Deep Rows Incorporation of Biosolids to Grow Hybrid Poplar Trees on Sand and Gravel Mine Spoils in Southern Maryland

Jonathan S. Kays[1], Gary K. Felton[2*], Carrie U. Buswell[2] and Eric J. Flamino[3]

[1]University of Maryland Cooperative Extension, Keedysville, Maryland 21756-1104
[2]University of Maryland, College Park, Maryland 20742-2315
[3]Erco, Inc., Glen Burnie, Maryland 21061
*To whom correspondence should be addressed. E-mail: gfelton@umd.edu

ABSTRACT

Using deep row biosolids application to grow hybrid poplar trees (Populus spp.) on sand and gravel mine spoils is a unique and innovative beneficial-use technique that solves many of the conventional problems. The technique was developed on 50 ha (125 ac) site in the Washington, D.C. metro area by a private company (ERCO, Inc.). Research has been carried out since 2001 to develop a better understanding of water quality impacts, operational methods, clonal selection, hybrid poplar growth and nutrition, and the factors affecting economics and profitability. There are no indications of nitrate leaching and the tree plantation systems are performing well. Given the large acreage of mine spoils in the metro area, deep row application has the potential to utilize significant amounts of biosolids produced in the region.

KEYWORDS: Biosolids, deep row application, incorporation, hybrid poplar trees, water quality

INTRODUCTION

The Washington, D.C. and Baltimore, MD metro area produces approximately 1.1 million dry Mg (1.2 million wet tons) of biosolids (MDA 2002; DC-WASA 2002). Utilization of biosolids has relied heavily on agricultural land application outside of Maryland (56%), as well as some instate application (9%). The remainder is utilized as follows: hauled out of Maryland (14%); storage (9%); composed (7%); incinerated (3%); and landfill (2%). Stricter nutrient management laws, the loss of agricultural land to development, odor problems, and political concerns of county and state governments requires that sewage treatment authorities find new and innovative methods to beneficially utilize biosolids. Finding methods that can be utilized in Maryland is becoming increasingly important as concerns of surrounding states become prominent.

Deep row incorporation of biosolids on sand and gravel reclamation sites is a unique alternative land application method that solves many of the problems associated with surface application techniques. We have placed biosolids at application rates of 385 to 660 Mg/ha (170 to 295 dry tons/ac) into deep rows that were approximately 76 cm (30 in) deep and 106 cm (42 in) wide and spaced approximately 2.4 m (8 ft) on center. Application rates represent the weight of biosolids placed in the trenches divided by the total land area (area of trenches plus area between trenches). The trenches were filled with 46 cm (18 in) of biosolids and the remaining 20-30 cm (8-12 in) of deep rows was filled with overburden, which eliminated odor problems and maintained biosolids in a fairly stable, anaerobic environment.

Developed by ERCO, Inc. (Felton et al., 2005), deep row incorporation with trees has been commercially used since 1983 on only one site in the world with no adverse water quality impacts. Approximately 4 ha (10 ac) were treated each year starting in 1984. The site was then planted with fast-growing, nutrient-demanding hybrid poplar trees (*P. deltoides X P. nigra*), the roots of which provided a natural recycling system that can utilize up to 340-500 kg N/ha (300-450 lbs N/ ac) per year over a six-year or longer period (National Agroforestry Center, 2000; Murray, 2003). Harvesting was performed at about 7 years on most sections.

Water Practice™ • V.1 • N.1 • A.2 © 2007 Water Environment Federation • 10.2175/193317707X194927

The success of this technique appears to be dependant upon: 1) the presence of a clay layer that impedes vertical leaching while tree roots utilize the nutrients; and/or 2) maintenance of biosolids in an anaerobic condition, thus minimizing nitrate generation and promoting denitrification.

The three objectives of the project reported here were: 1) determine the effect of tree density and biosolid application rate on water quality around deep rows on a gravel mine spoil; 2) determine the effect of tree density and biosolid application rate on the above ground growth, production, and survival of hybrid poplars with deep row biosolid applications; 3) determine the economic feasibility of deep row application with forest trees at different planting densities and application rates, as well as the value of its environmental benefits.

METHODOLOGY

Site Description

The 49.4 ha (122 ac) production site was a sand and gravel mine spoil in southern Maryland. It is within 40 km (25 mi) of many large municipal wastewater treatment plants. The site consists of a plateau with steep banks that fall away to a stream incision (Fig. 1). Each of the nine production sections is approximately 4 ha (10 ac) in area, which is the area that receives biosolids in a year's time with the standard application rate (383 Mg/ha or 171 dry tons/ac). All steep banks are covered with permanent forest cover. The plateau has an upper area (two sections) near the entrance on a 0-2% slope. 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 area. The research site is an existing reclamation site that has utilized deep row biosolid application with forest trees for between 13 and 23 years, depending on when application to the individual treatment section first occurred. Prior to any biosolid application, the reclamation site was representative of thousands of acres of sand and gravel mines in the Metro Washington, D.C. area. The entire site has received one biosolids application using deep row application. The edges of the plateau are bermed and runoff is routed to one of four detention ponds. The streams on the east and north sides of the site are protected by an additional three detention ponds. Additionally, the surface water flow on the site is significantly reduced due to the introduction of tree crops.

Geology

There are conventional soils on the steep side slopes that were not disturbed by sand and gravel mining, but there are no soils, as we normally think of them, on the plateau surface. In 1983, the spoil consisted of a clay layer with occasional remnants of sand and gravel and some filled-in gullies. The clay layer was five to 21 m (16-70 ft) or more thick. Description of geology at the ERCO site was derived from Wilson and Fleck (1990) and, to a lesser extent, Tompkins (1983). Below the surface is the lower Miocene Calvert Formation. The Calvert is a light to medium, olive gray to olive green, micaceous, clayey silt. The thickness of the Calvert in the Waldorf area is approximately 27-30 m (90-100 ft.). The formation represents deposition in a marine shelf environment.

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 23 m (75 ft.) below the surface of the site. This puts the water at the base of the Calvert formation.

