biosolid applications for forest product production has the potential to solve many of the problems associated with agricultural land application and other land disposal methods and enhance the multi-state Chesapeake Bay cleanup effort.

In responding to the need to utilize large volumes of biosolids from the Washington, D.C. area and reclaim gravel spoils, ERCO pioneered the deep-row biosolid technique in the early 1980's using hybrid poplar trees planted on treated land. The treatment site was a 49.4 (122-ac.) abandoned gravel spoil in Prince George’s County (Figure 1) owned by the company and within 40 km (25 miles) of many large municipal wastewater treatment plants. The spoil site consisted of a moderately well-drained Beltsville silt loam where the gravel mounds had been removed. What remained was a gravel overburden underlain by a clay layer. The overburden soils were treated to obtain a pH of 6.2. The company received a permit from the Maryland Department of Environment (MDE) for application of biosolids to grow hybrid poplar trees. The data provided in this paper were used for permit reporting procedures, but are used in this paper only to describe the technique, challenges and directions for future research.

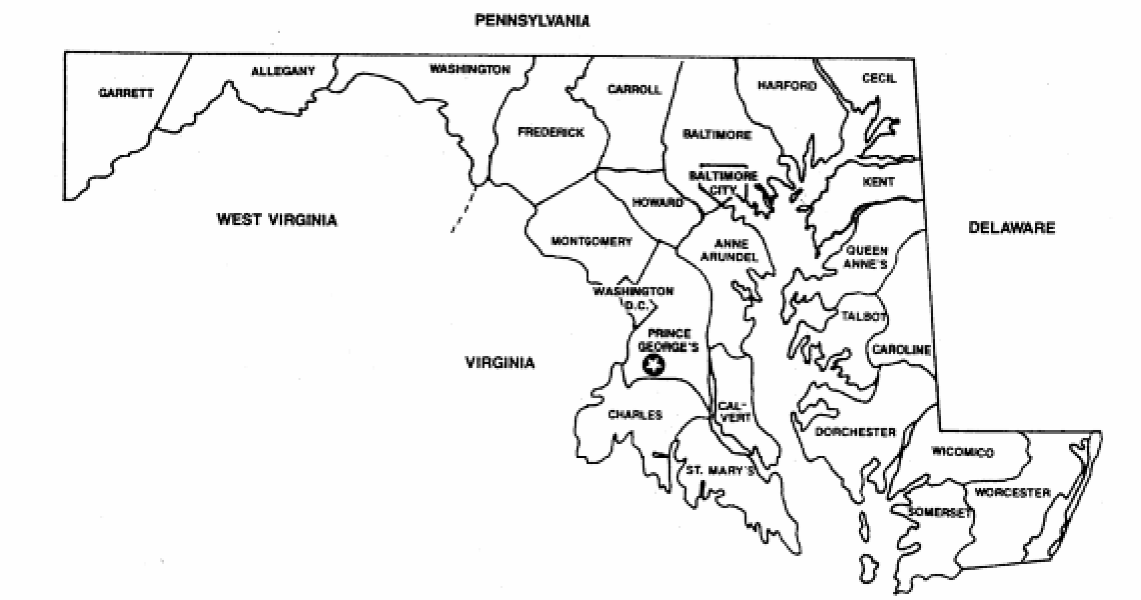

**Fig. 1**-ERCO study site marked with star is located in Prince George's County, MD; within the Washington, D.C. metro area..

**Figure 1** ERCO study site marked with star is located in Prince George’s County, Md; within the Washington, D.C. metro area.

## Related Research

Two studies are of particular interest. Sikora, with USDA-ARS at Beltsville, Md., reported on trench studies in both sandy soils and heavier soils. Sikora’s tests placed biosolids in 610 mm (24 in.) wide trenches 500-1300 mm (20-50 in.) deep on 1270 mm (50 in.) centers. Sikora’s various experiments grew corn and grass in field studies and Taylor et al. (1978) grew corn in 160 day simulated deep-row experiments in a greenhouse setting.

