Annual Report for Period of July 1, 2006 – June 30, 2007

Determination of Optimum Tree Density and Biosolid Application Rate and the Effect on Water Quality and Tree Growth Using the Deep Row Biosolids Incorporation Method

Grant Period: July 1, 2005 to June 30, 2008

MARYLAND COOPERATIVE EXTENSION
UNIVERSITY OF MARYLAND
COLLEGE PARK•EASTERN SHORE

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EXECUTIVE SUMMARY

Deep row incorporation of biosolids at rates of 171 to 294 dry tons per acre using hybrid poplar has been an operational technique on a 100-acre gravel spoil in Maryland since 1984. Developed by ERCO, Inc, this technique involves the placement of biosolids at application rates of 171 to 294 dry tons per acre into trenches that are immediately covered with overburden, eliminating odor problems and maintaining the biosolids in a fairly stable, anaerobic environment. The site is then planted with hybrid poplar trees, the roots of which provide a natural recycling system that utilizes the nutrients over a six-year period in most cases.

This technique has great potential for application on thousands of acres of gravel spoils in the region, however, replicated research is needed to determine water quality impacts, soil limitations, and the best production methods at different application rates and tree densities. An initial three year research project on the ERCO site established a 3-acre research area that was followed by another three year research project to continue monitoring of the experimental treatments.

This report summarizes five years of experimentation at the ERCO site. The objectives are to determine the effect of biosolids application rate and tree density on water quality around the deep rows on a gravel mine spoil, the nutrient losses to the vadose zone, nutrient removal by the trees, growth and survival of hybrid poplar, and to continue education of state and local environmental professionals about deep row applications to develop sustainable forest crops and simultaneously rehabilitate disturbed soils.

After five years of experimentation the movement of nitrogen through the soil profile and through woody biomass is becoming clearer from a landscape perspective using the water quality data, as well from the use of geotechnical exploration. This report summarizes the fifth year of the research and extension project on a 3-acre site within the ERCO property, as well as research incorporated into the operational part of the ERCO enterprise.

Geotechnical Exploration

Near surface borings ranging in depth from 5'-25' were taken to help us understand how the geological material would affect the flow of water from the deep row system. Considerations included any perched water tables, changes in hydraulic conductivity at various depths, and possible need for additional monitoring wells. It is hypothesized that while there is intrusive water moving in latterly from the un-mined gravel layer on the southwestern end of the property, this water flow stops as it enters the property. There was no "perched water" table identified on the property.

Hydraulic conductivity was assessed across the ERCO site, using the surface borings, and was generally low (10^{-5} to 10^{-6} cm/s), as might be expected with fine silt and clay soils. In general, hydraulic conductivities in the 5'-25' range below the surface are sufficiently low as to greatly inhibit flow of water through this material, further reducing the possibility of offsite nitrogen movement.

Nutrient Losses to the Vadose Zone

Agronomic Crops and Nitrate Losses
After five years of data collection the trends in nitrate movement around the trenches has begun to demonstrate identifiable patterns from which estimates of potential losses of nitrate from the system were estimated. However, nitrate losses from deep row application using biosolids must be couched in comparisons with other common land uses, such as nitrate losses for agronomic soils amended with biosolids or inorganic fertilizer to grow corn-soybean rotations, and biosolids application on strip mines to establish vegetative cover. To produce corn with yields of 125-175 bushels per acre, research from a variety of source finds nitrate in soil water and drainage water ranged from 10 mg/L if numerous BMP practices were applied to 32 mg/L for continuous corn. When surface applied biosolids are used in corn production soil nitrate concentrations increased and higher application rates resulted in higher levels of soil nitrate.

Strip Mine Reclamation and Nitrate Losses
High rates of biosolids are commonly applied to strip mines in Pennsylvania (68 dry tons/ac or 4,719 lbs N/ac) to provide to provide organic matter as a foundation for soil genesis and fertilizer for re-vegetation. By adding a large amount of organic matter, the one or two year leaching of nitrate is sacrificed for an ecosystem that can become established and sustain itself on the strip mine spoil, a result that does not occur if only inorganic fertilizer is used. The sacrifice results in nitrate concentrations in excess of 300 mg NO^3-N/L in the first year following biosolids application.

A 31-year old study sampled reservoirs and creeks around lands on which biosolids were surface applied at rates of 28.2 dry Mg/ha/year and adequate runoff and soil erosion control was implemented. They found what the authors termed "minor impacts on surface water quality." Nitrate in receiving waters rose from 0.9 mg NO^3-N/L to approximately 2.5 mg NO^3-N/L over the 31 years of the experiment.

Deep Row Forestry System and Nitrate
Nitrate concentration has been measured in pan and suction lysimeters in the deep row forestry system from 2003 through 2006, a period of 4 years. Up until July 2005, nitrate was not found in the pan lysimeters. Since then, the control treatment (zero biosolids) has reached levels of 2-3 mg/L and the treatments periodically reached levels of 10 mg/L. At the same time, nitrate in the soil water (as measured by the suction lysimeters) increased. The two highest application rates had the lowest nitrate concentration and the lower application rate had the highest nitrate concentrations, hovering around 10 mg/L.

Between July 2005 and October 2006, all nitrate levels fluctuated between 1 and 10 mg/L. The nitrate concentration draining from corn on agronomic soils using fertilizer or biosolids as the N source is as much as triple the nitrate level found beneath deep row forestry system, even with the highest biosolids application level. Because the hydraulic conductivity values in the plots are the same as to much lower than hydraulic conductivity values found in a typical silt loam agricultural field, the nitrate mass transport from the deep row forestry system is one third to one one-hundredth of that lost from a typical corn crop.

Deep Row Forestry and Ammonium

Ammonium concentrations between November 2003 and October 2006 were examined. Pan lysimeter ammonium from the control plots was well below that of the treatments. The highest rate of biosolids application exhibited a peak from November 2004 through August 2005, but then dropped to almost zero by February 2006. We have no explanation for this extreme behavior.

Ammonium in the suction lysimeters remained between 100-600 mg/L from March 2003 until August 2004, when there was a peak in the highest application rate to 800 mg/L from November 2004 to September 2005. For all the treatments, the increase in concentrations either leveled off or has started to decrease since sometime in mid to late 2005. The timing of the peak concentration of each of the three application rates is thought to be related to the additional time required for tree roots to penetrate down to the deeper trenches that were required to achieve heavier application rates.

Ammonium concentration is clearly decreasing with distance from the biosolids for all biosolids treatments, with significant differences between treatments becoming apparent from November 2003 to November 2005. Ammonium levels in October 2006 at 15 and 60 cm may have stabilized or decreased slightly to 1900 and 400 mg/L, respectively. While ammonium levels at 30 and 60 cm may have leveled off, additional suction lysimeters were installed during the summer of 2007 at 120 cm below the biosolids trench in all plots to better understand ammonium movement in the profile. Data collection will commence in October 2007.

Hybrid Poplar Survival and Growth (2003-2007)

Hybrid Poplar Survival (2003-2007)

During the first two growing seasons survival of trees in the research plot was excellent at 86% and 97%, even though height growth was reduced for seedlings damaged by deer browsing and 17-year locusts. In the first growing season, 20% of the seedlings were browsed, resulting in a 31% reduction in height growth from 52 cm to 36 cm for browsed seedlings. In the second year, 36% of seedlings were damaged by locusts, with a 28% reduction in height growth from 156 cm, to 112 cm for damaged seedlings.

Drought in the last three growing seasons (2005, 2006 & 2007) resulted in significant mortality with survival plummeting to 74%, 65%, and 70%, respectively. In an effort to maintain tree density, 32% and 38% of the dead trees were replanted in 2006 and 2007, however, due to the drought conditions, all the replanted trees died.

There were no differences in survival attributed to application rate or tree density, however, survival varied between the blocks in different years. There were no changes in survival between blocks in 2003 & 2004; however, there was a clear increase in survival from Block 1 to Block 3 (of about 20%) for the three drought years of 2005 to 2007. The trend is attributed to difference in soil composition that effect water availability during drought periods. Block 1 is located downhill on a mild slope and has a soil composition of loose sand and gravel with little clay, while the soil in Block 3 contains higher amounts of clay on more level ground that has increased moisture holding capacity to sustain trees during drought periods.

Hybrid Poplar Height Growth

Total height increased in a linear fashion from 2003 to 2006 and leveled off in 2007. There were clear differences in height growth between blocks, tree density, application rate, and biomass, although the differences for tree density and application rate are difficult to explain. A trend of increasing tree height from Block 1 to Block 3 started in 2004 and became more pronounced by 2007. The difference is attributed to the better moisture holding capacity of the soils in Block 3 that improved growth during the drought years.

A trend of increasing tree height for treatments with higher tree densities (435 trees/acre) compared to lower tree densities (290 trees/acre) started in 2004 and became more pronounced from 2005 to 2007. Tree height was greatest for plots with the mid-application rate of 8,000 lbs/N/ac. Similar to tree density, the trend started in 2004 and become more pronounced from 2005 to 2007.

Diameter breast height was only collected in 2007 and biomass equations developed at the ERCO site were used to determine the average biomass per tree (dry kg). Biomass doubled for trees on Block 3 (2.69 dry kg) compared to 1.39 dry kg for Blocks 1 and 2, a difference once again attributed to the better soil composition and water availability during periods of drought for Block 3.

Comparison of Trees in Research Plots and Operational Area

At three years of age, trees in the operational area of ERCO had more than doubled their height at 4.9 m. After five years, height and diameter of trees in the operational area were almost three times as high and biomass eight times as high. The combined impacts of no subsoiling for site preparation, deer browsing, and drought explains much of the poorer growth on the research plots.

Contrast of Tree Growth Using Deep Row and Surface Application of Biosolids on Mine Spoils

ERCO is the only place in the world with long-term data on deep row incorporation. A two-year old deep row application on an anthracite mine in Pennsylvania has found tree heights similar to those reported for the operational areas of ERCO. A study on a sand mine spoil in Virginia is just starting to report data. A comparison of survival and growth data for surface applied biosolids on mine spoils in Pennsylvania found they were similar to the growth and survival of trees on the research plots at ERCO.

Recommendations to Improve Growth and Survival

Other research supports the significant impact of drought stress on the biomass production of hybrid poplar. Clonal trials at ERCO has found the OP367 to be the best performer on the site, however, some research supports the possible susceptibility of clones from the *Populus* crosses to drought stress. Irrigation could provide significant improvements in survival and growth on the ERCO site that is exposed to extremes of drought, soil composition, and deer browsing.

The best strategy to reduce the increasing level of deer browsing is to get trees to 5-6 feet tall as quickly as possible to get them out of the reach of deer. Irrigation could help to maximize early height growth and vigor and minimize the impacts of changes in soil composition to reduce tree rotation length. More research is needed to determine if the additional cost of irrigation is cost-effective.

Foliar Nutrient Analysis
Higher rates of growth are usually related to increases in foliar levels of N. The overall foliar levels of %N and %P range from 2.89 to 3.39 across the research plots over the first three years, and fall on both sides of the 3% N suggested for fast growth. Foliar levels for N of 3.5% and higher are regularly reported on the ERCO operational area. The taller heights reported for trees in Block 3 are correlated with higher levels of foliar N and K.

Conclusion
The research plots at ERCO represent a worst-case scenario for growth hybrid poplar due to the multiple effects of deer browsing, drought, and soil composition changes. Given the importance of rapid tree rotations to the deep row business model, the use of irrigation to assure good survival and growth, especially during times of drought, may be well justified but more research is needed.

Effect of Tree Shelters on Early Growth and Survival of Hybrid Poplar Seedlings
After one growing season (2006), which was a year of extreme drought, there was no difference in survival for trees protected by tree shelters compared to those with no shelters (79%). The use of tree shelters did significantly affect the number of seedlings browsed and their total height. Fifty-five percent (55%) of the trees without shelters were browsed, compared to 0% for sheltered trees. Total height was 60% taller for sheltered seedlings (124 cm) compared to unsheltered seedlings (73 cm). There was no difference in basal diameter related to tree shelters. After one year, it is clear tree shelters improve survival and height growth, but have no impact of survival or basal diameter.

Effect of Vegetation Management and Phosphorous Amendments on Growth of 4-Year Old Hybrid Poplar
Four-year old trees grown at ERCO using deep row application of 4,000 lbs/N/yr were subjected to four, randomly assigned, and replicated treatments of vegetation management, phosphorous amendment, vegetation control and phosphorous amendment, and a control. Pretreatment measures of height, diameter, and biomass were compared with measures after the first and second growing season to determine the differences in growth for each year. Foliar analysis was taken after the first and second growing season. Statistical analysis was used to determine significant differences.

After one year, height growth of all treatments was significantly increased compared to the control. The vegetation management/phosphorous treatment resulted in a significantly increased diameter over the vegetation treatment or phosphorous treatment alone (at p=.07 level). The increases in height and diameter reported in year 1 did not result in any increases in biomass for any of the treatments.

In year 2, there was drought and only some late season rainfall occurred. There were no significant differences in height between the treatments, however, diameter and biomass was significantly increased for the vegetation management treatment compared to the control and for the vegetation/phosphorous treatment as well (at p=0.07 level). It is believed the lack of early season rainfall in year 2 resulted marginal height growth for all treatment using stored carbohydrates from the previous growing season. Once the cessation of height growth occurred due to drought, the late season rainfall allowed the trees with vegetation management to use the available moisture for diameter growth.

Foliar nutrient levels during the adequate rainfall of year 1 resulted in %N levels (3.6-4.0%) and %P levels (0.31-.42%) characteristic of maximum growth. Significant increases in growth for certain treatments appear to be correlated with higher foliar nutrient levels. The drought in year 2 resulted in a dramatic reduction in foliar levels of %N (8%), %P (35%), and %K (24%). The growth increases reported in diameter and biomass for year 2 for certain treatments did not correlate to any apparent trends in the foliar nutrient data.

The dramatic differences reported in growth and foliar nutrient levels between year 1 with adequate rainfall and year 2 with drought conditions, provides justification for the positive impacts that can be realized by irrigation. More research is needed to determine if the growth increases reported using vegetation management and/or P amendment are cost effective.

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INTRODUCTION

This project is continuing to build on successes of the initial three-year project to improve our understanding of how to best apply deep row biosolid technologies with forest trees to protect and enhance the environment. This project is expected to confirm the place of deep row biosolid application with forest trees as a valid and useful biosolid utilization technique. After two years into this grant period the project is making good progress and we have been able to accomplish more than expected in a shorter period of time. We are producing peer-reviewed publications based on the research as well. The progress of this project would not have been possible without the significant support and in-kind contributions of ERCO, Inc. This is an excellent example of a public-private partnership effectively working to solve a serious environmental challenge.

This report has four sections: 1) Progress Update on Objectives and Associated Projects; 2) Additional Research Projects at Site; 3) Research at Other Sites Directly Attributable to Research at ERCO Site; and 4) Presentations, Report, and Peer Reviewed Papers.

In 1983, ERCO Inc. developed the deep row application technique in response to the need to utilize large volumes of biosolids from the Washington, D.C. area and reclaim sand and gravel surface mine spoils. The company received a permit from the Maryland Department of Environment (MDE) for application of biosolids to grow nutrient-demanding hybrid poplar trees on nutrient-poor sand and gravel strip mine spoil. The trees were harvested at about 7 years of age when foliar leaf samples were below 3.5 percent nitrogen and total nitrogen mineralization in the biosolids reached 70 percent.

Approximately 10 acres were treated each year starting in 1984. The deep row technique initially involved the application of biosolids at a rate of 171 dry tons per acre and, for a special demonstration plot, at a rate of 294 dry tons per acre. Biosolids were placed in trenches that were 30 inches deep, 42 inches wide, and spaced approximately 8 feet on center. Trenches were filled with 18 inches of biosolids. The remaining 8-12 inches of trench were filled with overburden. The overburden soils were limed to obtain a pH of 6.2 as per permit requirements. Between 1984 and 1996, fast-growing, nitrogen-demanding, hybrid poplar cuttings were planted at a dense spacing of 3,000-4,000 trees per acre to utilize the nitrogen over a planned 6-year rotation. Since 1996, the tree spacing has been changed to 10 foot by 10 foot because the trees were found to grow much more with this spacing. Competing vegetation was controlled by mowing (no herbicides were used). After six or more years, a 10-acre section was harvested and subsequently cross-trenched for another biosolid application.

Site Location

The ERCO Beneficial Reuse Tree Farm site is a privately-owned 49.4 ha. (122 ac) sand and gravel mine spoil in Prince George's County, MD within 40 km (25 miles) of many large municipal wastewater treatment plants. The site is in the coastal plains physiographic region, approximately 20 miles east of the escarpment region that identifies the piedmont physiographic region. The site is approximately three miles north of Waldorf, MD (Figure 1).