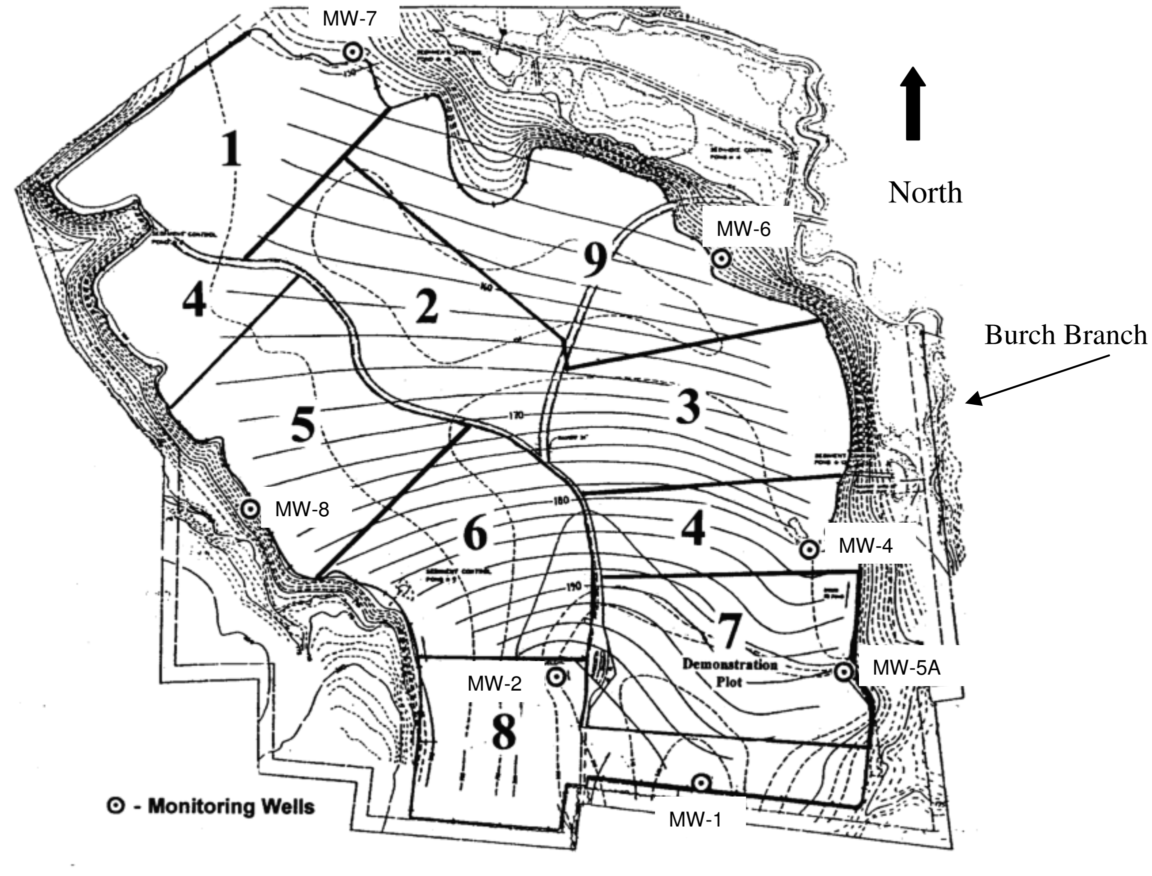

Figure 1. **ERCO study site topography with treatment sections (1-9), monitoring wells, and estimated ground water potential lines.**

Initial Production Treatments

The deep-row technique, developed in 1983, involved the application of biosolids, averaging about 20% solids, that were lightly amended with lime to control odor (but not lime-stabilized), at a rate of 380 Mg/ha (170 dry tons/ac.). The pH of the biosolids ranged from 7.0-8.0. Subsequently, approximately in 1993, the Blue Plains Waste Water Treatment Plant operated by DC Water and Sewer Authority began delivering aerobically digested lime-stabilized biosolids with a pH of 11-12. In 1988, the permit allowed for addition of a special demonstration plot with biosolids applied at 660 Mg/ha (295 dry tons/ac). Approximately 4 ha (10 ac) sections were treated each year beginning in 1984. Hence, only 8-16% of the site is exposed to rainfall and subject to runoff in any given year. The deep row dimensions were approximately 760 mm (30 in) deep and 1100 mm (42 in) wide, spaced on or about 2.4 m (8 ft) centers. The deep-rows were filled with 460 mm (18 in) of biosolids for the 380 Mg/ha (170 dry tons/ac) rate and 560 mm (22 in) for the 660 Mg/ha (295 dry tons/ac) rate. The remaining 200-300 mm was filled with overburden. After each section was filled, the site was leveled using a low-ground pressure bulldozer and disked, in preparation for planting. The application rate used at the tree farm is similar to experimental trenching site applications made from 1974 through 1980 on well-drained, silt loam soils of the Manor (Typic Dystrochrept) and Glenelg (Typic Hapludalf) soil series (Sikora, et al., 1982).

Experimental Treatments

The 1.3 ha (3.1 ac) study site is located on the existing ERCO property and has previously received one biosolids application. A replicated treatment design was used to determine the effect of three tree densities 0, 717, and 1,063 trees/ha (0, 290, and 430 trees/ac) and three deep row biosolid application rates on water quality and tree production. Unlike past application rates, which were based solely on biosolids weight, the experimental rates will be expressed in kilograms of total nitrogen per hectare (11900, 23800, 35800 kg N/ha).

The width of the deep rows was maintained at 1.1 m (42 in) and the depth was adjusted (Table 1) to accommodate the required amount of biosolids and allow for 200-300 mm of cover on top of the biosolids. The maximum depth of the deep rows is limited by the depth to which the poplar tree roots can reliably grow. If deep row depth exceeds 2.1-2.4 m (7-8 ft), which is quite possibly too deep to be sure that roots can reach the material, some of the same nutrient loss problems discovered by Sikora et al. (1982) could occur.

Table 1. Treatment rates, depth of biosolids in the deep row, total deep row depth, and approximate biosolids application rate.

Application Rate (kg N/ha) *[lbs N/ac]*	**Depth of Biosolids (mm)** *[in.]*	Total Depth of Deep Row (mm) *[in.]*	Biosolids Rate (Mg/ha) *[dry tons/ac]*
11,900 *[4,000]*	320 *[12.5]*	610 *[24]*	385 *[172]*
23,800 *[8,000]*	640 *[25]*	940 *[37]*	770 *[345]*
35,800 *[12,000]*	950 *[37.5]*	1240 *[49]*	1155 *[517]*

In spring 2002, plots were established at the ERCO site. The site was partitioned into three blocks based on a north-south gradient. Each block contained each biosolids application rate/tree density combination. There were 30 treatments: 3 densities (0,717, 1063 trees/ha), 3 application rates (11900, 23800, 35800 kg N/ha), 3 replicates, and 3 control treatments (no biosolids, no trees). The result was an incomplete split block experimental design. Figure 2 provides a layout of the relative locations of the three blocks and the treatments within each block as they were installed at ERCO. The total area depicted is 1.3 ha (3.1 ac).