Generalizations. The application rates at the ERCO site are consistent with trenching site applications made from 1974 through 1980 on well drained, silt loam soils of the Manor and Glenelg soil series (Sikora et al., 1982). In those studies, five years after the application, monitoring of ground water detected no increases in N and Cl, although elevated levels were found just beneath the trenches. Ground water pollution has been recorded in a separate ground water study in which trenches were located in a sandy soil, which is the worst case scenario (Sikora et al., 1979(b)). Metal movement through soil is generally considered minimal except in instances when the pH is below 5.5 (Chaney et al., 1977), which is not a problem on most sites due to liming requirements. The general conclusion concerning ground water pollution by biosolids at other deep-row sites is ground water immediately beneath the sites has the potential to experience increases in inorganic N and Cl, which should decrease with time.

Leaching Potential. Monitoring of nitrogen and chlorides in the biosolids and soils below the trenches was conducted in an effort to determine potential for leaching (Sikora et al., 1980). The data from these analyses demonstrated two distinct trends. First, the levels of ammonium, nitrate and chlorides all generally diminished from the first sampling period (665 days) to the last (1,508 days).

The second observation made from these data is an apparent enrichment of both ammonium and chloride with depth on the same sampling date. For example, for almost every sampling event, the dry weight concentration of ammonium is greater in the lower portion of the trenches than in the middle portion. The concentration of ammonium in the middle portion was generally greater than in the top portion.

This distribution did not hold for nitrate. For each sampling date, nitrate nitrogen concentration in the lowermost portion of the trench was less than or about equivalent to the concentrations in the upper two sections of the trench. Given relatively high levels of ammonium, the precursor to nitrate formation in these samples, it would be expected that the nitrate concentration in the samples would show similar trends as ammonium and chloride unless some mechanism for nitrate removal was acting.

Leaching is the first mechanism that comes to mind to explain this anomaly. However, the enrichment of the lowermost portion of the trench with chlorides suggests that leaching was not occurring rapidly enough to account for low nitrate concentrations. Two other explanations are plausible. The first is that conditions in the lower section of the trench were not conductive to nitrate formation, so conversion of ammonium was quite slow (this would account for the accumulation of ammonium in the lowermost portion). A second mechanism may be denitrification. Conditions, which are not favorable for nitrification, are required for denitrification. It is probable that both mechanisms were at work (Pepperman, 1995).

Denitrification. The comparison of chloride and nitrate concentrations in water samples from below the biosolids was utilized to assess the potential for leaching and, in this study, also to determine if denitrification occurred. The ratio of nitrates to chlorides decreased with depth below the trench indicating that there existed some mechanism for reduction in nitrates (since both nitrates and chlorides are expected to move through the soil at generally the same rate). Since there were no plant roots at the depths evaluated and microbial immobilization was discounted, it appeared that denitrification was occurring (Sikora et al., 1979(b)).

Taylor and his fellow researchers (Taylor et al., 1978) indicated that the relatively low oxygen and high methane content of the soil atmosphere adjacent to the biosolids would be an ideal environment for denitrification. It was suggested that, from the levels of nitrate found within the biosolids, after 160 days some nitrification had occurred. They concluded, however, that the extremely low levels of nitrate within the soil surrounding the biosolids indicated that, if such a transformation were occurring, very little nitrate was moving from the biosolids. They further concluded that it was likely that any nitrate which did move from the biosolids would have been subjected to denitrification.

Dewatering and Physical Appearance of Biosolids. The researchers (Sikora et al., 1979(b)) noted some interested characteristics of the biosolids in the trenches. First, the biosolids dewatered from the top down, or, in other words, the top of the trenches were dry, whereas the bottoms of the trenches remained wet. This observation led to the conclusion that mineralization and subsequent transformations began after in the uppermost portion of the biosolids, shortly after entrenchment but that denitrification was taking place concurrently as the leachate from the upper portion of the biosolids moved into the wetter lower portions of the entrenched biosolids. Sikora et. al. (1980) reported on the trenching of digested biosolids. Certain physical observations of the biosolids-filled trenches are meaningful. The first sampling of these trenches occurred almost two years after biosolids placement. At that time the top portion of the trench was densely rooted and "peat-like" and the middle portion was only sparsely rooted, wet in appearance, and ordorous. After four years, the top and middle portions were brown and odorless. The Sikora team concluded that trenched biosolids become "stabilized" with respect to further decomposition after about four years.