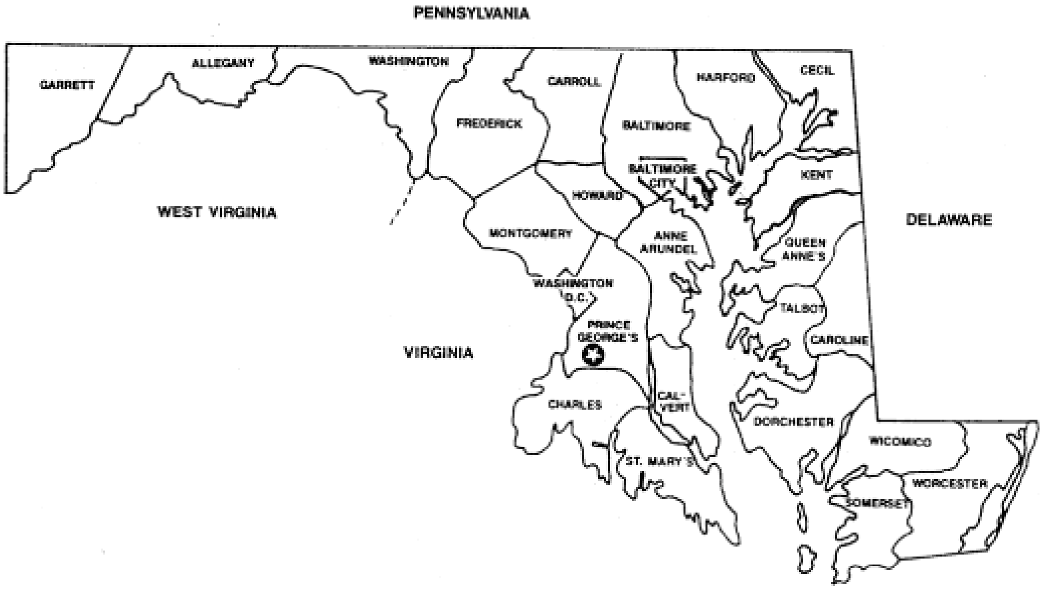

Figure 1. ERCO study site, located in Prince George's County, MD within the Washington, D.C. metro area.

Site Description

The site consists of a plateau with steep banks that fall away to incised streams. The edges of the plateau are bermed and runoff is routed to one of seven detention ponds. 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 plateau.

The research site is an existing reclamation site that has utilized deep row biosolid application with forest trees for 15 years. 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 been applied once with biosolids using deep row application. Approximately 25% of the site (13 ha) is in permanent cover, consisting of either forested steep slope, or detention ponds and buffers. 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. In addition, the surface water flow on the site is significantly reduced due to the tree crops.

1) PROGRESS UPDATE ON OBJECTIVES AND ASSOCIATED PROJECTS

OBJECTIVE 1. Determine the effect of tree density and biosolid application rate on water quality around deep rows on a gravel mine spoil from year 2 through year 5.

Project 1 - Determine the effect of tree density and biosolid application rate on water quality around deep rows on a gravel mine spoil from year 2 until year 5. This includes quantification of nutrient losses to the vadose zone.

This study continued the sampling and analysis of pan lysimeters, suction lysimeters, shallow wells and other sources to determine if water quality on the established 3.1 acre site at ERCO is affected by any of the treatments. The study has been expanded to include geotechnical exploration of the entire ERCO site to assess water movement, hydraulic conductivity, and other key factors. By utilizing the lysimeter and hydraulic conductivity data nitrate losses to the vadose zone can be quantified and compared to nitrate losses in corn production. Assessments on dentrification, ammonium, and orthphospate can be also be determined. A graduate student is responsible for the water quality sampling. Project Leader: Gary Felton.

Deliverables: (SEE APPENDIX A, B) Continued monitoring of water quality data from research plots to determine treatment effects. Assessment of nutrient losses to the vadose zone.

Progress Update: *The water quality data collected since the beginning of this experiment is now being incorporated to provide a more complete picture of nutrient movement at the site and implications for nutrient loss compared to other types of agricultural production.*

Nutrient Losses From Deep Row Application Forestry System to the Vadose Zone

Principal Investigator: Gary Felton

Geotechnical Exploration

This exploration was conducted to determine more about the near-surface geology. Near-surface borings were undertaken to attempt to understand what was occurring in the subsurface immediately below the biosolids. Specifically, in the depths 1.5 m to 7.6 m (5'-25'), the geological material has the potential to greatly affect the flow of water from the deep row system. The exploration was done to locate any perched water in this range, measure hydraulic conductivity at various depths, and to determine appropriate locations for monitoring wells.

Previous Explorations

In 1980, two test borings were done by National Foundation Engineering, Inc. The site was characterized as follows:

Surface to 0.9 m to 1.2 m (3' to 4'): mixed sand and gravel with some clay,
0.9 m– 2.4 m (3' - 8'): silts with some clay and trace of fine sand,
2.4 m – 5.5 m (8' - 18'): clays with some silt, and
5.5 m to 24.4 m (18' – 80'): very fine sand some clay and little silt.

At the same time, seven test pits were also dug to a depth of 3.1 m (10') and saturated hydraulic conductivity (K_{sat}) was determined for each pit. Values of K_{sat} ranged from $3.1X10^{-7}$ to $7.8X10^{-6}$ cm/s.

Some geological data were developed in a report from T.L.B. Associates (1996). Three borings were done on the site, one completed to 21.3 m (70') and two completed to 20.4 m (67'). These locations are identified on the site map as NR-1, NR-2, and NR-3 (Figure 2). From south to north, the elevation change is from approximately 68.4 m (225') MSL at the boundary near NR-3 to 57.8 m (190') MSL at the other (north) property boundary near MW-7. A vein of gravel was found in the NR-3 boring from approximately 60.2 m (198') to 64.5 m (212') [4.3 m (14') thick, beginning 4.0 m (13') below the surface]. The conclusions were that there was no continuous perched water table, but the possibility of a localized perched zone of water existed.

Soils and 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, following cessation of the sand and gravel mining activity, the spoil consisted of a clay layer with occasional remnants of sand and gravel and some gullies that were filled with spoil during the re-grading process in 1983. The clay layer was 1.5 m to 21.3 m (5' – 70') or more thick. The following description of soils and geology at the ERCO site was derived from Wilson and Fleck (1990) and, to a lesser extent, Tompkins (1983) and begins with the deeper deposit first and concludes with the surface deposit that was removed in the mining operations.

The lower formation is the Marlboro Clay (late Paleocene), a leaky confining unit of dense, reddish silty clay between 4.6 m and 7.2 m (15' – 30') in thickness. The lower Eocene Nanjemoy formation overlies the Marlboro Clay, and predominantly consists of beds of dark green, fine to medium, glauconite-bearing sands in the upper part of the formation and is a water-supply aquifer in many parts of southern Maryland. The thickness of the Nanjemoy at Waldorf ranges from 27.4 m to 38.1 m (90' – 125').

Overlying the Nanjemoy is the lower Miocene Calvert Formation. The Calvert is a light to medium, olive gray to olive green, micaceous, clayey silt which acts as a hydrologic confining unit. The thickness of the Calvert in the Waldorf area is 27.4 m to 30.5 m (90' – 100'). The formation is the basal unit of the Chesapeake Group and it represents deposition in a marine shelf environment.

The Calvert is overlain by the Pliocene Upland Deposits. The Upland Deposits consist of orange-tan, silty, fine to very course sands and gravels, and yellowish to orange, silty clays. The Upland Deposits range from 6.1 m to 15.2 m (20' – 50') thick and crop out throughout the Waldorf area. These materials were removed in the sand and gravel mining process. Hence, the ERCO site has very slight remnants of the Pliocene Upland Deposits over the Calvert clayey silt, over the Nanjemoy.

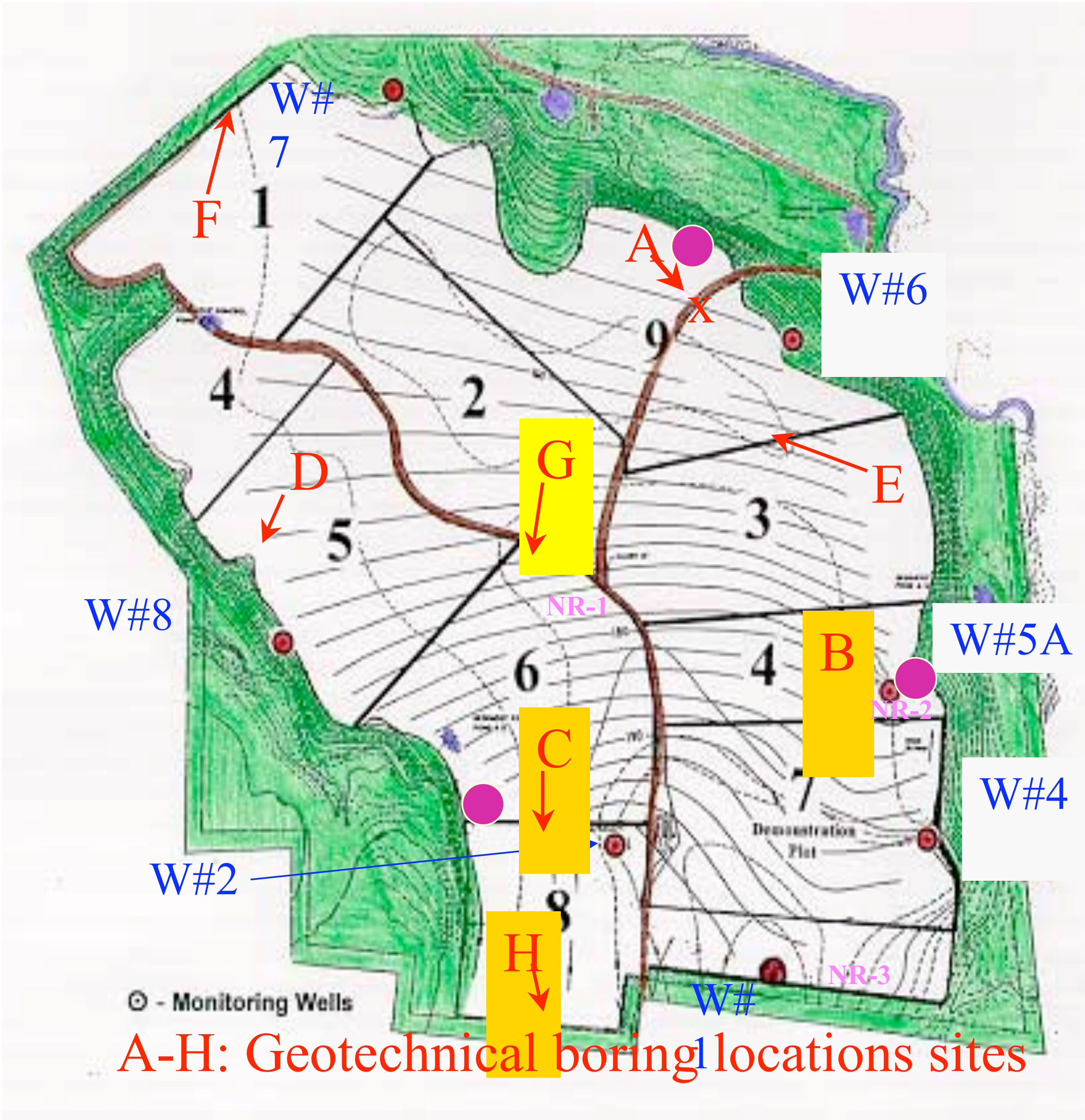

Figure 2. ERCO site section map with monitoring wells, retention ponds, boring sites (1995) and boring sites (2006).

Procedures

Continuous cores were taken using a 76 mm (3") diameter split tube sampler inside a 203 mm (8") auger. The core sampler is assembled with a cutting shoe, drive head, split tube, and the desired sample sleeve. The sample sleeve is housed in a split tube. The sample sleeve and split tube fits inside the auger and is pushed into the "undisturbed" material while the rotary auger cuts, removes, and lifts cuttings up the bore hole. The core sample collects in the sleeve as the auger advances into the bore hole. The auger-sampler assembly is removed from the hole and the sampler is then extracted from the auger and the sample sleeve removed. A new sleeve is placed in the sample tube. The sampler is advanced to the last depth of penetration by adding a series of auger flights, and the procedure is repeated.

The basic increment was 1.5 m (5'). The auger flights and the sampler were 1.5 m long. Where there was a clear visual difference in the cored material, it was noted. The field log (Appendix A) is a transcription of the hand-written field notes, amended with hydraulic conductivity results taken from the laboratory work done on the core samples. Cores were collected from 1.5 m (5') deep to 7.6 m (25') deep because the first five feet were disturbed by the re-grading and biosolids application processes. No cores were collected from site E because sample sleeves were not delivered. Cuttings were examined as the came up. Eight core holes were bored between March 23, 2006 and November 15, 2006. Each hole was left open for a day and then water depth (if any) was measured. The hole was then immediately backfilled with interspersed bentonite seals.

Hydraulic conductivity was determined on soil cores collected during from the borings. Analyses were performed in-house at the University of Maryland Biological Resources Engineering Soil and Water Laboratory using an adaptation of the constant head protocol delineated in Methods of Soil Analysis (Klute, A. 1986). Brass rings that were 5.4 cm (2.1") diameter by 6 cm (2.4") long were pressed into the 8 cm (3.1") diameter core samples to obtain a core sample for determining hydraulic conductivity. A constant head device (Mariotte tube) was used to apply a gradient to the sample (Figure 3). Flow and time were measured. Saturated hydraulic conductivity was then calculated. Twenty-three cores were successfully tested for saturated hydraulic conductivity.

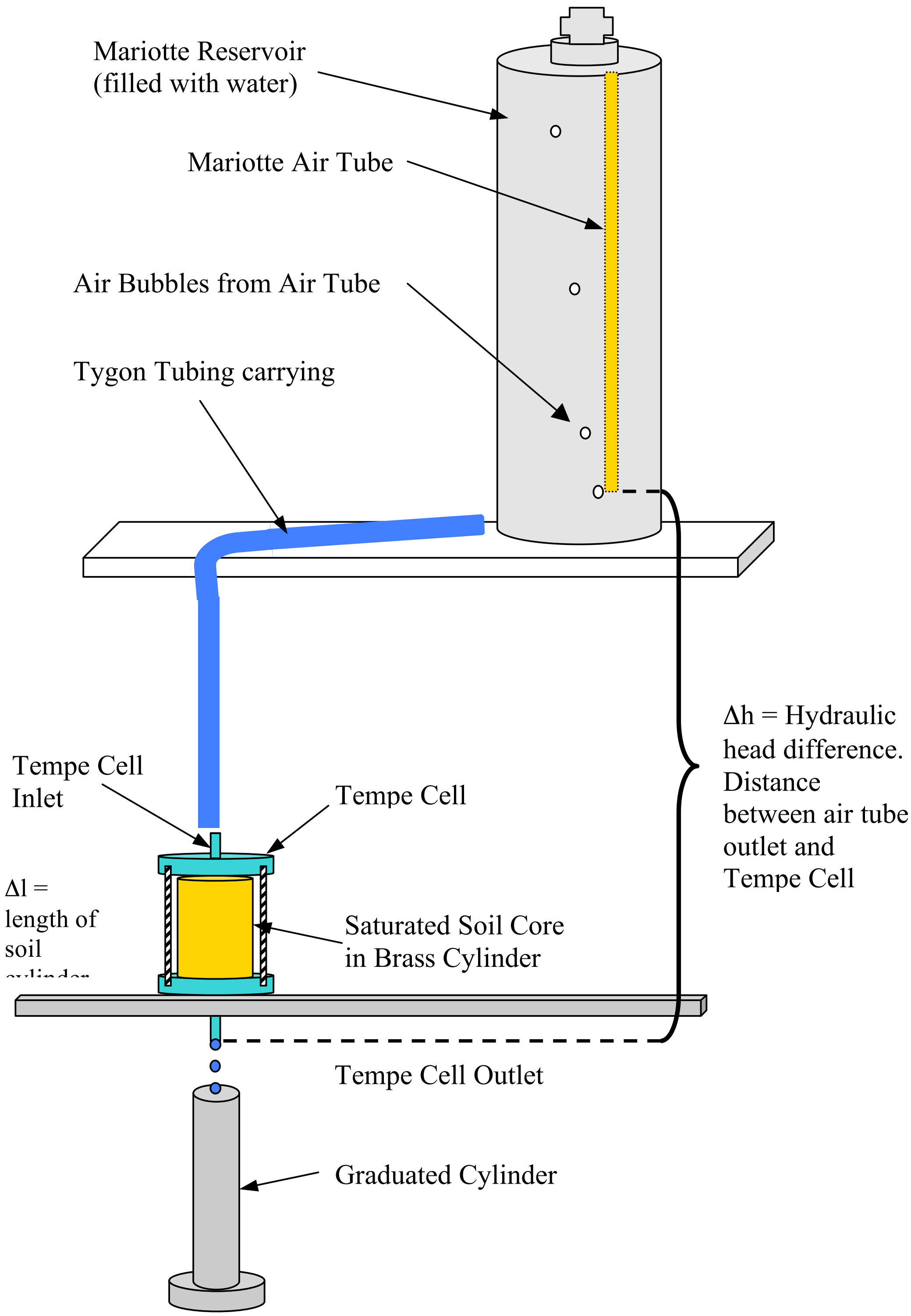

Figure 3. Steady-state laboratory apparatus for determining saturated hydraulic conductivity (K_{sat}) from core sample.

Results

The site map (Figure 2) shows the monitoring wells (labeled W#1, W#2, using blue lettering) and the approximate locations that the bore holes were located. The bore holes (labeled A-H using red lettering) were all 7.6 m (25') deep and filled the day after completion.

Marine clay

There was marine clay found in several borings. These bore holes were clustered near the south of the property (front). Core borings "C", "B", and "G" are clustered near the center of the plateau and this was originally the high part of a ridge. Core boring "A", to the north and east of these sites, has marine clay at a deeper location. It is probable that marine clay underlies the entire site and is deeper toward the boundaries of the site.