Within each treatment, the outer two rows of trees around the perimeter were used as buffers to isolate treatments and avoid edge effects at plot boundaries. The sample collection areas within each treatment consisted of the innermost 16 trees, to reduce possible edge effects. The central area of four rows by four columns of trees contained all soil water sample collection equipment. The three control treatments (no trees, no biosolids) were 10.7 m X 10.7 m with instrumentation in the central portion of the plots.

Biosolids application rates were randomly assigned within each block. Tree plantings were not randomized due to logistical considerations associated with the equipment and labor used.

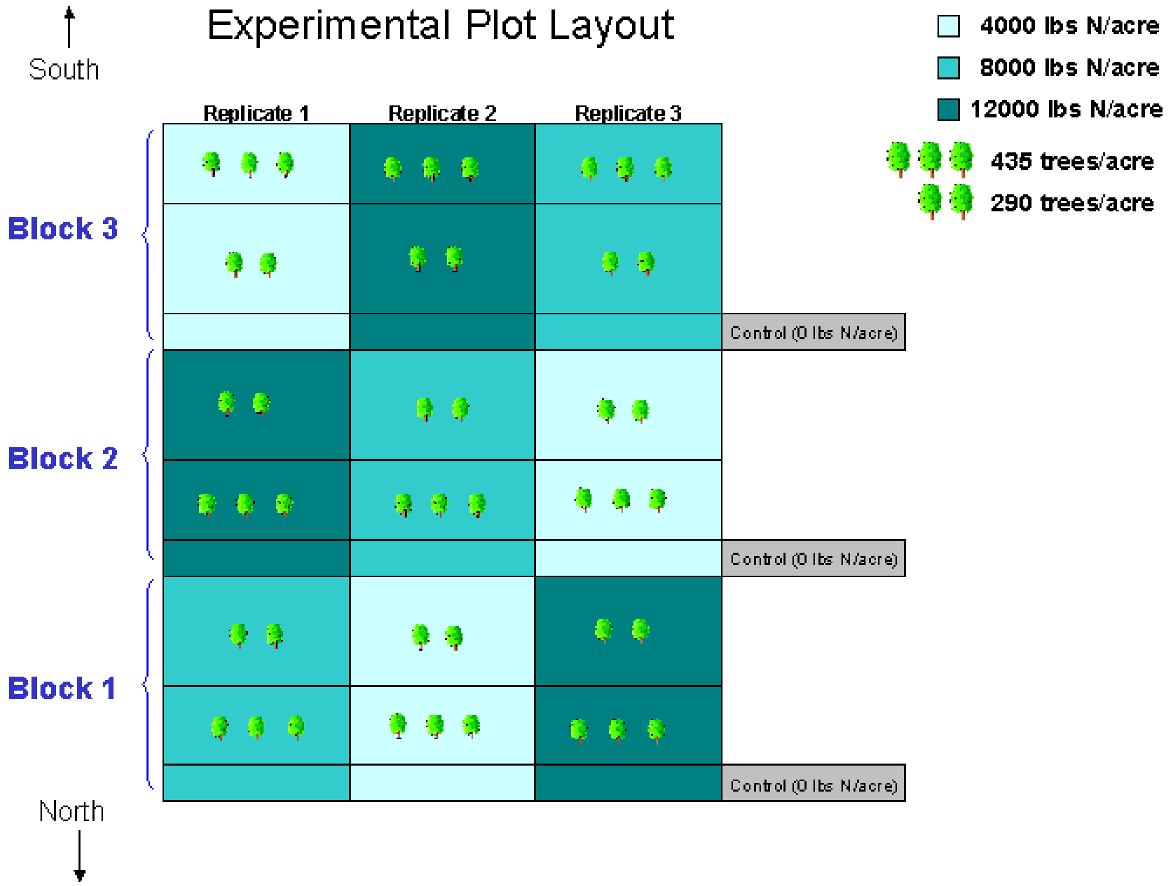

Figure 2. Schematic layout of treatments.

Water Quality Instrumentation And Measurement

Each treatment (application rate x tree density combination) within each block contained several types of sampling instrumentation to evaluate hydrology and/or nutrient transport: 1) in each of the 30 treatments, one zero-tension pan lysimeter positioned 305 mm (12 in) directly below the bottom of a deep row; and 2) in each of the 30 treatments, suction lysimeters nested under and around the deep row.

Pan lysimeters were installed from July 2002 through March 2003, just after the deep row was filled with biosolids, taking care to minimize disturbance to the trench above. Water collected from zero-tension lysimeters (i.e. pan lysimeters) may be macropore flow (Figure 3). Where macropores are minimal or non-existent, as may be the case in this drastically disturbed soil profile, the flow represents gravity-drained water. Because the water percolates relatively rapidly, and does not have prolonged contact with the soil matrix, there is less time for nutrient uptake from the surrounding soil matrix. Hence, concentrations from the pan lysimeters provide an estimate of the lower limit of nutrient loss.

Each plot also contains two sets of suction lysimeters installed under and around the biosolids rows (Figure 3). Suction lysimeters were installed after the deep row was filled with biosolids, after the area was leveled and disked, but before planting. Where water flows a great distance vertically to the water table, nutrients leaving a source generally create plumes that migrate downward. Therefore, one set of suction lysimeters were installed 150 mm, 300 mm, and 610 mm (6, 12, and 24 in.) directly below a biosolids row to monitor long-term migration of any plume in the vertical direction.

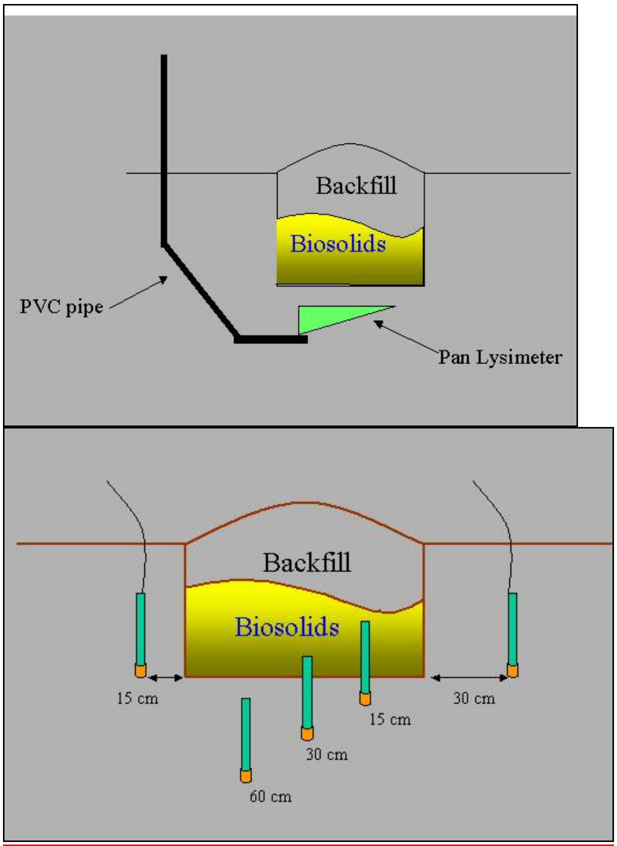

Figure 3. Pan lysimeter installation (left) and suction lysimeter installation (right).