Root Distribution. Taylor et al. (1978) attributed the restriction of root penetration to the expected environment within the entrenched biosolids – encapsulating biosolids in trenches created an environment similar to an anaerobic digester. Not only would such an environment be inhospitable to plant roots, would also suggest very low levels of oxygen and thus, not support the obligate aerobes which are required to mineralize the organic matter to ammonium and nitrate (Pepperman, 1995). Taylor et al's hypothesis was supported by Gouin (1994, personal communication) who suggested that mineralization rate of biosolids in deep rows would be slowed due to the low soil temperatures (at depth), relatively high moisture content of the biosolids and lack of oxygen. Thus, the anaerobic conditions and lower temperatures in the deep-rowed biosolids a) maintains N in organic forms that were not easily leached and b) inhibit root growth (Taylor et al., 1978).

## Site Description

The site consists of a plateau with steep banks that fall away to a stream incision. All steep banks are covered with permanent forest cover. The edges of the plateau are bermed and runoff is routed to one of four detention ponds. The stream on the east and north sides of the site are protected by an additional three detention ponds. The plateau has an upper section near the entrance which is on a 0-2% slope. There is an elevation drop of between 1.5 and 3 m (5-10 ft.). The remaining seven sections have an elevation drop of between 1.5 and 3 m (5-10 ft.), followed by a level section (0-2% slope) to the edge of the bermed area.

The surface water flow on the site is significantly reduced now, due to the tree growth. At any one time, only one or two sections (4.05 ha each) are cleared and replanted. Hence, only 8-16% of the site is subject to significant surface runoff generation. Approximately 25% of the site (13 ha) is in permanent cover, either forested steep slope or detention ponds and buffers.

At one time there were as many as eight monitoring wells placed around the perimeter of the site. Well placement was a condition of various permits. Wells encountered water at approximately 75 ft. below the surface of the site. This puts the water at the base of the Calvert formation and the top of the Nanjemoy formation. The clayey silts and fine clayey sands of the Nanjemoy are the sandier of the two formations. The Calvert formation, above the Nanjemoy formation, is less permeable, with estimated vertical conductivities that are two to three orders of magnitude lower than the Nanjemoy formation (Wilson and Fleck, 1990). Hence, water that rose in observation wells to within 15 feet of the ground surface was the result of the confining action of the overlying Calvert formation.

## Methods

Hybrid poplar stem cuttings were directly stuck at 7,400-10,000 cuttings per ha (3-4,000 cuttings/ac.). The purpose of the dense planting was to utilize the nitrogen (N) over a planned 7-year rotation. Periodic mowing marginally controlled competing vegetation. No herbicides were used.

Harvesting of the hybrid poplar on each 4.05 ha (10 ac.) section occurred when the crop was between 6 and 9 years old, depended on foliar analysis and soil tests. While harvest of the trees on one section did not take place for 10 years, diameter growth dropped after 7 years, probably due to overcrowding and reduction in available N through mineralization. According to the MDE permit, the trees could be harvested when foliar N levels dropped below 3.5 percent and total N mineralization reached approximately 70 percent. The trees were harvested and chipped wet and the chips used as a mulch on-site. Only one section was harvested and the chips trucked off-site after harvesting. Following harvest, the sites were disked, leveled, and deep-rowed for reapplication of biosolids. Biosolids used for reapplication were lime-stabilized due to changes in regulations.

The deep-row technique involved placing biosolids, averaging about 20 percent solids, (not lime-stabilized), at a rate of 383.3 Mg/ha (171 dry tons/ac.). A special demonstration plot (section 7) permitted placing biosolids at 659.1 Mg/ha (294 dry tons/ac.). The pH of the biosolids being applied ranged from 7.0-8.0. Approximately 4.05 ha (10 ac.) sections were treated each year starting in 1984 and continuing through 1993 (Figure 2). The deep-rows were dug using a tracked backhoe with a special bucket, which excavated the deep-row and simultaneously backfilled the biosolids placed in previously excavated adjacent deep-rows. The row dimensions were 762 mm (30 in.) deep and 1067 mm (42 in.) wide, spaced on or about 2.44 m (8 ft.) centers. The deep-rows were filled with 457 mm (18 in.) of biosolids for the 383.3 Mg/ha (171 dry tons/ac.) rate and 559 mm (22 in.) for the 659.1 Mg/ha (294 dry tons/ac.) rate. The remaining 200-300 mm was filled with overburden. After each section was filled, the site was leveled using a special low-ground pressure bulldozer, and disked in preparation for planting.