The borings that had no marine clay ("F" and "D"), did have substantial clay. Core boring "F", located at the northern-most extent of the property had a grey sandy clay from 4.3 m (14') to the bottom of the bore hole at a depth of 7.6 m (25'). Core boring "D" near the western boundary of the property had whitish-grey clay from 3.0 m to 7.3 m (10'-24') and a green clay from 7.3 m to 7.6 m (24'-25'). In summary, every site except "H" contained a substantial amount of clay and it is apparent that there are considerable facies changes in the strata between boring locations, as is characteristic of fluvial deposits.

Water

Water was found in four of the holes ("B", "C", "G", and "H"), shown in yellow highlights on the map. These boring sites were clustered toward the south edge of the site. At boring site "H", water was encountered at between 8.5' and 10' below the surface and was evident in the gravel cuttings and stood in the hole. However, when the hole was complete at 25' of depth there was no water in the hole and upon return the next day, no water was found standing in the hole. The material at this site was dramatically different from all other holes on the site. From 5' of depth on down, the strata was continuous river run gravel. This suggests that this area was not mined or was incompletely mined and this is the original gravel deposit that was removed from the rest of the mine.

Boring site "C" is located at the opposite side of section 8 and is downhill from site "H". At boring site "C", water was encountered at between 10' and 15' below the surface. The day after drilling, the water was approximately 5' below the surface, suggesting that this water was under approximately 5' of water pressure. There is at least 5' of drop between site "H" and site "C", hence it is possible that the pressure is simply gravity head.

Site "B" is downhill from the experimental plots in section 7. Wet sloppy mud was found at 6'-8', wet sandy mud was found at 15'-17.5' and wet, runny marine clay was found at 20'-21'. On returning the next day, about 5' of water was in the hole.

At site "G", no remarkable water or wet cuttings were found during the drilling operation. However, on returning the next day, approximately 3' of water was found in the hole.

In summary, the greatest depth of water was found at site "C" and the abundance of water diminished in a northward direction into the property. It is hypothesized that water is entering the property predominantly through the remaining gravel identified in boring site “H”. The concept of “perched water” may be the most standard terminology that exists, but it may be more descriptive to suggest that there is *intrusive* water moving in laterally from the gravel layer that is cut off at (approximately) the property line.

Groundwater flow within and from the property is uncertain. However, retention ponds exist on the edges of the plateau (magenta circles on Figure 2). The water may be slowly entering these two ponds.

Hydraulic Conductivity

Detailed measurements of hydraulic conductivity have shown that it commonly exhibits substantial spatial variability (Vargas and Ortega-Guerrero, 2004). The wide variability in hydraulic conductivity data makes it suitable for statistical, rather than deterministic, characterization (Freeze, 1975). The assumption of lognormal hydraulic conductivity has been widely adopted in stochastic groundwater hydrology. The lognormal probability density function has been accepted by many groundwater hydrologists as a general tenet for describing hydraulic conductivity data (Freeze and Cherry, 1979, pp30-31). The geometric mean is widely used as an average or “effective” hydraulic conductivity in groundwater hydrology (Loáiciga et al., 2006). Hence, the data were reported using geometric means.

For all 23 samples, the geometric mean hydraulic conductivity was $1.26X10^{-5}$ cm/s, the minimum was $1.50X10^{-7}$ cm/s, and the maximum was $3.67X10^{-3}$ cm/s. Similar values are presented for each site in the table below (Table 1).

Table 1**:** Hydraulic conductivity results from 23 core samples taken at different locations (sites A-G) and at depths between 5’ and 25’.

Site	Geometric Mean	Minimum	Maximum	Depth of Minimum
A	$1.61X10^{-5}$	$6.09X10^{-7}$	$6.09X10^{-4}$	20-25
B	$3.83X10^{-6}$	$1.60X10^{-6}$	$1.74X10^{-5}$	15-20
C	$1.05X10^{-5}$	$2.68X10^{-6}$	$3.23X10^{-5}$	15-20
D	$1.40X10^{-5}$	$1.50X10^{-7}$	$4.22X10^{-4}$	10-15
F	$4.07X10^{-5}$	$8.25X10^{-7}$	$3.67X10^{-3}$	5-10
G	$1.11X10^{-5}$	$5.47X10^{-7}$	$9.08X10^{-5}$	20-25

Hydraulic conductivity units are cm/s. Depth is in feet.

Each site had hydraulic conductivities that were generally low, typical of fine silts and clays. With the backdrop of $1X10^{-7}$ cm/s as the standard for clay landfill liners, the average hydraulic conductivities were one to two orders of magnitude larger. At any site, the minimum K_{sat} was the same order as, or one order larger than, a landfill liner. The hydraulic conductivities in the 5-20’ range below the surface are sufficiently low as to greatly inhibit flow of water down through this material.

Nutrient Losses to the Vadose Zone

The following is a literature synthesis that identifies nitrate concentrations emanating from corn crops, from corn crops that use biosolids, and finally, from strip mine spoils treated with biosolids. This provides a backdrop against which the results from this project can be compared.

Nitrate in Corn - fertilizer losses

This section is a brief literature review of data evaluating corn losses of nitrate for the purpose of comparing the deep row forestry system to a well researched conventional agricultural practice. Baseline nitrate-N in subsurface drainage water ranges from 3-10 mg/L if no fertilizer is added to the crop. This level of fertilizer results in a crop that is not economical (Andraski et al., 2000). For corn with yields of 125 to 175 bushels per acre, nitrate in drain tile water ranged from 18 to 30 mg NO_3-N/L (Weed and Kanwar, 1996; Kanwar, 1997). Randall et al. (1997) found nitrate in drain tile water to average 23 mg NO_3-N/L for corn-soybean two-year rotation and 32 mg NO_3-N/L for continuous corn. Randall and Vetch (2005) found nitrate in drain tile water to range from 10.7 mg NO_3-N/L to 14.3 mg NO_3-N/L for the corn phase of a corn-soybean two-year rotation. Jaynes et al. (2001) found that flow-weighted nitrate-N concentrations for economically viable levels of corn production were13-25 mg NO_3-N/L. Most of these studies indicated that nitrate concentration could be reduced to 10-12 mg NO_3-N/L if N application rate was reduced, cover crops were used, applications were split, and continuous corn was replaced with a corn-soybean two year rotation.

During periods of depressed rainfall, no subsurface flow occurred beneath crop systems that had high above ground biomass, while flow occurred beneath continuous corn and corn-soybean rotation (Randall et al. (1997). Perennial crops reduced the amount of residual soil nitrogen and reduced the drainage water flow compared to row crops.

Andraski et al. (2000) found nitrate-N levels from 18 to more than 20 mg/L in suction lysimeters for various economically viable levels of corn production.

In summary, nitrate in soil water and drainage water ranged from 10 mg/L if numerous BMPs were applied to 32 mg/L for continuous corn.

Nitrate in Corn - biosolids losses

Agronomic soils

Nitrate losses from spring-fertilized corn were greater than losses from spring-applied anaerobically digested biosolids Evanylo (2003) and coarser soils lost more nitrate than did finer soils.

Binder et al. (2002) applied biosolids to plots in the spring of 1996. Sampling indicated that a pulse of nitrate moved through the profile. It was not until the fall of 1999 that the nitrate distribution profile returned to levels that were similar to untreated soils (Figure 4). The authors point out that the nitrate in the profile had two exit pathways: leaching and denitrification.

the recommended rate of 177 kg organic N/ha (160 lbs N/ac) there was less nitrate in the profile than in the control (Figure 4). When the application rate was increased to 353 kg organic N/ha (315 lbs N/ac) the profile had slightly more N than the control. Only when excessive rates were applied (706 kg organic N/ha or 630 lbs N/ac) did the nitrate in the profile greatly exceed the control.

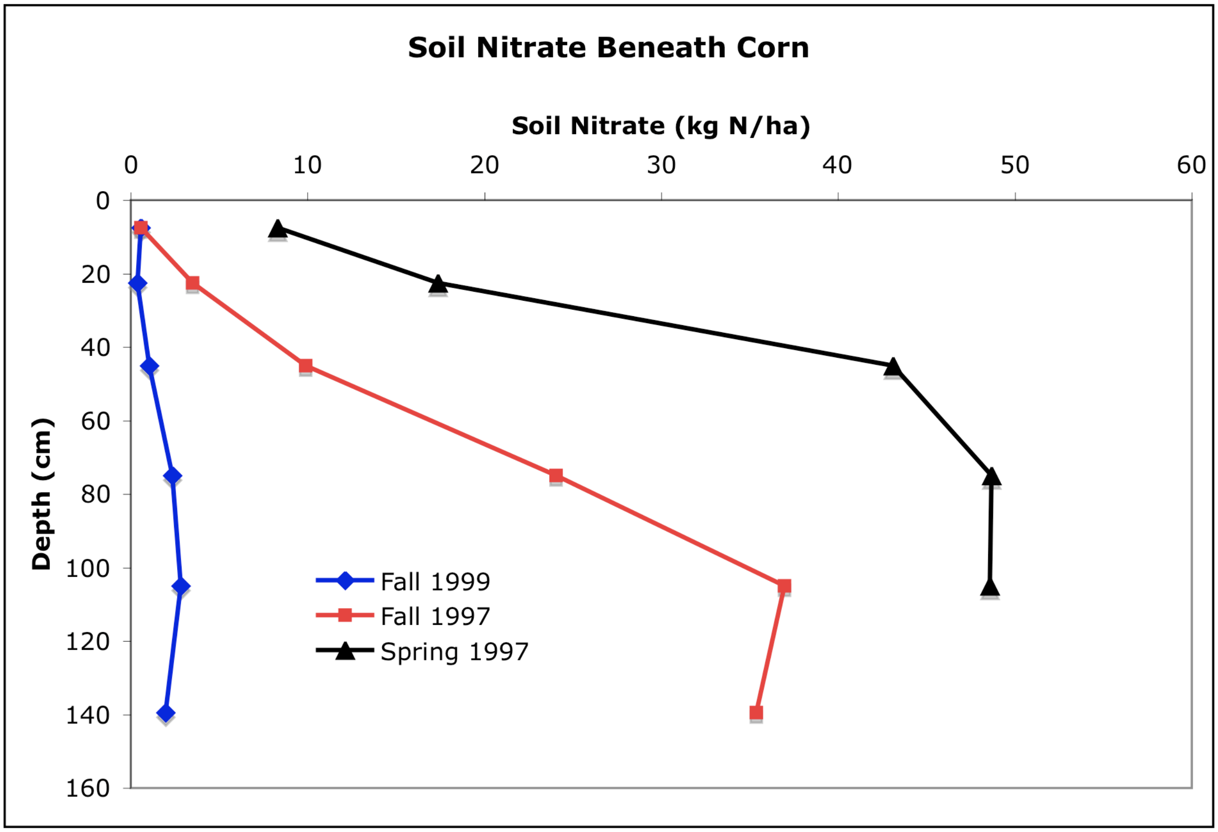

Figure 4. Soil nitrate profiles at different times following spring 1996 application of biosolids.

In the same experiment, biosolid application rates were examined. For biosolids applications in the spring of 1999 and soil tests from the fall of 1999, where the application rate was approximately the recommended rate of 177 kg organic N/ha (160 lbs N/ac) there was less nitrate in the profile than in the control (Figure 5). When the application rate was increased to 353 kg organic N/ha (315 lbs N/ac) the profile had slightly more N than the control. Only when excessive rates were applied (706 kg organic N/ha or 630 lbs N/ac) did the nitrate in the profile greatly exceed the control.

Clearly, surface applied biosolids increases soil nitrate concentration and higher application rates result in higher levels of soil nitrate (Binder et al., 2002).

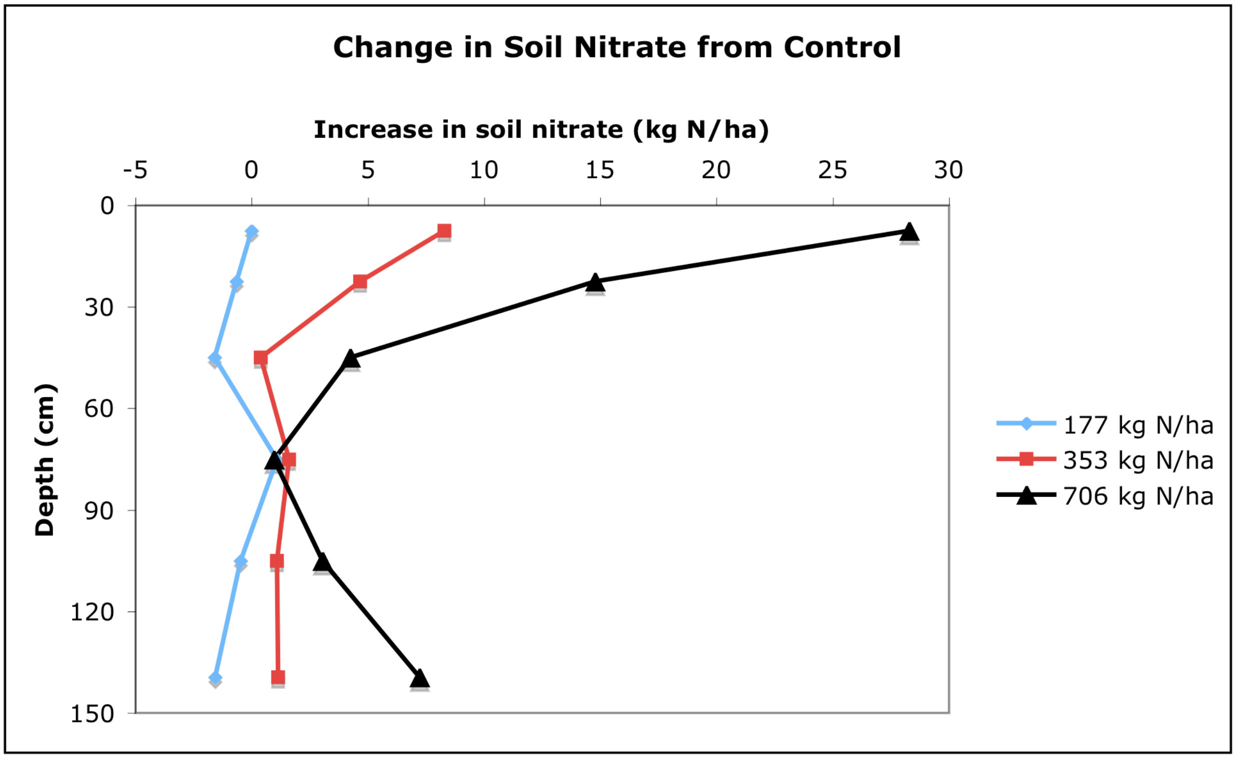

Figure 5. Change in soil nitrate from control levels for different rates of biosolids applications

Strip mine spoils

A mixture of 50% anaerobically digested biosolids and 50% composted anaerobically digested biosolids were applied at rates of up to 152 dry Mg/ha (68 dry tons/ac) or 5290 kg organic N/ha (4719 lbs N/ac). Using pan lysimeters installed one meter deep on a Pennsylvania strip mine, nitrate loss (Figure 6) occurred beginning approximately five months after application (Oct. 2001) and tapered off to low values by June of the following year (Stehouwer et al., 2006). The peak nitrate concentrations occurred in October 2001 and were greater than 300 mg NO_3-N/L. A smaller peak (150 mg NO_3-N/L) occurred in October of 2002. It was estimated that one-third of applied N was lost from the surface by leaching. Four ground water monitoring wells were installed at between 5.2 and 9.4 m depth (17-31 feet) and these wells showed very little impact from the nitrogen leaching. Brief increases in NO_3-N rose to concentrations of 6.5 mg NO_3-N/L or less.

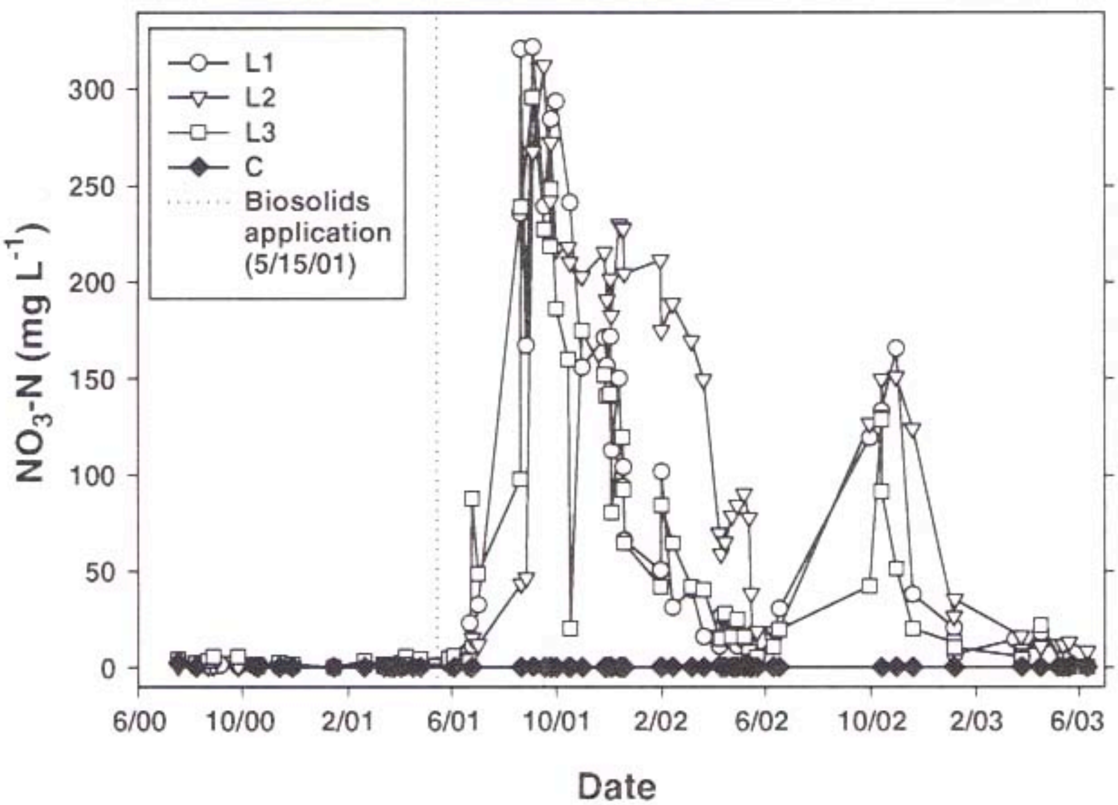

Figure 6. Nitrate concentration in pan lysimeters before and after application of 50% anaerobically digested biosolids and 50% composted anaerobically digested biosolids.