The second suction lysimeter nest is located beside the row in the soil, level with the bottom of the deep row. Because this site has a thick clay subsoil layer overlain with gravel and mixed clay loam backfill, lateral flow on top of the horizon interfaces (sometimes referred to as locally perched water) is a possibility. Suction lysimeters were installed 150 mm and 300 mm from the side of a row to monitor lateral movement. Suction lysimeters collect soil water that may contains nutrient levels elevated above that of free flowing sub-surface water. Hence, concentrations provide an estimate of the upper limit of nutrient loss.

Overall water quality in the ground water has been assessed by regular measurement from previously installed groundwater monitoring wells already resident in the top of the Nanjemoy formation, which is the first water supply aquifer beneath the site (Wilson and Fleck, 1990).

Figure 1 illustrates groundwater contours using data from all the wells located at the ERCO Tree Farm. The solid lines represent groundwater potential contours and the dashed lines represent topographic contours. There are seven functioning groundwater monitoring wells installed at the Tree Farm site that range in depth from 7.6 m to 39 m (25 ft. to 127 ft.). In Figure 1, the groundwater potential decreases from Section 8 toward Section 9. Overall, these contours show a general hydraulic gradient toward Burch Branch, which flows past the Tree Farm site to the north and east. An unnamed tributary to Burch Branch flows along the western boundary of the ERCO Tree Farm. Based on the ground water contours and the presence of perennial streams on three sides of the Tree Farm, water quality in the aquifer and aquaclude below the site can be reasonably well estimated by reviewing the historical analytical data from the monitoring wells.

Sampling Frequency & Parameters Measured

Water quality sampling began in April, 2003. Water samples from pan and suction lysimeters were collected on a monthly basis for the first year. For the following years, samples were collected every other month. These routine collections amounted to 3240 sampling attempts. Due to dry weather conditions and other climatic factors, however, there were instances in which water is not present. Specifically, 2341 samples were collected and successfully analyzed. All subsurface water samples have been sampled for pH, nitrate, nitrite, total nitrogen, orthophosphate, total phosphorus, sulfate, and chloride.

Pan and suction lysimeter samples were transported to the laboratory in a cooler on ice after collection. Samples were analyzed for pH on a Fisher Scientific accumet Basic AB15 pH meter. An aliquot of sample was vacuum filtered through a 0.45um pore size nylon membrane filter (Whatman part no. 7404-004) and frozen until analyzed. Filtered samples were analyzed for total nitrogen, ammonium, nitrite, and nitrate. All analyses were performed by the Appalachian Laboratory at the University of Maryland Center for Environmental Studies in Frostburg, MD. Analytical methods/protocols used included the following.

- Total nitrogen: Standard Methods, Method 4500-N B. In-Line UV/Persulfate Digestion and Oxidation with Flow Injection Analysis (APHA, 1998)
- Ammonium nitrogen: Lachet QuickChem Method 10-107-06-3-D, Revision Date August 26, 2003 (Sodium salicylate –based method).

- Nitrite/nitrate: Methods for Chemical Analysis of Water and Wastes (MCAWW) Method 353.2 Determination of Nitrate-Nitrite Nitrogen by Automated Colorimetry (using a Lachet Quick Chem 8000 Flow Injection Analyser) (EPA, 1993). Both nitrite and nitrite+nitrate are determined; nitrate is then mathematically calculated as the difference.

Tree Planting Method

The operational technique for planting hybrid poplar cuttings outside the 1.25 ha (3.1 ac) research area uses a low ground surface pressure bulldozer with a subsoiling bar to create a deep row about 30 cm (1 ft) deep. Subsoiling, in which a strip of compacted soil is broken up prior to planting, was implemented to break up the extremely dense overburden so that the newly planted cuttings were easier to plant, could quickly form roots, and could access the soil moisture and nutrients in the biosolids. The bulldozer then created another planting row 3.1 m (10 ft) from the existing row by lining a boom up on the existing row. When completed, the cuttings were easily hand planted where the 3.1 m planting rows intersect, creating a 3.1 m square grid.

The research site was planted in June 2003 using hand-planting with a dibble bar. The bulldozer weight had the potential to collapse the pan lysimeters. Both areas were planted on the same day. Vegetation management on the research area was implemented by applying pre-emergent herbicides such as Goal® and Pendulum®. The two distinct, but adjacent tree crops that were planted using the subsoiling method provided the opportunity to determine the effect of planting technique on the mortality and growth of the planted cuttings.

The total height and basal diameter (5 mm above the growth from the cutting) was measured for each cutting after the first and second growing seasons (2003 & 2004) in the research plot and for a subset of trees in adjacent plots.

Foliar Leaf Collection And Analysis

The collection of foliar leaf samples of hybrid poplar trees is an accepted method to assess the uptake of available nutrients by the trees and the impact of various treatments on tree growth (Hansen, E.A 1994; Hansen, E.A. and D.N. Tolsted 1985). Changes in foliar leaf concentrations for N and P have been correlated with changes in growth of hybrid poplar (Zabek, 1995). The literature on hybrid poplar foliar nutrition (Zabek, 2001) can be summarized as follows:

- Maximum growth of hybrid poplar under fertilized conditions occurs at 3.6% foliar nitrogen and 0.42% foliar phosphorous. However, fast growth occurs at 2.5 - 3.5% foliar nitrogen and 0.25 - 0.40% foliar phosphorous.
- Foliar N:P ratios of above or below 9.5 seem to coincide with differences in tree growth response to N and P applications. The ratio of N:P may prove to be an effective diagnostic tool.
- Foliar nutrient levels of N and P at or above the levels for fast growth, combined with a N:P ratio around 9.5 should be expressed in measures of increased growth (height, diameter, and biomass) over treatments with lower optimum levels.