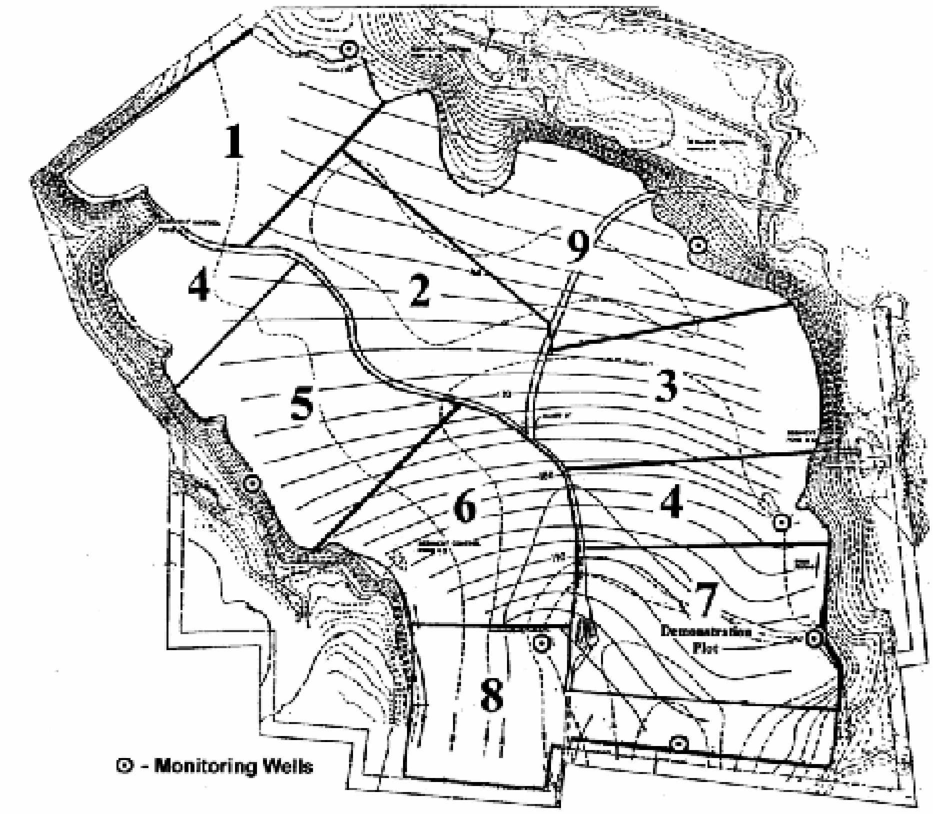

**Figure 2** Plot layout of ERCO site showing nine 4.05 ha sections planted with hybrid poplar, as well as seven monitoring wells that are numbered. Site is located on an abandoned gravel surface mine.

The distance between nutrient source and crop roots was considerably greater in previous experiments (Sikora et al., 1980; Taylor et al., 1978) because a) the trenches were deeper and b) their grass crop had a shallower root system. Additionally, because grass spends more time in a dormant state, their experiment had a shorter annual period of nutrient uptake. The result was a greater potential for nutrient escape to the ground water system. None of the previous trenching studies have used deep-rooted plant material for uptake of N to minimize leaching. The use of fast-growing, high N demanding hybrid poplars at high densities, on the ERCO site, provided deep root penetration around deep-rows.

To assess N uptake by the trees, foliar leave samples were taken every August. Three recently matured leaves were taken from five randomly selected trees in each 4.05 ha (10 ac.) section. All leaves were mixed into one composite sample to provide one foliar N value for each section.

Nitrogen content in deep-rows was assessed every August. Due to the gravel nature of the soil, a narrow backhoe was used in five locations in each section to take samples. A composite sample was made for each location by taking a similar volume of biosolids from the bottom, middle and top of the biosolids deep-row. Composite samples from the five locations were mixed into one sample and N content measured to provide one value for each 10 ac. section. The differences from year to year are assumed to be due to plant uptake of mineralized N and denitrification. The holes dug for the soil sampling enabled yearly monitoring of the decomposition and root growth patterns of the trees around the deep-rows. While quantitative data were not gathered, subjective evaluations were made and photographs were taken.

State regulations required intense monitoring to detect possible leaching of metals, nitrogen, and other nutrients into the water table. Seven monitoring wells ranging from 6-31 m (20-100 ft.) deep were installed under MDE’s direction and sampled biannually for nutrients, pH, metals, and coliform.