The high rates of biosolids application in the above experiment reflect the philosophy involved in reclamation. By adding a large amount of organic matter, the one to two year leaching of nitrate is sacrifices for an ecosystem that can become established and sustain itself on the strip mine spoil, something that does not usually occur if only mineral fertilizer is used.

Denitrification

Ryden (1981) measured denitrification rates between 47 and 69 kg N/ha/year from pasture land irrigated with municipal waste water. Russel et al. (1993) measures rates between 12 and 240 g N/ha/hr immediately following irrigation of a forest site with meat processing effluent. This corresponds to 100 to more than 2000 kg N/ha/year.

Nitrate in Surface Waters

A study by Tian et al. (2006) reported on surface application of biosolids at and average rate of 28.2 dry Mg/ha/yr for a 31 year period. Water was sampled for nitrogen from 20 reservoirs and 6 creeks. Sampling rate was monthly for the first decade and then 3 times per year following that. Nitrate in the receiving waters rose from 0.86 mg NO_3-N/L at time zero to just below 2.52 mg NO_3-N/L after 360 months. The difference between the control and the treated waters was 0.13 mg NH_4-N/L. The authors state that “the application of biosolids for land reclamation at high loading rates from 1972 to 2002, with adequate runoff and soil erosion control, had only a minor impact on surface water quality".

Nitrate from the Deep Row Forestry System

The data in Figure 7 represent nitrate concentrations in the pan lysimeters between November 2003 and October 2006. The control data points are the average of three data points and the levels are the average of nine data points. In approximately July 2005, nitrate began to appear in the water sampled by the pan lysimeters. The levels typically have been below 10 mg/L. At this point, variation in the biosolids application rate is not clearly related to the nitrate concentration. The control (no biosolids) also went up during the same period of time. This suggests that there may be a meteorological change that is affecting the nitrate loss from the surface. However, the control reached levels of 2-3 mg/L while the treatments reached levels of 10 mg/L.

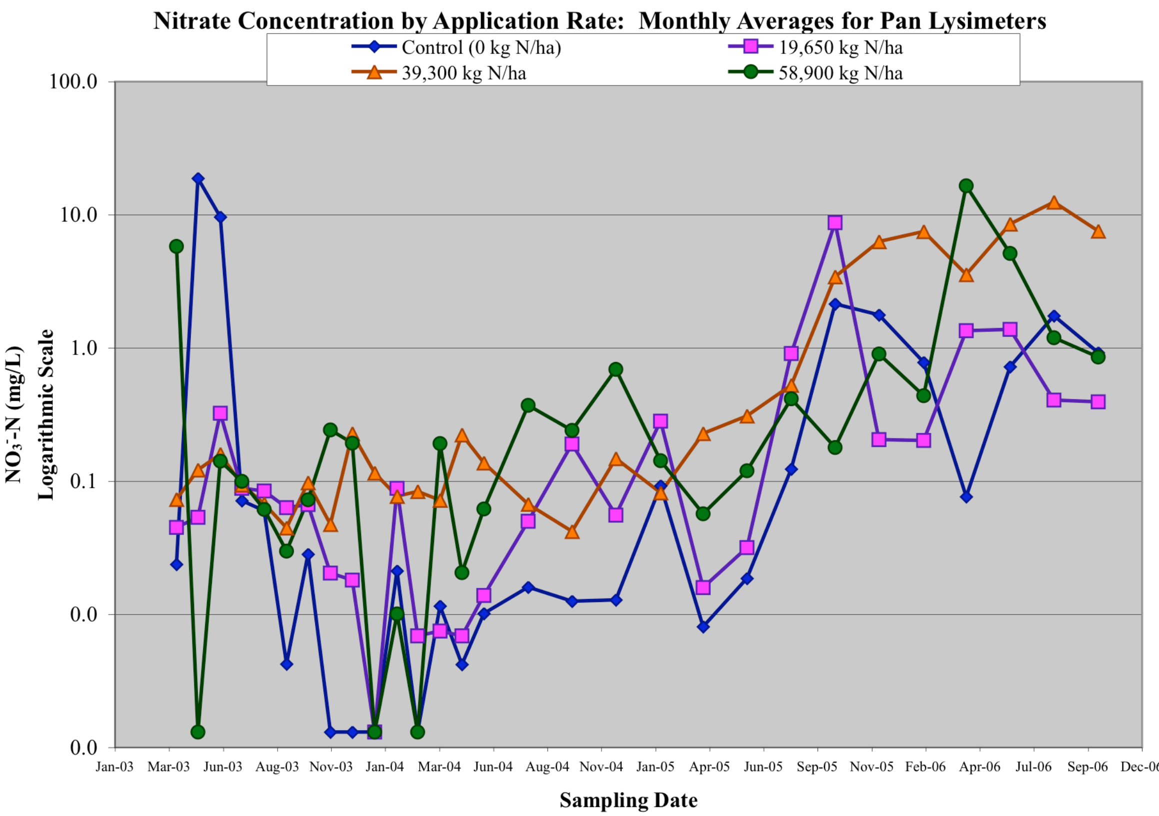

Figure 7. Monthly average nitrate concentration in pan lysimeters. (Nov. 2003-Oct. 2006)

At the same time, nitrate in the soil water, as sampled by the suction lysimeters, increased (Figure 8). The highest value was observed in the control (13.9 mg/L) for the November 2005 sampling. The highest two application rates (58,900 kg N/ha and 39,300 kg N/ha) had the lowest nitrate concentration and the lower two application rates had the highest nitrate concentrations, hovering around 10 mg/L. Between July 2005 and October 2006, all nitrate levels seemed consistent at between 1.0 and 10.0 mg N/L except for the highest application rate, which seems to be starting an increase toward 10 mg N/L from June 2006 to October 2006. The explanation for the lowest application rate increasing first may be that as application rate increases, depth increases. Hence temperature, oxygen, and microbial activity are all delayed in the heavier rates and, as a result, the formation of nitrate may be delayed in the deeper trenches.

Nitrate concentration draining from corn on agronomic soils using fertilizer or biosolids as the N source is significantly (as much as triple) higher than nitrate found beneath the deep row forestry system, even for the highest biosolids application level.

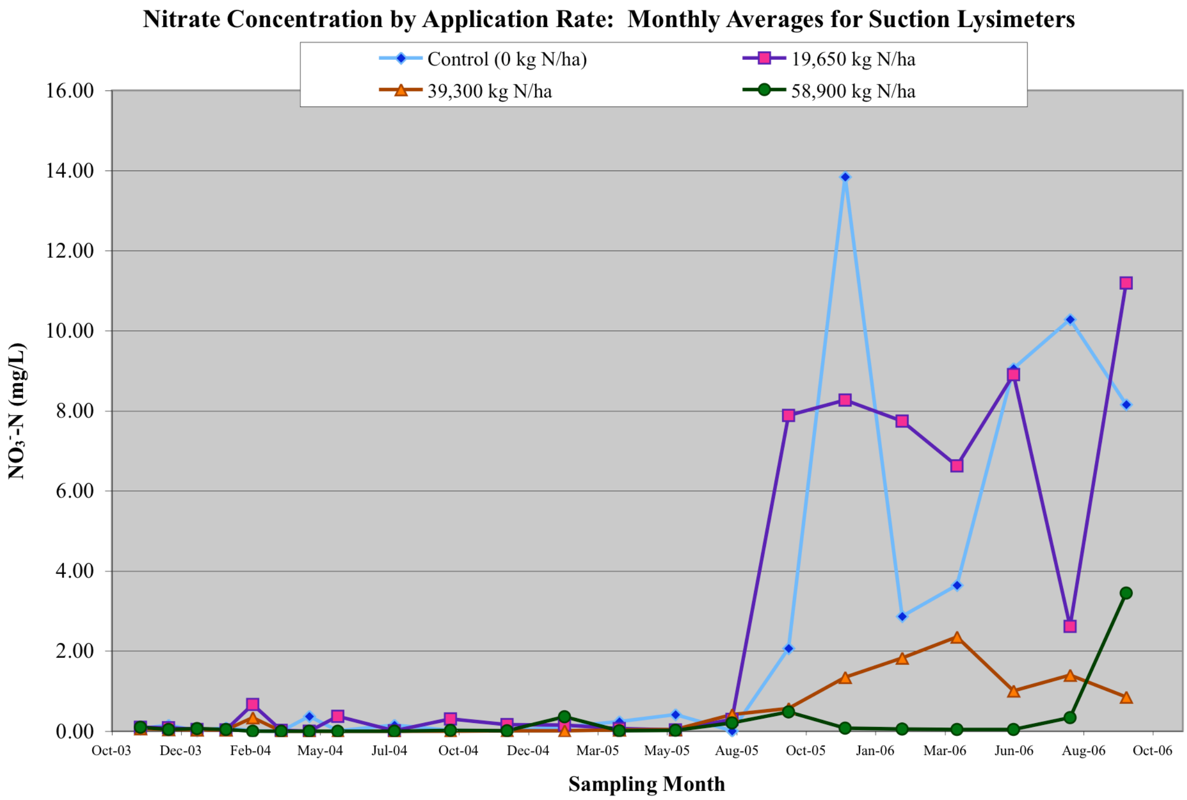

Figure 8. Monthly average nitrate concentration in suction lysimeters. (Nov. 2003-Oct. 2006)

Ammonium in Pan Lysimeters

Ammonium (mg NH_4-N/L) concentrations found in the pan lysimeters are plotted in Figure 9. Clearly, the control was well below the treatments. This was not true for the nitrate values. At about February of 2004, the three application rates had ammonium concentrations of 450-600 mg NH_4-N/L. By September 2006, these values had dropped to 175- 320 mg NH_4-N/L. This is clearly a downward trend. The heavy rate of application exhibited a peak from January 2005 through August 2005 that was not exhibited by the other two application rates. This suggests that something in the system is not responding the same in the heaviest rate. A preliminary assessment is that the heaviest rate may not be appropriate.

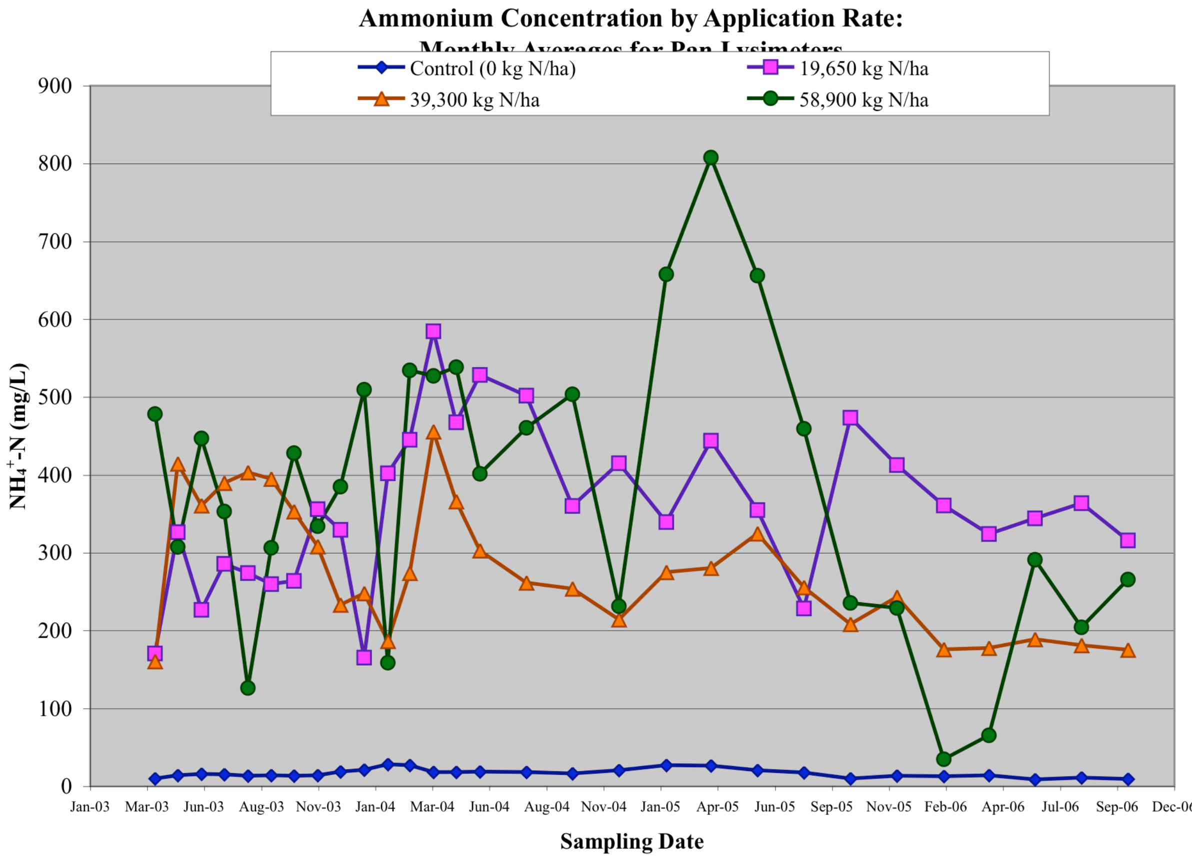

Figure 9. Monthly average ammonium concentration in pan lysimeters. (Nov. 2003-Oct. 2006)

Ammonium in Suction Lysimeters

Ammonium (mg NH4-N/L) concentrations found in the suction lysimeters are plotted in Figure 9. Consistently, the control (no biosolids application) had ammonium concentrations in the suction lysimeters just above zero. For the treatments, between October 2003 and December 2004, the ammonium level rose from approximately 400 mg/L to approximately 625 mg/L. This rise was independent of the application rate. Then in 2005 and from there on, the lowest application rate was fairly consistently at a lower concentration level than the other two rates.

There was a jump in December 2004 in the concentration from the middle application rate (39,300 kg N/ha). The concentration rose from approximately 590 mg/L to approximately 775 mg/L. The middle application rate concentration remained elevated above the lowest rate and the highest rate until March 2006. Between August 2005 and August 2006, both the low application rate (19,650 kn N/ha) and the middle application rate (39,300 kg N/ha) dropped to a low in February to April 2006 and then rose to a temporary high in August 2006. This is most likely a seasonal variation. However, the levels dropped by about 100 mg/L over that year. From March 2006 through October 2006, the concentration mirrored the application rate.

Additionally, the increase in concentration has either leveled off or has started to decrease since sometime in mid to late 2005. This was the case for all application rates.

Effects of time may be different for each application rate because the heavier rate is deeper than the lower rate. The lowest rate peaked in August 2005. The middle rate peaked in October 2005, and the highest rate peaked in August 2006. This may be due to the time required for tree roots to grow deeper for the heavier application rates. When the tree roots appear, oxygen is introduced and microbial action may change dramatically.