To establish a baseline for the foliar nutrient uptake and enable trends to be identified in the future, foliar nutrient samples were collected during the second growing season (August, 2004) using an accepted protocol (VanHam 2003). All samples were analyzed by a commercial laboratory.

Statistical Analysis

All statistical analysis was completed using SAS Analysis Systems with some form of ANOVA. Water quality data required extra attention because of large numbers of low or non-detect values. Specifically, data were subjected to the following procedures. The monthly measurements were averaged on a quarterly basis for each subplot.

Non-detect results were set to a value equal to 2/3 of the detection limit (Douglass, L., personal communication, 2005). Data for each analyte were then evaluated to determine if they met the normal distribution and homogeneity of residuals assumptions of ANOVA. Upon determining that they did not, data were log transformed and again evaluated. Log transformation produced data sets that met the assumptions for ANOVA.

The split plot experimental design and collection of data over time provides a repeated measures data set best analyzed using the Mixed procedure with repeated measures analysis techniques that: 1) estimate the covariance residuals and 2) use the variance and covariance estimates to determine appropriate standard errors and test hypotheses (Douglass, 2005). Six different covariance structures were evaluated to determine which structure best described the random variances and covariances among the repeated measures. These included: compound symmetry (CS), heterogeneous compound symmetry (CSH), first-order autoregressive {AR(1)}, heterogeneous first-order autoregressive {ARH(1)}, spatial power{SP(power)}, first-order ante-dependence {ANTE(1)}, unstructured (UN) (Littell, R.C., et. al., 1996).

Upon determining the most appropriate structure for the data set (i.e., the one with the best goodness of fit measurement), the program was run to evaluate whether or not the null hypothesis was rejected. The null hypothesis and alternate hypothesis were:

Ho = Treatment effects means and interaction effects means are equal

Ha = Treatment effect means and/or interaction effects means are not equal

Tests of fixed effects showed which null hypotheses were rejected based on a probability level of 0.05. Those rejected null hypotheses were further evaluated by the least squares difference (LSD) procedure to compare individual treatment means. Significant differences ($p < 0.05$) from the LSD analysis were then studied to determine if any differences were important in the context of the experiment (Kuehl, 2000; Littell, R.C., et. al., 1996).

RESULTS AND DISCUSSION

Water Quality – Long Term Monitoring Wells

Monitoring wells were installed for permit purposes and to test the hypothesis that NO_3-N was not reaching drinking water supplies. Nutrients, primarily nitrate, have the potential to leach into groundwater. Nitrate

(NO_3-N), is the product of aerobic microbial breakdown of organic nitrogen and is soluble in water. Nitrate is a health concern in drinking water at levels greater than 10 mg/L.

The historical nitrate concentration data from the ERCO monitoring wells showed no samples have even approached the 10 mg NO_3-N/L limit for drinking water since sampling began. In fact, only one sample exceeded 1.0 mg/L. These data indicated that there was no nitrate migration to groundwater supplies as a consequence of the biosolids related activities at the ERCO site between 1983 and 2005 in the deep wells required by the operating permits.

Water Quality – Lysimeters
The null hypothesis for the lysimeter experiments was that nitrogen, both as NO_3-N and as NH_4-N, was not leaving the biosolids. Samples were collected on a monthly basis during application to the experimental site to monitor the concentrations of macro and micronutrients. Prior to beginning applications in mid-March 2002, four biosolids samples were collected from routine deliveries at the ERCO site to determine nitrogen content. The four samples together produced an average value of 1.16% total N. During the design stage of the research project, several biosolids samples were collected upon drop off at the tree farm and showed, on a wet weight basis, an organic nitrogen concentration of 1.16% (11,600 mg/kg), total phosphorus content of 0.38% (3800 mg/kg), pH of 11-12, and percent solids content of 20-25%. Mean nitrogen content was 4.12 % on a dry weight basis. Ammonium (NH_4-N) was 0.27%. Inorganic nitrogen constitutes 7% of the total nitrogen, neglecting nitrate and nitrite which was very low.

The product, NH_4-N, is soluble in water and easily infiltrates the soil profile, though movement is often limited by the cation's attraction to negatively charged particles in the soil (Haynes, 1986). In fact, more than half of the pan and suction lysimeter samples contained NH_4-N concentrations in excess of 1000 mg/L. There were no significant differences between any application rates, tree densities, or time. Experiments conducted by Brutsaert, et al. (2004) on nitrate leaching from biosolids stockpiles showed that leachate samples collected over an eight month time frame in pan lysimeters installed in the soil profile one and two feet under the stockpile contained 800-1500 mg/L total Kjeldahl nitrogen (most of which was in the form of NH_4-N). Three feet below the stockpile, a marked decrease in total Kjeldahl nitrogen was noted, with values typically below 100 mg/L. Leachate collected directly from the stockpile contained 2,800 – 4000 mg/L NH_4-N, demonstrating that some attenuation or conversion of NH_4-N had occurred.

Based on the fact that NH_4-N is held in the soil by the reversible process of cation exchange, in which NH_4-N is adsorbed to negatively-charged soil sites, as well as the non-exchangeable process of fixation within clay lattices (Haynes, 1986), it may have been expected that NH_4-N would be more selectively absorbed by those subplots with higher silt and clay concentrations. Haynes (1986) and others have noted that, barring other factors, leaching losses of NH_4-N are usually only problematic in soils with a low cation exchange capacity (CEC), as is often evidenced in sandy soils. Block 3 contained the highest amount of clay in the soils, followed by block 2. Block 1 contained the sandiest of the subplots. Based on this logic, block 1 should allow the highest amount of NH_4-N to flow through the soil profile to the pans, followed by block 2, with block 3 hindering flow the most. It is evident from the results that no single block stands out as having predominantly higher results across the treatments. All soils are texturally sandy clay loams, though it must be remembered that these "soils" originate in parent material that was 10-15 m below the surface prior to mining. Our results do not exactly follow the observations of Haynes (1986) but there is a great deal of variability and that may explain the lack of statistical differences. It is also possible that the short distances between the source and the samplers did not provide sufficient opportunity for cation exchange and fixation.

There was an overall trend of an increase in NH_4-N concentration with time, but the trend was not consistent and was generalized, because it does not differentiate between suction lysimeter positions (i.e., the "application rate by tree density by position by quarter" interaction was not significantly different). Comparison of application rates did show the controls to have significantly less NH_4-N than other application rates.