## Results and Discussion

The major environmental concern of deep-row biosolids application is potential for contamination of ground water by N and metals leached from biosolids. The permitted application rates of 383.3 Mg/ha (171 dry tons/ac.) and 659.1 Mg/ha (294 dry tons/ac.) were two to four times less than the Sikora experiments and resulted in no degradation of water quality, as measured by monitoring well results. Sampling from the seven monitoring wells, which have been in place since 1984, have not reported any elevated level of the measured factors as of 1996.

For all wells, nitrate water concentrations were most commonly at or less than detection limits. In the most recent sampling and analysis event, the nitrate concentration in all wells at the Tree Farm was determined to be below detection limits. Occasionally, nitrate concentrations were reported at higher levels than detection limits but never did the level reported approach the drinking water standard of 10 mg/l.

No trend of increase in chloride concentration in the well samples was seen after biosolids application. Twice Well #2 (an up-gradient well) exhibited nitrate concentrations above the detection limits: on November 10, 1982 (the day after well was drilled and before any biosolids were applied to the site), the nitrate level as reported at 1.5 mg/l; and on May 24, 1989, the level was reported at 1.9 mg/l.

On this latter sampling date, several samples from the other wells also were reported to contain nitrate concentrations above the detection limits. Well #4 was reported to contain nitrate concentrations at 1.3 mg/l and Well #5A was reported to contain nitrate concentrations of 1.6 mg/l. Wells 2, 4, and 5A are each screened in 3.1 m (10 ft.) intervals and range in depth to the top of the screen from 7.6 m to 9.4 m (25 ft. - 31 ft.). All are in a silty clay sand layer that is surrounded by layers described as "white clay" and "green clay" (Pepperman, 1995). Hence , because the events were singular in time and the wells appeared to intercept isolated layers, it would suggests that lateral inflow was documented.

Well #1, an upgradient well, was reported to contain nitrate concentrations of 1 mg/l. This well was screened at 21.3 m to 24.3 m (70 to 80 ft.) deep, which corresponds to the top of the Nanjemoy formation (Wilson and Fleck, 1990). The increased nitrate levels in the up-gradient well #1 suggest classic lateral inflow occurred, which would be consistent with an aquifer formation (the Nanjemoy) beneath an aquitard (the Calvert).

Total nitrogen content of the biosolids at the time of application averaged 3.32 percent and ranged from 3.16-3.63 percent (Table 1). When the sites were harvested and prepared for reapplication of biosolids at 6 to 9 years after the initial application, total N of the biosolids was 1.21 percent, which suggests that much of the biosolids had mineralized and/or denitrified. Soil nitrogen levels averaged 0.02 percent only 150 mm from the deep-row laterally and 0.04 percent 150 mm below the deep-row. This strongly suggests that nitrate is not migrating out of the trench.

Excavation of deep-row sites three years after hybrid poplar had been planted revealed biosolids in the deep-row had roots surrounding the deep-row area, but not penetrating. The large root mass found around the deep-row appeared to act as a sink, taking up N as it is mineralized, which greatly reduced chances of leaching. The clay subsoil layer likely contributed to the lack of movement through the soil profile. At the time of reapplication the biosolids appearance was similar to dried peat, with no moisture in evidence, which agrees with the findings of Sikora et al. (1980).

The uptake of N by the hybrid poplar was further demonstrated by foliar nitrogen levels. Hybrid poplar is capable of utilizing nitrogen at rates similar to corn, but unlike corn, this nitrogen is extracted by a perennial deep root system. When the trees were actively growing, foliar N levels were in excess of 3.5 percent. After 6-9 years, foliar N levels dropped to below 3.5 percent, indicating that plants were utilizing N faster than the mineralization rate of the biosolids.

| **Sections** | **Material Sampled** | **Depth** | **Age Span (years)** | **Total Nitrogen (%)** | **Organic Nitrogen (%)** |
|---|---|---|---|---|---|
| **1**<br>through<br>**9** | Initial Biosolid Analysis | * | 0 | 3.32<br>(3.16-3.63) | 3.10<br>(2.89-3.46) |
| | Biosolid Residue | 20"–34" | 6 - 9 | 1.21<br>(0.23-1.78) | 1.10<br>(0.18-1.67) |
| | Soil surrounding deep-row | 18"–40" | 6 – 9 | 0.02<br>(0.01-0.04) | 0.02<br>(0.007-0.041) |
| | Soil – 14"-18" below deep-row | 58" – 60" | 6 – 9 | 0.04<br>(0.01-0.09) | 0.03<br>(0.006-0.086) |

**Table 1** Summary of biosolid and soil analysis for all nine 10-acre sections at the ERCO site. Average and range of values for each measure are provided.