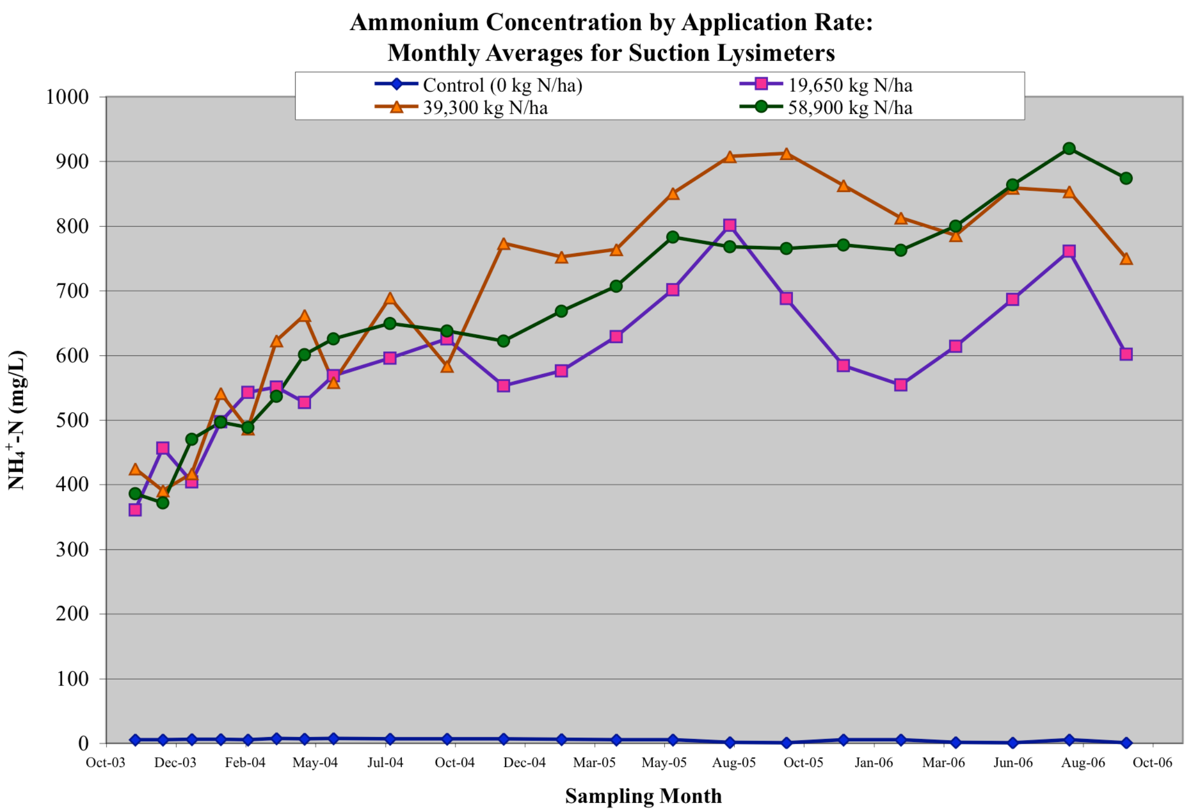

Figure 10. Monthly average ammonium concentration in suction lysimeters. (Nov. 2003-Oct. 2006)

Ammonium with depth

Figure 11 represents the effect of depth or the distance ammonium is migrating. Each data point represents 27 observations (3 replicates X 3 application rates X 3 tree densities). The controls (no biosolids) were not plotted.

First, ammonium is clearly increasing over time. At 15 cm below the trench, the ammonium level has increased from approximately 1000 mg N/L in November 2003 to approximately 2000 mg N/L in November 2005. At the 60 cm depth, the increase was from approximately 175 to 400 mg N/L. The 30 cm depth was uniformly in between. The ammonium levels at the 30 and 60 cm depth may have leveled off. The ammonium levels at the 15 cm depth may be decreasing. Additional data are necessary to draw any meaningful conclusions.

Because of the findings here, suction lysimeters were installed at 120 cm below the biosolids trench in all plots during summer of 2007. Data collection will commence in October 2007 for these lysimeters. As with most new installations, it may be six months before the readings have any meaning.

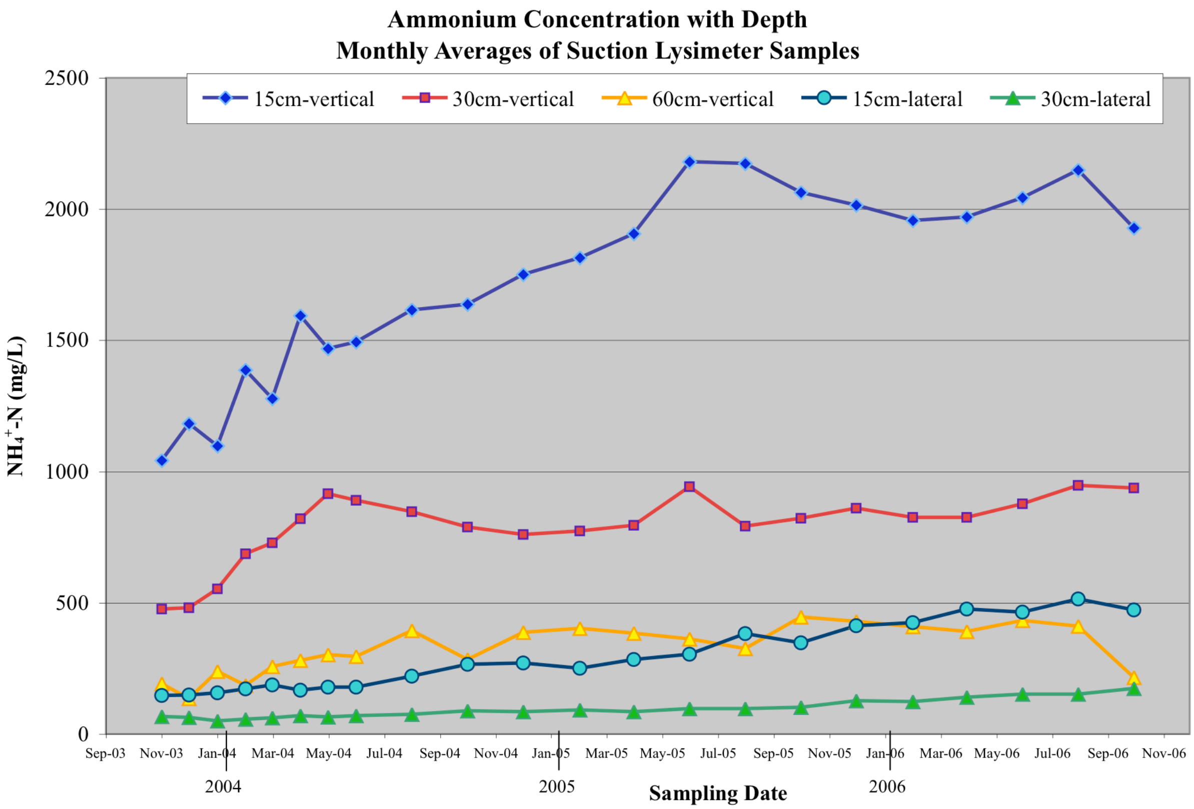

Figure 11. Monthly average ammonium concentration in suction lysimeters, sorted by depth below (vertical) and to the side of (lateral) the biosolids trench. (Nov. 2003-Oct. 2006)

Orthophosphate

Orthophosphate was monitored heavily during the first 18 months. Of approximately 220 samples, eight samples were above 1.0 mg P/L. There was no trend. It was expected that phosphorus would bind to soil particles.

Anecdotal Observations

As the additional lysimeters were being installed this past summer, the effects on the biosolids that had taken place in the past four years were obvious. Where there were trees, the biosolids were drier, not as thick, and essentially odor-free. In the control plots with biosolids and no trees, the biosolids were about the same consistency as the day they went in and the odor of ammonia was very strong. It is clear that the trees are an important moisture sink and are instrumental in removing the ammonia.

Synthesis – Nitrogen Fate and Transport
Hydraulic potential data were not collected in this study. Hydraulic potential data is the component that is necessary to calculate mass flow using Darcy's equation or the Richards equation. In the absence of such data, inferences may still be made about mass transport, based on hydraulic conductivity (K_s).

Typical silt loam soils used in agricultural operations have hydraulic conductivities ranging between 1 x 10^{-4} cm/s and 1 x 10^{-6} cm/s (Fetter, 1994). The sub-surface soils in the plots had hydraulic conductivities averaging 1 x 10^{-6} to 1 x 10^{-5} cm/s. The surface soils had K_s between 1 x 10^{-7} up to 1 x 10^{-3} cm/s but the average was between 1 x 10^{-6} and 1 x 10^{-4} cm/s, depending on the plot (Buswell, 2006). Therefore, the subsoils are one to two orders of magnitude lower than agricultural soils and the surface soils are the same or one order of magnitude less than agricultural sols classified as silt loams or silty clay loams, (sandy agricultural soils have much larger K_s than silt loams, on the order of one to 3 orders of magnitude).

Because the nitrate concentrations in the research plots are lower than published values found for agricultural fields, the nitrate loss (mass transport) logically will be less than lost from a typical corn crop. Because the hydraulic conductivity in the research plots is the same to two orders of magnitude less than agricultural soils, the mass transport will be the same order of magnitude as a corn crop to two orders of magnitude less than a corn crop.

There is an additional benefit from the slowing of subsurface flow caused by the relatively low hydraulic conductivities found in the research plots. Nitrogen that enters the soil water stays in the upper layers of the profile for a longer time (orders of magnitude longer). Hence, there is a much greater opportunity time for uptake by plant roots and denitrification by microbes to occur. This is the logical reason that the system does not lose nitrogen in large amounts.

OBJECTIVE 2. Quantify the fate of nitrogen immediately after incorporation of biosolids into deep rows and for the first six months.

Project 2 - Short Term Entrenched Biosolids Study

Instrumentation installation on the 3.1 acre research site at ERCO made it impossible to collect water quality data for the six month period from biosolids incorporation until water samples were collected. Concern was expressed by MDE that this may provide an opportunity for nitrogen to leave the site through leaching. Our expectation, based on literature and experience, is that nitrogen will not migrate early in the cycle. There is no nitrate in the biosolids when deposited and the conditions are poor for nitrate generation.

In an effort to prove this hypothesis, a single trench, approximately 90-150 feet long, was to be constructed on the ERCO site. Three pan lysimeters and three sets of suction lysimeters would be installed beneath and beside the trench to provide replication for the single treatment.

Water samples would be collected weekly for 4 weeks and twice a month for five months, after which, the experiment would be over. Project Leader: Gary Felton.

Deliverable: Analysis of water quality data to assess leaching of nitrogen during the first six months of deep row application.
Progress Update: *This project had been postponed due to the lack of biosolids in spring of 2007 when the study was to be implemented. After analyzing the recent water quality data, including nitrate and ammonia movement, it is clear that there is no early loss of nitrate from the site. To put time and resources into this experiment would not be useful. Therefore, this project has been eliminated.*

<u>OBJECTIVE 3</u>. Quantify the activity of denitrifying bacteria biosolids applied using deep row application.

Project 3 - Quantify the activity of denitrifying bacteria in different aged biosolids applied using deep row application.

The water quality results of the first two years indicate that the usual transformation of nitrogen compounds from organic nitrogen to nitrate, nitrate, ammonium, N_2, and other compounds are impacted by the environmental conditions that exist in the deep row trenches. This study will collect biosolid samples from different locations in the deep row trenches from different years and analyze them for denitrifying microbes. This analysis will help to determine if nitrogen transformations are being inhibited, accelerated or unaffected by the deep row environment and how this may affect plant uptake, leaching and other issues.
Project Leader: Scott Angle, Jennifer Becker, & Gary Felton.
Deliverables: Analysis of biosolid samples from different aged hybrid poplar plantations for microbial activity and transformations. Analysis will also compare results from different locations in the deep row trenches. Synthesis of results will provide an estimate of denitrification from the deep row process.
Progress Update: *A student was hired to perform this analysis but due to unexpected problems, the results of this study are not available. It will have to be repeated in the final year of the project.*

<u>OBJECTIVE 4</u>. Determine the effect of tree density and biosolid application rate on the above ground growth, production, and survival of hybrid poplar with deep row biosolid applications.

Project 4 - Monitoring of Hybrid Poplar Growth in Research Area

This project involves the measurement of trees planted within the research area to determine the effect of the treatments (biosolids application rate and tree density) on tree growth and survival from 2003 to the present (5 years). During the course of the project other studies have been initiated to answer additional research questions that have been raised as a result of the initial results. The initial results of all the studies are provided.
Project Leader: Jonathan Kays.
Deliverables: Analysis of tree growth (height and diameter), design and implementation of tree shelter study to determine the effect on growth and survival.
Progress Update: *The monitoring of the research plots is ongoing and five-year growth and survival results are provided as well as one year results of a tree shelter study initiated to determine the effect of tree shelters on tree growth and survival. The combination of drought, deer browsing, and lack of subsoiling during site preparation has resulted in significant mortality in the research plots during the summer of 2005 & 2006, which prompted*

replanting of approximately 35% of the trees in spring 2006 and spring 2007, respectively. Trends in the data from the research plots are provided along with comparisons to trees in the operational portion of the ERCO property. Recommendations for follow-up studies are provided.

Project Details:

<u>Hybrid Poplar Survival and Growth Results for Main Research Plot at ERCO Tree Farm</u>

Principal Investigator: Jonathan Kays

Survival and Damage by Deer & Locusts

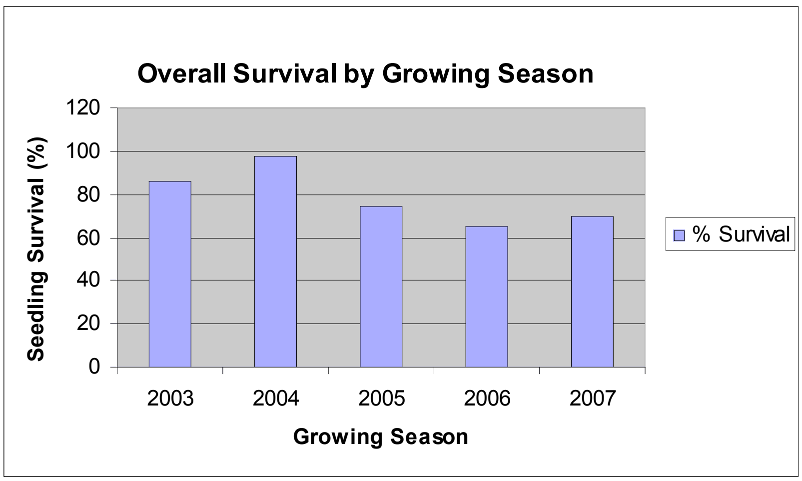

Figure 12. Overall survival by growing season

The research plot was planted with 12" hybrid poplar steckings in the spring of 2003. Competing vegetation was controlled for the first three growth seasons using Goal herbicide applied with a backpack sprayer in a 6-foot strip around the rows of seedlings. Other vegetation in the rows was controlled by mowing. No chemical control was used in years 4 & 5, only mowing. The operational site preparation method used to prepare the site for planting includes ripping the soil with a subsoiler on a 10' grid and planting steckings at the intersections of the troughs. Due to the instrumentation the research site could not be subsoiled and trees were planted with a dibble bar.

Survival in first and second growing seasons was acceptable at 86% and 97%, respectively (Figure 12). The higher survival in year 2 was due to replanting of dead seedlings after the first growing season. Survival was good despite the impact of damage agents such as deer browsing and locusts. Deer damaged 20% of the trees in the first year (Figure 13) and continued to be a factor although the damage was not assessed after year 1 since all trees less than 5 ft. were affected. In general, deer browsing appears to increase each year due to nearby land clearing for development. The deer browsing had a significant impact on height growth the first year. Trees that were browsed averaging 36 cm in height and those not browsed averaging 52 cm, a difference of 16 cm, or a 31% reduction in height growth. Since deer have a major impact on growth, it is critical to find strategies to maximize first year growth so the trees can reach a height of 5 feet and the terminal leader be free from deer browsing.

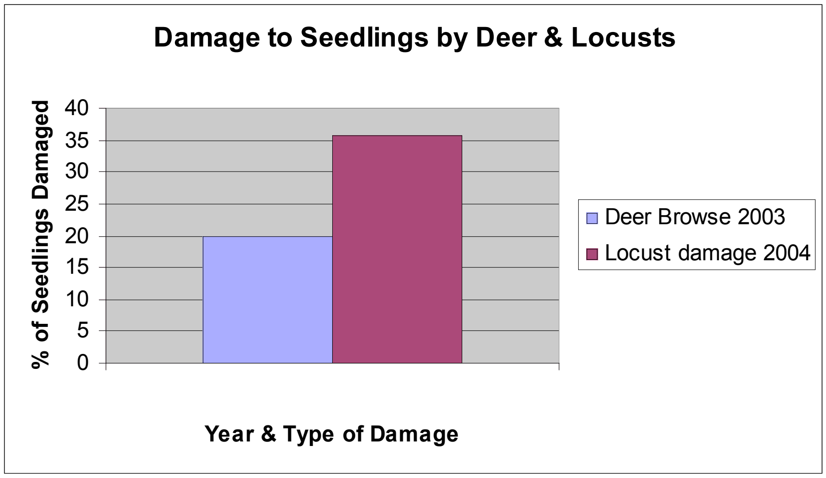

Figure 13. Percent of seedlings damaged by deer and locusts in 2003 & 2004.

The arrival of the 17-year locusts in the second growing season (2004) damaged 36% of the trees (Figure 13). This rare occurrence did not impact survival for the second growth season, although locusts do lay eggs that result in broken branches and leaders during the present year and the following year (i.e. the third growing season) that will make them less vigorous. The locusts did impact height growth across the plots the second growing season. Trees with no damage averaged 156 cm in height while those damaged averaged 112 cm, a difference of 44 cm, or a reduction in height growth of 28%.

Survival in Years 2005 to 2007

Rainfall data indicates that 2003 and 2004 were years with adequate rainfall, however, the three year from 2005 to 2007 were periods with below average to drought conditions. Survival plummeted from 97% in 2004 to 74% in 2005. The combination of low rainfall, locust damage and deer browsing could have all contributed to this decline. In spring of 2006, all of the dead trees (32%) were replanted using a dibble bar to create a hole for the new stecking, and a tree shelter was installed to protect the new growth from deer browsing. The lack of early spring rainfall and drought conditions throughout the season resulted in mortality of almost all of the replanted steckings, and some established trees.