The most notable trend from both observational and statistical analysis is that NH_4-N concentration decreased with depth below the biosolids which suggests that more NH_4-N is reaching the first of the vertical suction lysimeters, with attenuation as it travels deeper through the soil profile. The decrease with depth could be due to cation exchange reactions in the soil that hold the NH_4-N and delay movement with soil water, microbial interactions (i.e., immobilization) or, though less likely, conversion of NH_4-N to nitrate with subsequent immediate denitrification. Finally, an overall increase in concentration with time was indicated.

Figure 4 presents the 2341 NO_3-N-N results from both the pan lysimeter samples and the suction lysimeter samples by application rate for all treatments, with the 10 mg/L drinking water level highlighted.

- Of the 521 pan and 1820 suction lysimeter results taken from 11/03 to 4/05, only 5 results (0.2%) exceeded the drinking water MCL of 10 mg NO_3-N/L.
- Some individual results with statistically significant differences were found, but there were no discernable trends between application rates (including controls), tree densities, and/or time.
- Statistically significant differences in such low levels of NO_3-N do not translate to significant differences from an agricultural, engineering, or water quality perspective.

Regardless of the soil composition, it appears nitrates are not being produced or leached into the water table, even before the tree roots are in place. The conditions in the deep rows are not conducive to the production of NO_3. The biosolids lack oxygen due to encapsulation by soil. Because of encapsulation, ammonia volatilization is impeded. The moist or near-saturation conditions create an anaerobic environment which impedes nitrification. Additionally, high salt content strongly inhibits nitrifying bacteria. However, work by Taylor et al. (Taylor et al., 1978) suggests that root penetration was not inhibited, which suggests that salts are not present in prohibitive levels. This is further supported by findings of Sikora et al. (1979) in which Cl content in drainage water peaked at 18 months post application and fell off after that. Hence, salts probably don't inhibit nitrifying bacteria at least after 18 months post application. The depressed temperatures, ranging from approx. 13-18°C (55-65°F) also slow bacterial activity.

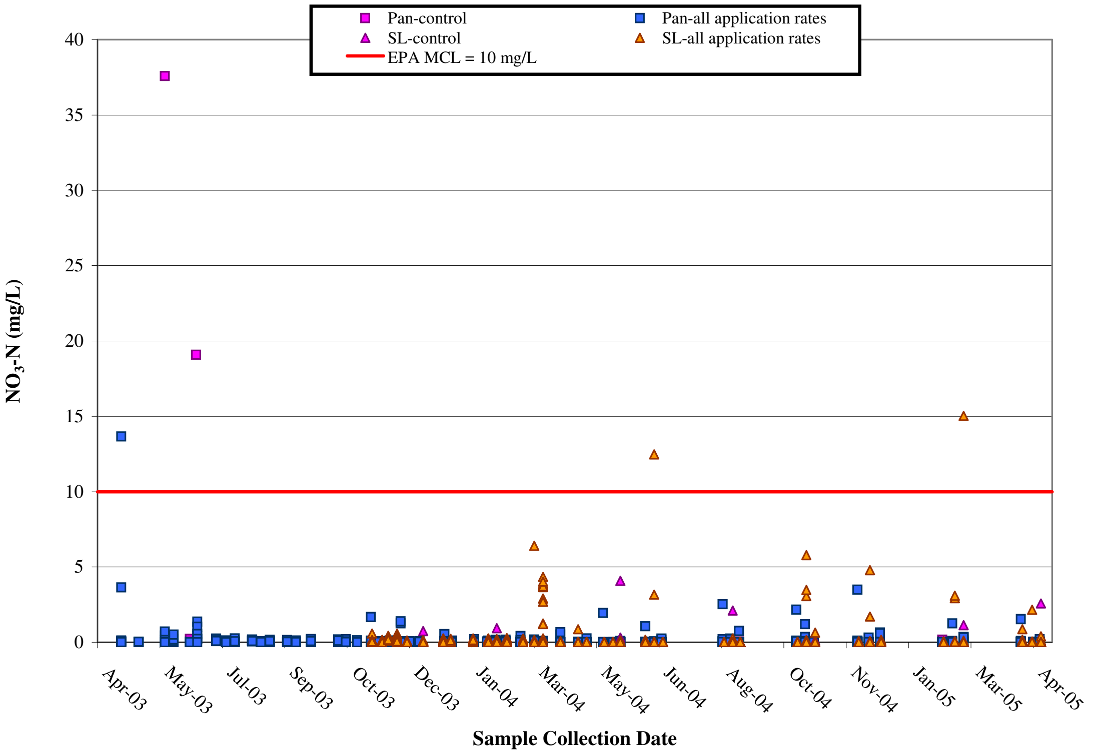

Figure 4. Nitrate levels from pan and suction lysimeters (April 2003-April 2005).

Foliar Nutrient Status Of Hybrid Poplar Trees

It is expected that the tree roots will access the biosolids in the first 24 months. It was not expected that any of the treatments would cause any significant differences in growth or foliar nutrient uptake during the first two years. It is not until the trees have established their root systems and the crowns and roots of the trees start to compete with each other for nutrients that treatment effects will occur.

Values for percent foliar nitrogen in the research area ranged from 2.72 – 3.13 and values for percent foliar phosphorous range from 0.25 – 0.31, both well within the range of values typical of fast growth on fertilized plantations. The N:P ratios range from 10.1 to 10.9, above the value of 9.5 in the literature that corresponds with rapid growth.

Field observations indicate these trees (in growth year two) are just in the process of accessing the available nutrients in the biosolids.

Tree Planting Method

Our null hypothesis was the planting with a dibble would not affect survival or growth of the trees. After one year, the mortality of cuttings on the plots with subsoiling was much lower (1.7%) compared to the cuttings planted without subsoiling (14.2%). Height growth of the cuttings planted without subsoiling was also much higher (0.524 m) than the cuttings planted without subsoiling (0.339 m). The lower mortality and better growth of cuttings planted with subsoiling occurred even though these stems sustained a much higher level of deer browse (51% for subsoiled plots compared to 20% for plots without subsoiling). It would be expected that a higher percentage of stems browsed would likely reduce overall height growth and survival, but that did not occur.

It was assumed that the better growing conditions created by subsoiling were in part the cause of these differences in mortality and height growth. The long-term impacts of planting without subsoiling are that trees will take longer to establish themselves and that rotation length may need to be extended to accrue similar amounts of biomass compared to trees planting with subsoiling. This can have economic implications as rotation length has a direct impact on how quickly the site can be reapplied. The first year results indicate that subsoiling is an essential part of site preparation for planting and is critical to good survival and rapid site colonization by hybrid poplar.