Pepperman (1995) performed a detailed nitrogen balance for the ERCO site. Some highlights of the computations are : denitrification was 40% of biosolids N, volitilization was negligible, mineralization was 6% of organic N, and the total requirement to meet immobilization, tree, and understory requirements was 605 kg/ha (540 lb/ac). The requisite application rate to meet these needs was 506.6 Mg biosolids /ha (226.7 tons /ac).

The combination of high density planting (7,400-12,350/ha) and lack of vegetation management resulted in small tree diameters (less than 12 cm DBH) that were not commercially marketable. Harvesting on all sections, except section 4 was done using hand labor and a wood chipper, with the chips left on the ground. Harvested chips from section 4 were sold to a local sanitary commission for composting with average yields of 45 Mg/ha (20 wet tons/ac.) on section 4. This yield was well below the 67-204 Mg/ha (30-91 wet tons/ac.) reported in managed plantations of 8-10 years (Heilman et. al, 1995; Gates and Byant, 1990). Lucrative pulp markets exist for hybrid poplar in the Northwest and other areas. In the Mid-Atlantic region most pulp mills use a continuous digester with heavier species such as oak and hickory. When poplar is mixed with these species, it cooks down and produces little product. Therefore, most pulp mills in the Mid-Atlantic are not interested in purchasing hybrid poplar chips (Gates and Byant, 1990).

While rapid root development around the deep-row is desired, lower planting densities of 1700-2500 trees/ha (700-1000 trees/ac.) are being tested to produce larger diameter trees that may be suitable for commercial sawtimber markets. The additional time it would take for roots to colonize the site may not be significant given the stable N form of the biosolids in the anaerobic environment. Other species with higher commercial potential such as sycamore, sweetgum, and paulownia are also being tested.

## Conclusions

Monitoring well data indicate that nitrate and chloride are not entering the water bearing formations that are 7 to 21 m below the site. Over time, the total nitrogen content of the entrenched biosolids dropped by more than half to 1.21%. Soil samples surrounding the trench had nitrogen levels of 0.02-0.04%, which indicates that nitrate is not invading the surrounding soil. Literature suggests that mineralization is depressed by both temperature and anoxic conditions. These same conditions favor denitrification, so nitrate is generated only slowly and it is likely that any nitrate that is not quickly captured by the roots of the trees is denitrified. Foliar leaf values suggest that plant-available nitrogen is decreased to less than the crop needs by the sixth year.

The gravel spoil in this study was previously incapable of supporting any significant vegetation or wildlife habitat, and was subject to massive erosion. While wildlife abundance and habitat was not objectively measured, it is clear that the site has been reclaimed and transformed into a stable forested habitat with abundant deer, beaver, quail, doves, and other wildlife. Gravel spoils similar to the ERCO site (complete with clayey subsurface geology) are found in a reasonably wide North-South band along most of the Mid-Atlantic region, close to large metropolitan center, and provide excellent candidates for reclamation using deep-row biosolid applications.

The technique allows the utilization of large volumes of biosolids per unit area to produce forest products at a site near to treatment plants in urban areas, which greatly reduces the land requirement, compared to conventional land application. Because there is no crop at the time of application, this technique can be used at a steady rate over the entire year, which is a second advantage over conventional land application to agricultural lands. Development of this technique could contribute to a multi-state effort to reduce nutrient loading of the Chesapeake Bay. However, the comparative cost of deep-row applications is presently higher than tipping fees at out-of-state landfills. It will require political cooperation of states involved in the Chesapeake Bay watershed to discourage landfill dumping and encourage alternative methods such as deep-row applications.

The deep-row biosolid application technique has proven environmentally friendly in the reclamation of the gravel spoil at the ERCO site after stringent long-term regulatory oversight. In 1990, the National Association of Counties recognized Prince George’s County, Maryland with an achievement award for the Tree Farm Biosolids Utilization Project at the ERCO site. More research is needed on intact soils, particularly Coastal

Plains and Piedmont soils, and reclamation sites with different nutrient demanding species at varied rates to determine implications for water quality, forest and wildlife management, and economic realities. Regulatory reform should also be considered to reduce stringent regulatory requirements for proven practices and to encourage private entrepreneurship.

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