In spring of 2007, 38% of the trees on the plot were replanted with new steckings. This included trees replanted in 2006 (32%) that died as well as additional trees. To increase the chance for success a hydraulic hole digger was used to dig a hole 12” deep and then pack the excavated dirt around the stecking. The tree shelter was reinstalled. Once again there was a complete lack of early season rainfall and a severe drought throughout the summer of 2007, resulting once again in mortality of most of the seedlings. At the end of the 2007 growing season there was 70%

survival overall, similar to 2006. The site will not be replanted again so that we can follow the existing trees.

Tree Survival Variation Across the Research Area

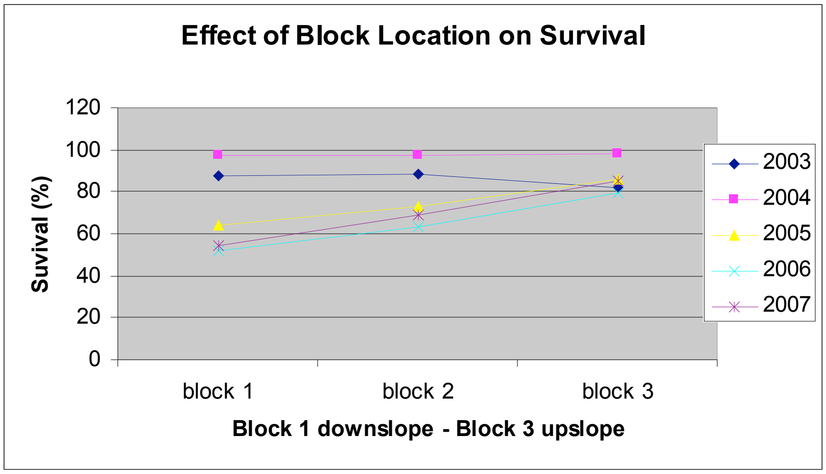

Figure 14. Percentage of seedling survival 2003-2007

Various analyses were completed to see if there was variation in survival across the research plot during the first 5 years. There were no differences in survival between any of the treatments (application rate & tree density), however, the survival varied between Blocks in different years. While there were no changes in survival between Blocks in 2003 & 2004, there was a clear increase in survival from Block 1 to Block 3 for the three drought years of 2005 to 2007 (Figure 14). For example, in 2007 the survival was 56%, 69% and 85% for Block 1, 2 & 3, respectively. This is a difference of 30%, or the difference between a poorly stocked and adequately stocked plantation.

The trend is attributed largely to differences in soil composition combined with drought during the 2005 to 2007 growing seasons. Block 1 is located downhill on a mild slope and has a soil composition of loose sand and gravel with little clay, resulting in the inability to hold moisture during critical periods of drought. Moving upslope to Block 2 and then to Block 3 the soil composition changes to one with higher amounts of clay and moisture holding capacity to sustain the trees during times of drought, as well as more level ground to prevent runoff.

The slight slope on which Block 1 and part of Block 2 are located combined with the site preparation method used on the research plot may also be a factor. The operational site preparation method creates small troughs from subsoiling that run on a 10' grid across the site, which creates areas where rainfall can collect, capturing runoff and making water available close to seedlings. The instrumentation on the research site made this operation impossible, so there was no breaking up of the ground to allow deep root development, or the troughs available to collect runoff. Therefore, the seedlings were more susceptible to mortality during drought conditions. The collection of water in troughs on the operational area was noticed anecdotally in the field during August 2007.

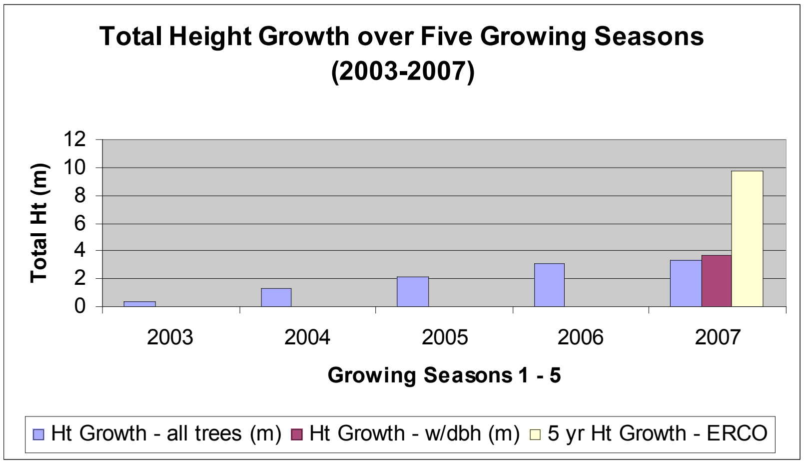

Figure 15. Total height growth from 2003-2007.

Total Height

Total height growth over the five growing seasons increased in a linear fashion from 2003 to 2006, and leveled off in 2007 (Figure 15). Total height in 2007 was slightly higher when only those trees with dbh were included.

Trends in total height between different tree densities, application rates, and blocks, are provided below. However, these analyses may not be representative of differences in plantations grown using normal subsoiling for site preparation.

The trend of increasing tree height from Block 1 to Block 3 started in 2004 and became very pronounced by 2007 (Figure 16). The better water holding capacity of Block 3 & 2 compared to Block 1 along with the more level topography (less runoff) may have allowed trees in Block 2 & 3 to better handle the drought conditions.

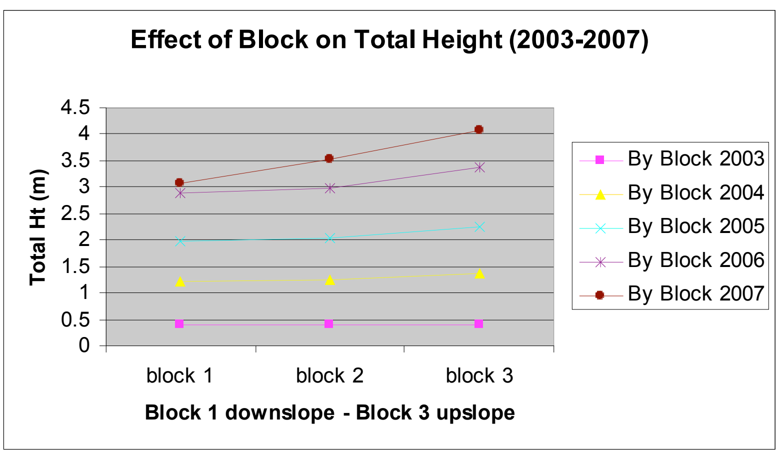

Figure 16. Trend of increasing tree height in relation to Block location

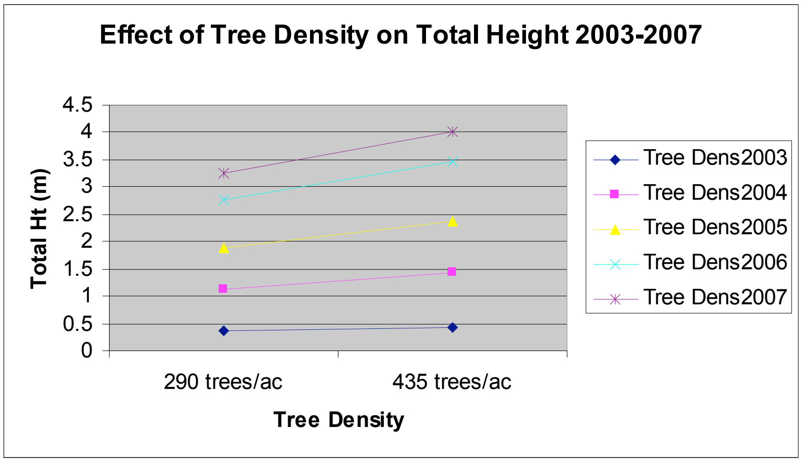

Figure 17. Trend of increasing height as it pertains to tree density

A trend of increasing height for treatments with higher tree densities (435 trees/acre) compared to those with lower tree density (290 trees/ac) started in the second growing season (2004) and become more pronounced from 2005 to 2007 (Figure 17). The reason for this difference is unclear. It would seem intuitive that plots with fewer trees would be able to compete more effectively for the available nutrients and scarce moisture during periods of drought, however, the trend is directly counter.

Biosolid application rate appears to have an impact on tree height growth (Figure 18). Starting in the second growth season the mid-application rate of 8000 lbs/N/ac was higher than that of the lowest and highest rates. It would seem logical that the higher application rate would have higher amounts of nutrients and water to sustain tree growth, especially during periods of drought.

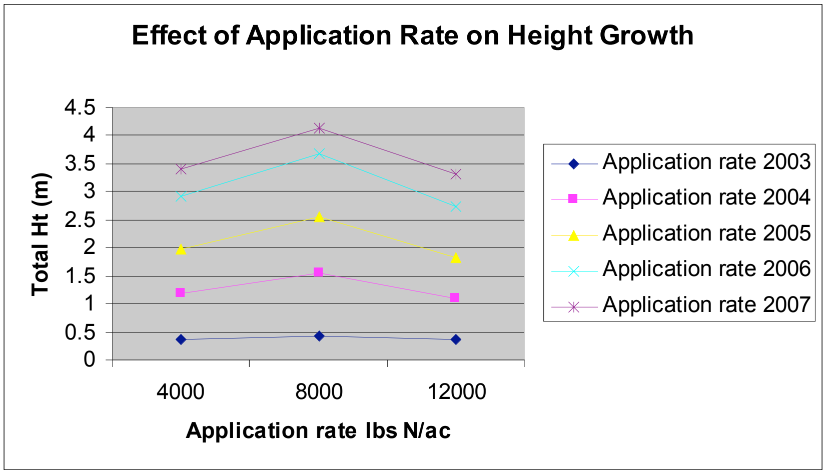

Figure 2. Biosolid application rate and its effect on height growth

It is possible that the trench depth of the highest application rate made it difficult for the tree roots to wrap around the trenches and utilize the nutrient resources since the raw biosolids are toxic to tree roots initially. The lack of height growth response for the lowest rate which should be the most available and accessible is unclear.

Biomass Production

Biomass of the trees was calculated using a growth equation developed from destructive sampling of trees in the ERCO operational area that were planted from 1999 to 2003, and harvested in October 2005 (Felix, Tilley, & Felton in press). Different equations were used depending upon if the diameter was more or less that 4 cm. The taller tree heights on Block 3 compared to Blocks 1 & 2 translated into almost doubling of the average biomass per tree on Block 3 (Figure 19). The better moisture holding of the soils and more level terrain is likely responsible for the increased production.

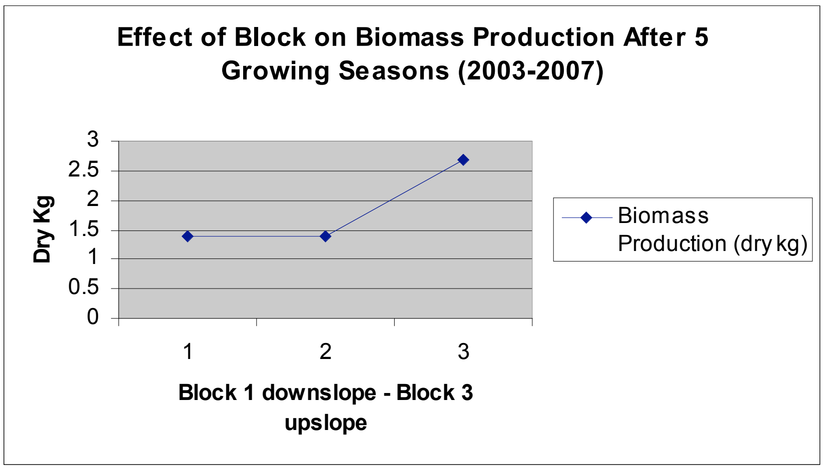

Figure 19. Effect of Block on biomass production after five growing seasons

Comparison of Trees in Research Plots and Operational Area of ERCO

The average growth of one tree, at three and five years of age, on the operational portion of the ERCO site (Felix, Tilley, & Felton in press) is compared with results from the research plot (Table 2). At three years of age trees in the operational area had more than double the height at 4.9 m. After five years, height and diameter of trees in the operational area were almost three times higher than those in the research area, while biomass was eight times higher.

Table 2: Average growth for individual trees at 3 & 5 years in the Research & ERCO Operational Areas

	Research Plot Tree Growth 2003-2007		Operational area Tree Growth1999-2005	
	3 years	5 years	3 years	5 years
Total Height (m)	2.1	3.3	4.9	8.4
DBH (cm)	-	3.2	-	9.5
Biomass (dry kg/tree)	-	1.83	-	14.9

The lack of proper site preparation and heavy deer browsing of young seedlings on the research plots explains much of the poorer growth and production. Another major factor is the drought years of 2005, 2006 & 2007 which impacted the growth of the research plots but only impacted the last year of growth for the trees destructively sampled in 2005.

Foliar Nutrient Analysis

To assess the uptake of nitrogen and other nutrients by the trees, foliar leave samples were taken each growing season in mid to late August. A composite sample was taken from each of 18 plots with different tree density and biosolid application rate treatment. The samples were analyzed by A& L labs in Richmond, Virginia for the full range of nutrients. The nitrogen/phosphorus ratio was calculated.

There are no comprehensive empirical studies correlating levels of foliar nutrients concentrations and poplar growth, however, higher foliar nutrient levels are usually correlated with faster growth. Hansen (1994) summarized data from 435 foliar samples collected over a period of 10 years from studies in north-central United States. Means of foliar N, P, K, and Ca concentrations were provided from those plantations designated as nutritionally adequate for fast growth. Foliar concentrations of hybrid poplar clones with adequate nutrition had the following concentrations for each nutrient: N (3.29%); P (0.33%); K (1.51%); and Ca (0.63%). In separate studies on hybrid poplar clones, both Hansen (1988) and Heilman and Xie (1993) suggest that maintaining a 3% foliar N concentration was desirable for fast growth. Clonal studies by Zabek (1995) on the eastern side of Vancouver Island found maximum growth occurred at foliar concentrations of 3.6% N and 0.42% P.

Maintaining balance between N and other essential nutrients in critical for optimal production. Recommended ratios for poplar based on laboratory grown plants are, 100 N: 11 P: 48 K: 7 Ca: 7 Mg (Stanturf et al.).

Zabek (1995) did one and two year fertilization experiments of hybrid poplar clones in British Columbia and found that N:P rations may provide an effective tool for determining when to fertlize with N and P. Trees with foliar N:P ratios less than 9 generally increased growth in response to N addition as well as N and P addition. Those with ratios of 9 to 11 responded to only N and P or had a greater growth response to N and P than to N alone. Addition with only N in the second year of fertilization increased ratios, suggesting possible P deficiencies for trees with ratios greater than 11.

Table 3: Summary of foliar nutrients for the entire research plot area for each year at ERCO.

YEAR	PER_N	PER_S	PER_P	N/P RATIO	PER_K	PER_MG	PER_CA	PER_NA
2004	2.89	0.51	0.28	10.48	1.34	0.31	0.94	
2005	3.39	0.40	0.20	16.58	1.27	0.41	1.12	0.01
2006	2.99	0.34	0.28	10.69	1.52	0.39	0.94	
2007								

YEAR	PP_B	PP_ZN	PP_MN	PP_FE	PP_CU	PP_AL
2004	24.17	60.50	154.78	143.50	7.83	25.39
2005	30.50	78.56	310.67	76.78	16.56	15.11
2006	28.17	61.56	150.72	84.44	10.56	12.06
2007						

In 2004 and 2006, the N:P ratio was between 9 and 11, indicating the nutrients were in balance for continued growth. In 2005 the N:P ratio increased dramatically to 16.58 due to the high N foliar level and low P level. In this case, continued growth responses would require more P to improve the balance, providing some justification for fertilization with P to the trees for continued growth the next growing season.

The overall values for nitrogen and phosphorous in this study ranged from 2.89 to 3.39 over the first three years, which are on both sides of the 3% N suggested for fast growth (Table 3). While this indicates the trees are accessing nutrients in the biosolids, values of 3.5 and higher are regularly reported in the operational areas of the ERCO site. The lack of subsoiling in the research plots may have limited root growth and development needed to utilize the nutrients in the biosolids at greater depths. This may have resulted in poorly developed root systems that were unable to withstand drought in later years of growth, leading to greater tree mortality.

A statistical analysis was completed to determine if foliar nutrient values were significantly affected by block location, tree density and/or biosolids application rate. In general, the most significant differences occurred between different blocks, while tree density and application rate did not affect foliar nutrient levels. A consistent pattern of higher levels of foliar N from Block 1 to Block 3 is seen starting in 2005 with a major trend expressed in 2006 (Figure 20). The 2007 date is still being analyzed and will help determine if this trend continues.

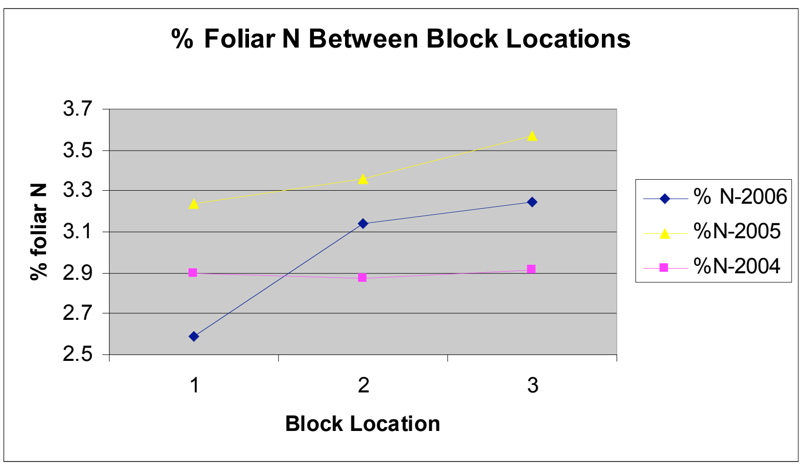

Figure 20. Percent foliar N between different blocks for 2004, 2005, and 2006.