In general, the benefits of subsoiling using the operational technique described were as follows:

- Provided a symmetrical layout that eased vegetation management and other stand entries throughout the rotation.
- Was essential to reduce compaction of dense soils which increased survival and early height growth
- Allowed young trees to overcome the negative impact of deer browsing

Hybrid Poplar Clonal Trials

The premise being tested is that some clones will perform better than others in terms of growth and survival. It is assumed that reasons for this include climate and deer preference, but those factors are not actually being tested. In Section 5 of the ERCO tree farm (Figure 1) an area of 122 m by 110 m (400 ft by 360 ft) was set aside for a planting of different hybrid poplar clones to test their growth and survival under the unique conditions of the site. The test plots were divided into 11 equal sized blocks, which were 31 m X 37 m (100 ft by 120 ft). Commercially available cuttings were planted on a 3.1 m (10 ft) spacing, so that each block contained 120 trees. The vegetation competition between the rows was controlled by periodic mowing. The total tree height was measured after each growing season and survival was assessed after the first and second growing season.

Survival after the second growing season was greater than 90% for three clones with three other clones in the 80-90% range. These clones in order of survival percentage were: OP367 (96%); DN70 (94%); DN5

(93%); DN82 (88%); NM6 (87%); and DN34 (82%). The survival of clone 15-029 at 70% was lower than the others, but should receive some consideration due to its good performance in total height. The survival of other clones was under 80%, which would indicate they are not well adapted to survive in this environment. It is possible that deer browsing may have had an impact on survival since some clones may be more favored than other. However, because fencing to exclude deer is not operationally possible, clones must be able to survive browsing pressure early on.

After four growing seasons, both the OP-367 and DN-17 clones were significantly taller than the other clones (9.3 and 8.3 m respectively), but not significantly different from each other (Figure 5). Throughout the four year period, OP367 consistently had the best height growth, with it being significantly taller that all the other clones after the end of year 1 and year 2.

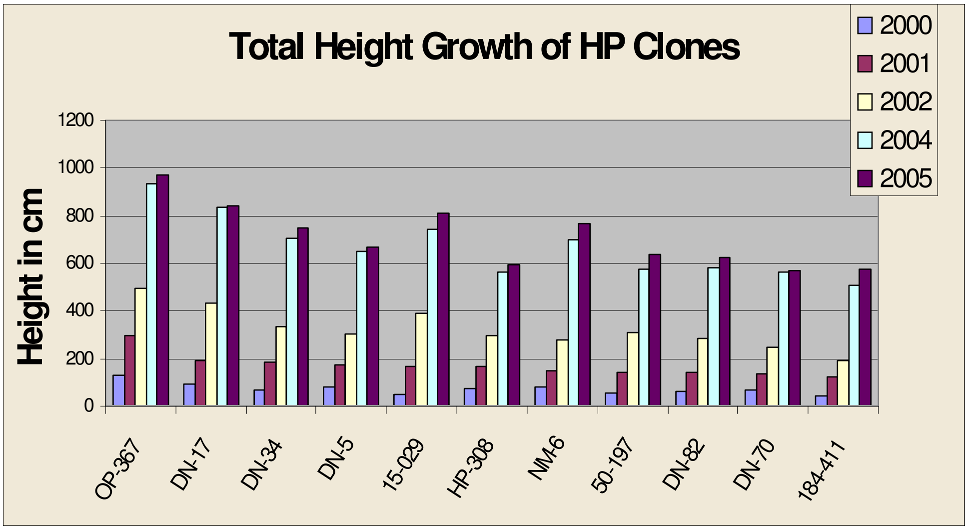

Figure 5. **Total average height for each of 11 hybrid poplar clones, 2000-2005**

After five years, DN17 maintained its place as the second tallest clone in terms of total height growth. The five tallest clones after the fifth year were: OP367 (9.3 m); DN17 (8.3 m); 15-029 (7.4 m); DN34 (7.1 m); and NM6 (7.0 m).

OP-367 consistently demonstrated superior annual height growth compared to the other clones except for DN-17 and 15-029, which had better annual growth in year 2-3. The height growth of OP-367 in the second year was 1.7 m, 0.50 m more than the next best performer DN17, with 1.2 m. By the fifth year, OP367 had an annual height growth of 4.4 m, which was only slightly higher than NM6 at 4.2 m.

After five years, the OP367 clone was the superior performer of all the clones tested for survival and total height. The DN-17 clones had the next highest height growth after five years, but its survival was poor (47%) after two years.

Some clones were unacceptable due to problems with insects and disease or form, although they may have good survival and height growth. More data and analysis is necessary to determine the cause of the poor survival. Field notes indicated that deer had caused serious mortality on some clones. When a stem was damaged by deer browsing or rubbing, it typically died back to the base. In many cases these stems died, impacting overall survival. For those stems that did grow, the lower heights could also impact the overall mean height of the entire block.

Economic Analysis

We believe that hybrid poplar production using deep row biosolids can be profitable. Economic analysis was the tool used to evaluate this hypothesis. The economic analysis first identified the business resources required under three headings: 1) land & buildings; 2) site development; and 3) equipment and personnel.

This enabled the determination of costs associated with each expense. The analysis assessed the income generated under the different application rates that were part of the research study: 11,900, 23,800, and 35,800 kg/ha (4000, 8000, and 12,000 lbs per acre) of nitrogen (N) for the six-year rotation.

An important aspect of deep row application is the land requirements. Since one application is made every rotation, there must be adequate land available during the rotation length before reapplication is needed. In our scenario we used a rotation length of 7 years on a 51 ha (125 ac) land base. This project attempted to estimate annual income and expenses based on the expense factors identified and the present income structure of the industry. The value of $25 per wet ton (actual tipping fee) was assumed for the analysis, which does not include the cost of trucking to the site, which may be figured into actual contracts in a number of ways.

The main expenses that change with the higher application rates are equipment operators, and dozer and excavator equipment costs. Many of the other costs are not significantly impacted by higher application rates. The general trend in equipment operator needs is that an additional equipment operator is needed when you go to the next higher application rate.

The hypothetical business analysis of a deep row operation based on reasonable assumptions and values found that an application rate of 11,900 kg N/ha/yr resulted in only $4,075 profit (income – expenses) per year. However, if the application rate was increased to 23,800 or 35,800 kg N/ha/yr then the profit increased to $208,300 and $412,600 per year, respectively, despite the fact that equipment and personnel needs increased.

The profitability of the enterprise can be improved by: 1) reducing taxes by utilizing a woodland assessment; 2) decreasing water quality monitoring costs; 3) reducing costs for permits and assessment; 4) producing larger trees that can be sold for pulp; and 5) reducing the opportunity cost of the land. Additionally, this deep row technology has the capability to reduce external costs to society caused by pollution and other factors.

CONCLUSIONS

The following conclusions can be drawn from the research highlighted:

- The well data indicate that the aquifer (a potential drinking water supply) and aquiclude below the site are not impacted by the biosolids application.

- Taken as a whole, the water quality work suggests that the deep row biosolids application rates used in this study are not releasing NO_3-N to the environment in the first 24 months following application. Contrary to the null hypothesis, NH_4-N is leaving the biosolids pack but the NH_4-N concentration decreases with distance from the biosolids in the distance range 0-600 mm. This suggests that the NH_4-N is becoming bound in the soil shortly after exiting the biosolids.

- The trees responded similarly to fertilized plantations, based on foliar nitrogen and phosphorous levels.

- Our results contradicted our null hypothesis. The use of subsoiling prior to planting to reduce soil compaction improved early growth and survival.

- Deer can be an impediment to early plantation establishment and must be considered in the planning process.

- The OP-367 clone expressed superior performance, survival, and growth compared to the other 10 clones.

- The profitability of deep row application was marginal at the 23,800 kg/N/ha (4,000 lbs/N/ac) rate, but increased dramatically with the higher application rates.

ACKNOWLEDGMENTS

The authors wish to acknowledge the commitment and financial support of Steve Gerwin with the Washington Suburban Sanitary Commission throughout this project, as well as the ideas and support of Chris Peot with the Washington, D.C. Water and Sewer Authority. The installation of the equipment, data collection, and analysis on this project would not have been possible without the hard work of the graduate students, Carrie Buswell and Tommy Griffith. The expert machine operation of Scott Flamino has been critical to making things work. The University of Maryland authors on this project have the greatest respect and admiration for the years of commitment and hard work by Eric Flamino, who without his effort and support this technology would not have advanced.

REFERENCES

APHA, 1998. Standard Methods for the Examination of Water and Wastewater, 20th edition. American Public Health Association, Washington, DC.

Brutsaert, W., J.M. Peckenham, and Hunter. 2004. Report for 2003ME18B: Nitrate mobility in shallow groundwater near biosolids stockpiles. http://water.usgs.gov/wrri/02-03grants_new/prog-compl-reports/2003ME18B.pdf

DC-WASA, 2002. Biosolid utilization statistics. Washington, D.C. Water and Sewer Authority. Washington, D.C.

Douglass, L. 2005. Biometrics, Chapter 10 Laboratory: Analysis of Repeated Measures Designs. University of Maryland, College Park.

EPA, 1993. Methods for Chemical Analysis of Waters and Wastes. EPA 600/4-79-020.

Felton, G.K., J.S. Kays, C.U. Buswell, E.Flamino. 2005. Determination of optimum tree density, biosolid application rate, water quality impacts, and tree growth effects using the deep row biosolids incorporation method. Washington Suburban Sanitary Commission, Laurel, MD. pp127.

Hansen, E.A. 1994. A guide for determining when to fertilize hybrid poplar plantations. Res. Pap. NC-319. St. Paul, MN: USDA Forest Service, North Central Forest Experiment Station.

Hansen, E.A. and D.N. Tolsted. 1985. Nitrogen sources and fertilization rates affect growth of hybrid poplar. In: Proc. Fifth Central Hardwood Forest Conf., J.O.Dawson and K.A. Majerus (eds). Dept. Forestry, University of Illinois, Urbana-Champaign, IL.

Haynes, R.J. 1986. Mineral Nitrogen in the Plant-Soil System. Academic Press, Inc. Orlando. Florida.

Kuehl, R.O. 2000. Design of Experiments: Statistical Principles of Research Design and Analysis, 2nd edition. Brooks/Cole Publishing Cmpany, Pacific Grove, California.

Littell, R.C., G.A. Milliken, W.W. Stroup, R.D. Wolfinger. 1996. SAS® System for Mixed Models. SAS Institute, Inc., Carey, N.C.

MDE. 2002. Sewage sludge utilization in Maryland,@ Maryland Department of Environment, Design and Certification Division, Baltimore, MD.

Murray, M. 2003. Poplar trees how promise for phytoremediation of PCP. HDR Innovations, Volume 11, No. 3. http://www.hdrinc.com/Assets/documents/Publications/InnovationsWRE/Fall2003/Phytoremediation.pdf

National Agroforestry Center. 2000. Working trees for treating waste. Publication NPS 00-0254. United States Department of Agriculture National Agroforestry Center. University of Nebraska Lincoln, Lincoln, NE.

Sikora, L.J. and D. Colacicco. 1979. Methods used and costs associated with entrenchment of sewage sludge. P. 169-174. In Natl. Conf. On Municipal and Industrial Sludge. Composting-material handling. Information Transfer, Inc., Rockville, Md., in cooperation with USDA-ARS. Sikora, L.J., W.D. Burge and J.E. Jones. 1982. Monitoring of a municipal sludge entrenchment site. J. Environ. Qual. 11(2): 321-326.

Taylor, J.M., E. Epstein, W.D. Burge, R.L. Chaney, J.D. Menzies, and L.J. Sikora. 1978. Chemical and biological phenomena observed with sewage sludge in simulated soil trenches. J. Environ. Qual. 7(4): 477-482.

Tompkins, M.D. 1983. Prince Georges County Ground-Water Information: Well Records, Chemical-Quality Data, Pumpage, Appropriation Data, Observation Well Records, and Well Logs. Maryland Geological Survey Water Resources Basic Data Report No. 13.pp160.

Van Ham, M.D. 2003. Personal communication.

Wilson, J.M. and W.B. Fleck. 1990. Geology and Hydrologic Assessment of Coastal Plain Aquifers in the Waldorf Area, Charles County, Maryland. Maryland Geological Survey, Report of Investigation No. 53. Baltimore, MD.pp138.

Zabek, L.M. 1995. Optimum Fertilization of Hybrid Poplar Plantations in Coastal British Columbia. M.Sc. thesis. University of British Columbia, Vancouver BC.

Zabek, L.M. 2001. Nutrition and Fertilization Response: A Case Study Using Hybrid Poplar. Ph.D. Dissertation. University of British Columbia, Vancouver BC.