Foliar K also demonstrated a similar pattern with a significant increase in % foliar K in Block 3 compared to Block 1 and 2 (Figure 21).

Growth rates of hybrid poplar are known to increase at higher foliar concentrations. The increase in height growth reported for trees in Block 3 (Figure 17) is related to an increase in foliar N and K for Block 3, indicating this relationship hold for this research.

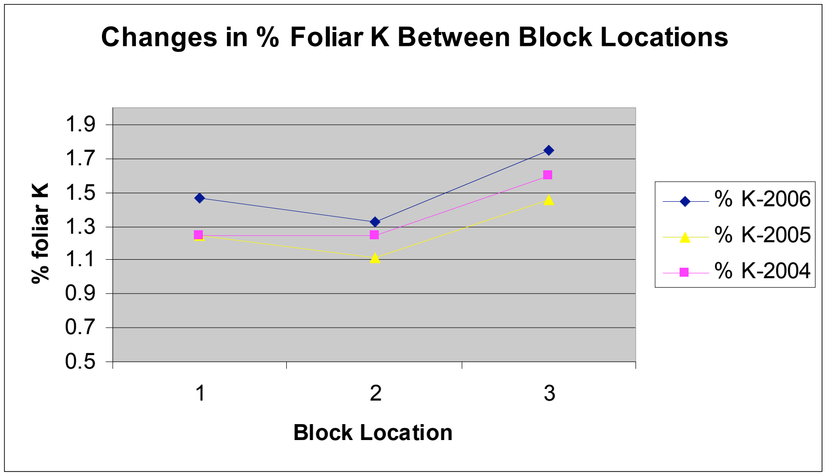

Figure 21. Percent foliar K between different blocks for 2004, 2005, and 2006

<u>Conclusions</u>

The ability to assess the growth of hybrid poplar trees and how it may be impacted by application rate and tree density is limited. The mortality and deer browsing has left large holes in the research area and even those trees that are now growing out of the reach of deer had their growth significantly impacted during the earlier years of growth. Still, measurements will continue to be taken, including dbh, which up until the 2007 growing season, had not been recorded.

The harshness of the research site for the growing of hybrid poplar trees can not be overstated. The lack of proper site preparation, combined with variable soil composition, deer browsing, locusts, and drought has resulted in significant reductions in height, diameter, and biomass production compared to trees in the operational area of the ERCO site that have not been as heavily impacted by these forces.

There appears to be a clear transition in soil composition from the loose, gravelly material that makes up Block 1, to the flatter, upslope location of Block 3 composed of soil material with more clay. Block 2 appears to be a transition zone between the two areas. Block 1 has poorer moisture holding capacity that manifests itself by poorer tree growth and survival compared to Block 3. After five years of growth it is clear that initial site preparation has a significant impact on the ability of the trees to withstand drought on this harsh site. The effectiveness of the subsoil troughs to capture what little water falls may contribute to survival in the worst of conditions.

Several trends in the data indicate that plots with higher tree density (435 trees/ac) are taller than plots with lower density (290 trees/ac). Height growth is taller in plots with the mid application rate (8000 lbs N/ac) compared to those in the 4000 and 12,000 lb N/ac application rate. The reasons for these trends are unclear but in both cases the trend only developed in the last two growing seasons (2006 & 2007). These were years of serious drought and these effects are likely related to interactions of drought and other factors.

Height and diameter growth of 3 & 5 year-old trees in the operational plots at ERCO were higher by about a factor of three and biomass production increased by a factor of eight. This was due to the cumulative impacts of many factors found on the research plot. The use of proper site preparation (subsoiling) is essential to allow early root growth and development, as well as to provide troughs that can hold water during times of drought. The stunted early growth of trees on the research plots made the trees more susceptible to deer browsing, which resulted in a longer time to reach about 5 feet in height and then be free to grow and develop the crown. The lack of early root development and growth likely contributed to the high levels of mortality of trees that were 3, 4 and 5 years old.

The ERCO overall has experiences significant increases in deer pressure due to surrounding development. New strategies are needed to maximize early height growth and root development to get the trees over 5 to 6 feet tall and minimize browsing impacts. The use of drip irrigation needs to be considered and experimented with to determine practices that are cost-effective.

The foliar nutrient results indicate that the trees are accessing the biosolids but there is great room for improvement. Maximum growth of hybrid poplar under fertilized conditions is thought to occur at 3.6% foliar nitrogen and 0.42% foliar phosphorous. However, fast growth is known to occur when foliar N levels are over 3%. The range in foliar N in the research plots ranged from 2.89% to 3.39%, which indicates the trees are accessing the nutrients. These foliar N levels are lower than those found in many of the operational areas of ERCO; however, the growth rates of trees in the operational areas are far superior. It is possible that while the trees are utilizing the nutrients, the stress imposed by hard soils combined with drought, as well as deer browsing, require the tree use its food reserves for basic plant maintenance rather then height growth. Once again, if irrigation were used, it is likely the foliar levels along with growth with increase dramatically but more research is needed.

Table 4: Individual data statistics for each of the five growing seasons used to develop the various figures and tables in the previous section.

Table 4. Survival & growth data in research plot for each of the five growing seasons (2003-05)

Survival & Growth in Research Plot after 5 Growing Seasons - 2007

	block 1	block 2	block 3	treedens290	treedens435
# obs w/ht only	172	218	269	338	321
Total ht (m)	2.77	3.15	3.69	2.83	3.74
# obs w/ht &dbh	148	187	238	279	294
Total ht (m)	3.08	3.53	4.07	3.24	4.02
dbh (cm)	2.84	2.9	3.61	2.69	3.64
biomass/tr (dry kg)	1.39	1.39	2.69	1.34	2.47
biomass/ha (dry kg)	245	245	473	236	435
biomass/ac (tons)	1				
% trees with ht & dbh	15.7	9.8	25.2	29.5	31.1
% trees with ht	18.2	23.1	28.5	35.8	34
% Survival	54.6	69.2	85.4	70	69.5
% Replant	48.2	36.8	20.3	37.5	32.7

	rate4000	rate8000	rate12000	All trees

# obs w/ht only	229	226	204	659
Total ht (m)	3	3.84	2.96	3.27
# obs w/h & dbh	193	205	175	573
Total ht (m)	3.4	4.14	3.31	3.64
dbh (cm)	2.85	3.73	2.89	3.18
biomass/tr (dry kg)	1.55	2.44	1.73	1.83
biomass/ha (dry/kg)	273	429	304	322
biomass/ac (tons)				
% trees with ht & dbh	20.4	21.7	18.5	60.6
% trees with ht	24.2	23.3	21.6	69.7
% Survival	69	71.8	68.5	69.7
% Replant	36.8	31.8	36.9	35.1

Survival & Growth in Research Plot after 4 Growing Seasons – 2006

	block 1	block 2	block 3	treedens290	treedens435
# obs w/ht only	162	199	251	302	310
Total ht (m)	2.88	2.98	3.39	2.76	3.48
basal diam (cm)	3.51	3.84	3.91	3.41	4.15
% Survival	51.8	63.1	79.7	62.7	67.1
% Replant	43.8	33.7	18.4	35.6	28.1

	rate4000	rate8000	rate12000	All trees
# obs w/ht only	203	215	194	612
Total ht (m)	2.92	3.68	2.73	3.12
basal diam (cm)	2.85	3.73	2.89	3.78
% Survival	64.4	68.6	61.6	64.8
% Replant	31.8	28.9	35.2	32

Survival & Growth in Research Plot after 3 Growing Seasons - 2005

	block 1	block 2	block 3	treedens290	treedens435
# obs w/ht only	202	231	270	349	354
Total ht (m)	1.99	2.05	2.26	1.87	2.36
basal diam (cm)	1.98	2.07	2.15	1.81	2.34
% Survival	64.1	73.3	85.7	72.3	76.6

	rate4000	rate8000	rate12000	All trees
# obs w/ht only	236	241	226	703
Total ht (m)	1.97	2.54	1.82	2.12
basal diam (cm)	1.84	2.56	1.81	2.07
% Survival	75	76.5	71.8	74.3

Survival & Growth in Research Plot after 2 Growing Seasons - 2004

	block 1	block 2	block 3	treedens290	treedens435
# obs w/ht only	306	306	308	468	452
Total ht (m)	1.212	1.256	1.382	1.138	1.434
basal diam (cm)	1.65	1.72	1.63	1.51	1.82
% Survival	97.1	97.1	97.8	96.9	97.8
% locust damage	35.2	43.8	27.6	34.8	36.4

	rate4000	rate8000	rate12000	All trees
# obs w/ht only	308	305	307	703
Total ht (m)	1.195	1.559	1.098	1.283

basal diam (cm)	1.53	2.02	1.46	1.67
% Survival	97.8	96.8	97.5	97.4
% locust damage	33.3	50.8	22.5	35.6
Total ht - no damage (cm)				156.8
Total ht - damaged (cm)				112

Survival & Growth in Research Plot after 1 Growing Season - 2003

	block 1	block 2	block 3	treedens290	treedens435
# obs w/ht only	275	278	258	414	397
Total ht (m)	0.389	0.396	0.401	0.3696	0.422
basal diam (cm)	0.04	0.04	0.05	0.04	0.05
% Survival	87.3	88.25	81.9	85.71	85.9
% browse	22.5	21.3	15.87	12.6	27.5

	rate4000	rate8000	rate12000	All trees
# obs w/ht only	276	278	257	811
Total ht (m)	0.369	0.437	0.377	0.395
basal diam (cm)	0.04	0.05	0.04	0.05
% Survival	87.6	88.2	81.6	85.8
% browse	12.7	32.7	14.3	19.9
Total ht - no browse (cm)				52.4
Total ht - browsed (cm)				35.6

Contrast of Tree Growth Using Deep Row Application at Different Locations

The ERCO site is the only place in the world with long-term data on deep row incorporation using hybrid poplar. However, two separate studies have been implemented in Pennsylvania and Virginia based on the ERCO production model on very different reclamation sites and the opportunity exists to compare some of that early data with results from the ERCO study.

In May and June 2005, 14-acres of hybrid poplar clone (OP367) were planted after deep row application of biosolids on an anthracite mine reclamation site near Pottstown, PA (Toffey, et al. 2006). Deep row application rates from 0 to 100 dry tons per acre were applied in deep rows with extremely stony soils with virtually no organic mater or nutrients. In general, tree growth increased with higher application rates. After two growing seasons the average height of the tallest trees was 3.03 meters, which is much more than the 1.3 meters of growth reported after two years on the ERCO research plots. While we lack specific measures for two years of growth on the operational area at the ERCO site, three year's growth averaged 4.9 meters, so using some interpolation, seems similar to that for the Pottstown site.

Deep row incorporation was initiated on a mineral sands mine reclamation site near the Coastal Plain-Piedmont fall line in Dinwiddie County, Virginia. The objective is to quantify the transformations of nitrogen and phosphorus applied to the soil as entrenched biosolids. The experimental design consists of 8 treatments replicated four times. Two types of biosolids were applied in subsurface trenches at two rates: lime-stabilized at 328 and 656 tons/ha and anaerobically-digested at 213 and 426 tons/ha. Four additional treatments include four rates of nitrogen fertilizer. The sites are fully instrumented with lysimeters and initial results should be available soon.

Contrast of Tree Growth on Mine Spoils with Surface versus Deep Row Application

It is useful to contrast the production of hybrid poplar using deep row application with results from other mine spoils sites using surface application, although soil composition and nutrient availability are different. Sopper (1990) looked at individual height growth response to four biosolids treatments on mine spoils in Pennsylvania and found three year height growth varied from 2.56 to 2.92 meters, which is not much more than the height growth of trees on the research plot (2.1 meters). Likewise, Sopper (1990) found that survival of hybrid poplar after the first, second, and third years was 70, 65 and 60%, compared to 86, 97 and 74% for the research plots at ERCO. Even with the negative impacts of browsing and lack of proper site preparation, hybrid poplar in the ERCO research plots performed as well as trees planted on Pennsylvania mine spoils amended with surface application of biosolids. The use of more current clonal varieties in the Sopper study may have impacted these results.

Conclusions and Discussion

The growth and biomass production of hybrid poplar using deep row incorporation on the operational area at ERCO is much greater compared to growth and survival using surface application of biosolids on mine spoils or trees grown in the research plots at ERCO. The poorer performance of trees in the research plots at ERCO compared to the operational area indicates that differences in soil composition, subsoiling, deer browsing and drought can significantly reduce growth and survival of hybrid poplar.

Trying to determine the relative effect of each factor on survival and growth is difficult, however, it does appear drought stress, whether imposed by soil composition, proper site preparation, or deer browsing is a major factor. Other research confirms that hybrid poplar species are the most susceptible woody plants to drought, and that significant genotypic variability has been recorded in water deficit tolerance and patterns of response to water deficit (Ceulemans et al. 1978; Pallardy and Kozlowski 1981; Gebre and Kuhns 1991; Liu and Dickman 1996; Chen et al. 1997; and Marron et al. 200, 2003). Research by Lie, Yin, and Li (2006) demonstrates that drought stress significantly reduces growth (height and biomass production) imposed by drought. Two contrasting populations of *Populus przewalskii* from wet and dry climate regions of China were exposed to three different watering regimes in a greenhouse study. There were significant differences in drought stress between the two contrasting populations. Compared to the wet climate population, the dry climate population showed lower dry matter accumulation and partitioned more biomass to root systems.

The clonal variety used on the ERCO site since 1999 is OP367. It was selected after five years of clonal trials at the ERCO site using the operational site preparation technique of subsoiling, and an application rate equal to the 4000 lb N/acre (Kays 2006). Eleven *Populus* clones were tested that had performed well commercially in different environments across the United States. The OP-367 clone was the best performer in terms of survival (96%) and total height growth after 5 years (9.3 m). A study of survival and growth of 31 *Populus* clones in South Carolina on two different sites (with irrigation as a treatment), found the OP367 had a rank of 2 out of the 31 clones for survival after three growing seasons (Coyle, et al. 2006).

The OP367 clone is derived from the *Populus deltoides X Populus nigra* crosses. Monclus et al. (2006) examined the relationships among productivity, water use efficiency and drought tolerance in 29 genotypes of *Populus x euramericana*, a *Populus deltoides x Populus nigra* variety, and found that most of the productive genotypes displayed a low level of drought tolerance (i.e. a large reduction in biomass), while the less productive genotypes presented a large range of drought tolerance. The OP367 clone has proven itself as a productive genotype on the ERCO site compared to others tested, but its poor performance under drought conditions within the research plots (poor survival and biomass production) confirms its limitations in this extreme environment and suggests other options need to be examined to remedy the situation.

The clonal trials at the ERCO site occurred during a time frame when there were no significant droughts or deer browsing, therefore, it is difficult to make any conclusions regarding the performance of tested clones under the unique conditions of deep row application. One option is to perform another clonal trial without the standard site preparation of subsoiling (i.e. plant with a dibble bar) and follow the performance of the clones for one or two years to see which are able to survive and grow under the poor rooting conditions and likely drought stress imposed. Prior to the use of the OP367 clone, the HP308 clone was used for 16 years with no recorded plantation failure from drought. However, deer browsing, which imposed significant stress on early growth, was not an issue during that time. It may be possible that the poorer growth and higher incidence of canker of the HP308 may be balanced by the ability to grow under higher levels of drought stress.

The other option to improve performance under drought stress is to irrigate. The positive effect of irrigation on *Populus* growth is well established, as trees in this genus are hydrophilic (Souch 1998; Shock 2002). Much of the short-rotational intensive hybrid poplar culture has been in the Pacific Northwest on the west side of the Cascades where the climate is wet and mild. A 4-year old plantation on a10-ft spacing reached 12.4 tons/ac/yr in the fourth year (Heilman and Stettler 1985). However, with adequate irrigation, some hybrid poplar clones on the drier eastern side of the Cascades can grow faster (Heilman et al. 1995). The study by Coyle et al. (2006) of 31 hybrid poplar clones under irrigated and nonirragated treatments in North Carolina reported a 63% increase in volume for clones.

Irrigation can be the most expensive management practice in poplar plantation culture (Rose and DeBell (1978). Therefore, before irrigation can be justified on the ERCO site, research must be completed to determine if the improvements in survival and biomass production which translate into economic gains through reduced rotation length, are greater than the increased cost of irrigation, vegetation management, and other costs.

Within the research area deer browsing appears to be a major factor that impacted survival, height growth and biomass production. Very little research has been done on *Populus* spp. to examine the potential to breed clones for wildlife foraging resistance, although there are some field observations that indicate some clones are less palatable to deer, elk, and voles (Moser and Witmer 2000). A study of the effect of deer browsing on tree height of 13 hybrid poplar clones in Wisconsin found that there was no apparent preference for any particular clone (Netzer 1984). The percent of newly planted seedlings browsed averaged 55 percent and ranged from 13% to 85%. However, only 24% of the trees greater than 6.08 ft (1.6 m) were browsed compared with 70% of those less than 4.3 ft (1.3 m).

Observational data from ERCO confirms the research by Netzer (1984) that the best way to reduce browsing is to plant the fastest growing clones and use the best means of plantation establishment so the trees grow out of the reach of deer (height greater than 5-6 ft) as fast as possible. The OP367 is the fastest growing clone on the ERCO site, however, the use of vegetation management and irrigation will help to maximize early growth. A separate tree shelter study has been initiated and early results confirm their effectiveness at reducing deer browsing but the cost associated with the purchase, installation, maintenance and removal may be cost prohibitive.

Separating Effects of Site Preparation and Deer Browsing

It is difficult to separate out the effects of site preparation and deer browsing on the growth of hybrid poplar in the research plots. However, since the operational area that surrounds the research plots was planted at the same time using the standard subsoiling technique it is possible to measure trees raised in these areas and compare their 5-year growth with that of the trees in the research area. It will be important to make sure that that comparison is between trees growing in similar soil composition since that is a factor that impacts growth on this site. Since all thee trees in the research area and those surrounding it have been subjected to the same amounts of deer browsing and insect infestations, growth and survival differences can logically be assumed to derive from the site preparation method. This is an area for future study.

The five-year data from the research plot indicates that poor tree survival was at levels that would result in plantation failure, at least in Blocks 1 & 2. This is a permanent impact. However, while tree growth is almost a third of what may be possible in the operational area, it is difficult to say if the remaining trees will increase in height and biomass and catch up with those in the operational area in years to come.

The deep row biosolids application business model relies upon planned tree rotations of approximately 6 years, followed by a harvest, and re-applications. The variability caused by the above factors can extend rotations for years, and result in plantation failure, resulting in lost revenue and operational difficulties. Past experience at the ERCO site demonstrates that with adequate moisture, tree survival and growth is consistent. The use of irrigation could provide needed moisture to maximize early establishment and growth that will give the trees that best chance of outgrowing the negative impacts of deer browsing in the first two years. Irrigation research is needed to determine how to best implement this practice.

Effect of Tree Shelters on Early Growth and Survival of Hybrid Poplar

Principal Investigator: Jonathan Kays

The impact of deer browsing on newly planted seedlings has become so severe at the ERCO site that plantation establishment has failed in some cases, requiring replanting. It is known that plastic tree shelters can effectively eliminate browsing and improve early growth but they have not been tested on the severe environmental conditions of this gravel spoil. Therefore, the following research design was implemented on operational areas of the tree farm planted in spring 2006 using a10-foot spacing with a deep row application rate of 171 dry tons of biosolids per acre.

Objectives

- Determine the effect of trees shelters on first and second year growth and survival of hybrid poplar trees; and
- Determine the effect of the removal of tree shelters after the first growing season on growth and survival of hybrid poplar trees in the second growing season

Experimental Design

There are two initial treatments – a control with no tree shelters and trees with shelters. There are six paired replicates of this combination at the ERCO property. After the first growing season one-half of the trees shelters (25) will be removed to allow a comparison of trees with and without shelters for the second growing season.

Treatments & Replicates

There are six replicates with 50 trees in each replicate-treatment combination for a total of 600 individuals.

- Year 1: 2 treatments - control (no tree shelters), protected (with tree shelters)
- Year 2: 3 treatments - control (no shelters), protected one growing season and shelters removed prior to second growing season, protected with shelters for two growing seasons.

- Year 3: 3 treatments – control, protected one growing season and shelters removed prior to second growing season, protected with shelters for two growing seasons and shelters removed prior to third growing season.

Measurements
After the first growing season (February 2007) the height to the nearest live bud (cm) and the basal diameter at 5 cm (in mm) will be recorded for each individual. These same measures will be made after the second growing season (Winter 2008).
Treatments for the first growing season will recorded as:
- C (controls)
- S (tree shelters)

When the tree shelters are removed after the first growing season, the treatments will be referred to as:
- C (controls),
- S1 (shelters for one year)
- S2 (sheltered two years).

The removal of the tree shelters will be done in spring, when growth has started and other browse is available for the deer in the area.

Analysis
An analysis of variance procedure (using SAS) will be used to compare the control and shelter treatments after the first growing season. The variables will be total height and basal diameter. The analysis of the second year growing season data will use the same variables of total height and basal diameter as well as the difference in height and diameter growth between year 1 and 2. There will be the additional treatment variable for the plots with the shelters removed after the first growing season.

Table 5: Differences in survival, browsing, height and basal diameter for trees grown with and without tree shelters in 2006.

	Trees with shelters	Trees with no shelters
Survival	79% a	78% a
Deer Browse	0% a	55% b
Total Height (cm)	124.0 (SE -2.05) a	73.3 (SE - 1.70) b
Basal Diameter (cm)	7.7 (SE - 0.12) a	7.7 (SE – 0.17) a
Values with different letters are significantly different at p=0.5 level		

Results and Discussion
There was no significant difference in survival of seedlings with and without tree shelters (Table 5). However, 55% of the unprotected seedlings were browsed with a significant reduction in height compared to protected seedlings. There was not significant difference in basal diameter.

After one year it is clear that the tree shelters provided 100% protection from deer browsing which resulting in taller growth after one growing season, however, survival was not impacted. It is worth noting that these seedlings were planted in operational conditions (with subsoiling during site preparation) and have good survival, while seedlings replanted at the same time in the research plot had almost 100% mortality.

OBJECTIVE 5: Determine the effect of vegetation management and phosphorous amendment on the growth and biomass of different aged hybrid poplar plantations.

Project 5 - Effect of Vegetation Management and Phosphorous Amendments on Growth and Nutrient Status of Hybrid Poplar in Three Different Aged Plantations

An important aspect of the overall research is to determine the movement of nitrogen and phosphorous in the system and the amount of biomass produced. Since all nutrients provided come from the biosolids in this system, we are interested in determining how much is taken up by the trees, how much is lost to leaching or denitrification, how much is immobilized, etc. To estimate the total amount of nutrients in the above ground biomass requires determining the actual percentage of nutrients in the tissues times the weight or biomass of material. The initial project design of providing different treatments of vegetation management and phosphorous was changed due to the results of Project 6, and the greater need to develop biomass equations over the range of plantation ages. To replicate vegetation and phosphorous amendments over the eight years of different plantation ages would have been impossible with the available resources, so instead the project design focused on a range of ages, assuming the operation nutrient levels of 171 dry tons per acre.

A destructive sampling procedure was developed to select trees from different age classes, determine their weight and the percentage of nutrients per unit weight, and then develop regression equations to determine total biomass from either dbh and/or height. Plantations outside the research area but within the operational area of ERCO were used to secure the needed samples and the destructive sampling was implemented and data collected and analyzed. Project Leader: Gary Felton & Dave Tilly. Graduate student Erica Phelix used the data for a master's thesis

Deliverables: Biomass equations based on height and dbh and nutrient content of the biomass.

Progress Update: *The study has been completed and a peer review paper is now in the process of being submitted for publication.*

OBJECTIVE 6. Effect of Tree Shelters on Early Growth and Survival of Hybrid Poplar Seedlings

Project 6 - Effect of Vegetation Management and Phosphorous Amendments on Growth of Four-Year Old Hybrid Poplar Trees

Update: An existing study highlighted in the three year report entitled, "Effect of Vegetation Management and Phosphorous Amendments on Growth of Four-Year Old Hybrid Poplar Trees," was finished during the first year of the continuing project. Project Leader: Jonathan Kays.

Deliverable: Research results will be analyzed after second year of data and written up for submission to a peer-reviewed journal. Synthesis will determine if vegetation management and phosphorous additions collectively or separately significantly affect tree growth.

Progress Update: *The data for this study has been a collected and analyzed, however, it has not been prepared for publication as of this report.*

Project Details:

Effect of Vegetation Management and Phosphorous Amendments on Growth of Four-Year Old Hybrid Poplar Trees

Materials and Methods

Maximizing the growth of hybrid poplar should result in faster utilization of the biosolids, which can decrease the rotation length and increase the economic return on the property. Contrary to most forest ecosystems, the nutrient base of this deep row system is found underground in the biosolids trench, while the upper soil layers provides little in the way of available nutrients. However, moisture from rainfall does come down through the upper layers and vegetation on the surface can limit what reaches the tree roots, once the moisture in the biosolids is extracted. Research on tree growth in forest plantations has found that controlling surface vegetation typically results in increased growth and biomass of the trees. However, adding nutrients without controlling surface vegetation usually does not result in increased growth, because the additional nutrients and water are taken up by the surface vegetation before the deeper tree roots can reach them.

The addition of nutrients can result in significant increases in height and biomass accumulation. This has been found to be the case in phosphorous-limited soils in pine plantations on the coastal plain. Inspection of the trees in the deep row application system has found that phosphorous levels may be limiting the ability of the trees to uptake nitrogen, which would likely result in faster growth rates.

This study was implemented in order to determine the effect of vegetation management and phosphorous additions on the growth and biomass accumulation of hybrid poplars using the deep row application method.

Experimental Design

The treatment design is a 2×2 factorial with 2 levels of P (P, no P), 2 levels of vegetation management (strip herbicide spray, no spray), for a total of four treatments. There are three replications for each treatment combination for a total of 12 plots. Each treatment combination was assigned randomly to a tree plot containing 25 hybrid poplar trees four years of age. Each 25 tree treatment area consisted of a 5 X 5 block of trees. Each plot was separated by a buffer row of trees that received no treatment. All trees were planting on a10' X 10' spacing after deep row application of 171 dry tons per acre. The planting site is located on the ERCO tree farm. The four year old trees had never received any phosphorous amendments or chemical vegetation management prior to this study. The only vegetation management used since planting was mechanical mowing with a tractor and bushog. The crowns of the trees had closed but the understory has an established layer of grasses and weeds.

The plot layout below (Figure 22) shows the random assignment of the four treatments in each 25 tree block: 1) C – control; P - phosphorous amendment only; V - vegetation management only; and PV - phosphorous and vegetation management combined

V1	P1	PV1	C1
P2	V3	C2	V2
PV3	C3	P3	PV2

Figure 32. Plot layout of 240' X 180' showing randomly assigned treatments

Application of Treatments
On the plots receiving vegetation management, it was necessary to use a combination of herbicides to kill the established grasses and broadleaf plants, and to use a pre-emergent herbicide to stop new plant establishment. Roundup® herbicide mixed with Goal® herbicide was sprayed in 3 foot strips on each side of the tree on April 7, 2004 for vegetation management. The Roundup killed existing vegetation and the Goal herbicide provided pre-emergent control throughout the growing season. The phosphorous amendment was applied using commercial corn starter. It was applied in late-March before trees leaf out but when roots are actively growing. A dibble bar was used to dig a hole 6 inches deep (3 holes per tree) to apply the prescribed rate of phosphorus (0.6 cups per tree total).

Prior to the growing season, all the trees were tagged with an aluminum tag and the diameter at breast height marked with red paint so that the diameter would be taken at the same place each time. The diameter and heights were taken prior to the growing season and after the first growing season, so that changes in height and diameter could be assessed. Biomass was calculated in dry kg from a biomass equation developed from trees onsite (Felix, Tilley, Felton in press).

In mid-August at the peak of the growing season, two foliar leaf samples were taken from four trees in each of the treatment plots to provide one composite sample for each treatment using the protocol previously described. The first fully expanded leaves at the top of the tree were sampled using a lift, which is usually 5-7 leaves down from the terminal leader. If you sample leaves that are still actively expanding, the leaf will be receiving nutrients from the tree and give unrealistic value. If the leaf is not expanding it will be a net exporter of nutrients and values may be low. All samples were taken at mid-day. The sampling resulted in 12 total leaf samples that were analyzed for nitrogen, phosphorous and other nutrients by an independent lab.

Results

Height, Diameter, and Biomass
The one-year height growth of all three treatments was significantly taller than the control. The vegetation/phosphorous treatment had a significant increase in diameter over the vegetation and the phosphorous treatments by themselves (at p=0.07 level), but not over the control (Table 4). None of the treatments significantly increased biomass after one year. In year 2, there was no significant increase in height between any of the treatments. However, diameter and biomass was higher for the vegetation management treatment compared to the control. The diameter and biomass of trees in the combined vegetation/phosphorous treatment was also significant larger compared to the control (at p=0.07).

Rainfall for the study was normal in year one, however, in year two there was a drought which resulted in a 55-65% decrease in measures of diameter, height, and biomass compared to year 1. Overall, the results indicate that the treatments did have an impact on height growth the first year and for diameter in the vegetation/phosphorous treatment, but no impact on biomass production. In year 2, height growth was unaffected. However, diameter and biomass of the vegetation management treatment was significantly increased compared to the control, as was the vegetation/phosphorous treatment at the p=0.07 level. Reporting data at the significance level of 0.07 in this study is justified due to the large variability and need to discern trends.

Vegetation Management

The positive benefits of controlling competing vegetation and its significant impact on tree growth and survival is widely proven in research and practical operations, especially in cases with limited moisture and nutrient availability. Removing competing vegetation allows more moisture to be available for uptake by the tree roots, which facilitates utilization of N and other nutrients for growth. In the case of phosphorous amendment or any nutrient amendment, removing competing vegetation allows trees roots to access the available P rather than promote the growth of weeds. In year 1 there was adequate rainfall and the two treatments with vegetation management were significantly taller, however, only the vegetation/phosphorous treatment had a larger diameter. In this case the combined effect of vegetation management and P amendment was synergistic.

In year two there was a drought, and there was no difference in height growth between any of the treatments. However, there was a significant increase in diameter and biomass between the control and the vegetation management treatment, and between the control and the combined vegetation/phosphorous treatment (at p=0.07 level). This results point out that vegetation management can increase diameter growth during periods of drought.

The lack of any impact of vegetation management on height growth during the drought in year 2 may indicate there was just enough moisture and stored carbohydrates from the previous year to produce height growth in the earlier part of the second growing season, regardless of treatment. The lack of moisture during the early part of the growing season may have then resulted in premature cessation of height growth. This is contrary to year 1 when moisture was adequate and height growth was sustained throughout the growing season, resulted in significant differences in height growth of treatments over the control.

Diameter growth typically starts after most of the height growth is produced (mid growing season), so any later season rainfall around trees with vegetation management moved into the roots and was available to the trees for uptake and growth. Available P from trees amended with phosphorous only, lacked sufficient rainfall to carry P through the surface vegetation cover to the roots, so it was likely utilized by the many weeds present on the surface, resulting in the lack of impact on growth. This is contrary to year 1 when there was adequate rainfall and the P amendment by itself did result in an increase in growth comparable to vegetation management alone.

Table 6: Changes in Height, Diameter, and Biomass for Year 1 and Year 2 for each of the four treatments

One year change in:	Control	Vegetation Mgt	Phosphorous Additions	Vegetation/ Phosphorous
Height (m) **Year 1**	2.38a	2.73b	2.56b	2.73b
Year 2	1.03a	1.15a	1.06a	1.15a
Diameter (cm) **Year 1**	4.14	4.11*	4.11#	4.36*#(.07)
Year 2	1.39a*	1.62b	1.49	1.62* (.07)
Biomass (dry/kg/tree) **Year 1**	10.26a	10.93a	10.67a	10.93a
Year 2	3.61a*	4.21b	4.20	4.21*(.07)
Statistical analysis using mixed model repeated measures at P<0.05 * or # means statistically different at level in parenthesis				

Foliar Nutrient Status

The low number of samples likely contributed to the lack of statistical significance (p<0.05) for the foliar nutrients (Table 7). However, the N:P ratio was very significant for year 1, but since it was developed from other measures of N and P that were not significant, its relevance may be questionable. While significance may have been limited, trends in the data were telling. The vegetation/phosphorous treatment had the highest %N value at 4.0%, which would be expected since the removal of competing vegetation and addition of P allowed improved uptake of the nutrients by the trees. Also, the more balanced N:P ratio is representative of levels related to growth increases. A similar trend existed for %P, with the highest value found again for the vegetation/phosphorous treatment in year 1 (0.42%).

In year 2 none of the foliar nutrient levels were significantly impacted by the treatments and there were no obvious trends in the data. Year 2 was a drought year and all measures of growth were much reduce compared to year 1 (Table 4). Foliar levels of % N, %P and % K were reduced by 8%, 25%, and 24%, respectively. The increase in %N and %P for the vegetation/phosphorous treatment in year 1, although not significant, do correlate with the increase in diameter and height growth for that treatment in year 1. The fact that there were no correlation or trends in year 2 between foliar nutrients and the significant reported increases in diameter and biomass for the vegetation and vegetation/phosphorous treatment indicates that drought suppressed nutrient uptake. The growth differences reported in year may have just been an opportunistic response to late season moisture.

Table 7: Percent foliar nutrients of N, P, K, and N:P ratio for year 1 & 2 for each of the four treatments.

	Control	Vegetation Management	Phosphorous Amendment	Veg. Mgt/ Phos. Amd.	P Value significance<0.05
% N – yr 1	3.6	3.6	3.7	4.0	0.55
% N – yr 2	3.3	3.1	3.3	3.2	0.19
% P – yr 1	0.35	0.33	0.31	0.42	0.09
% P – yr 2	0.22	0.20	0.20	0.22	0.53
N:P ratio Yr 1	10.4 [b]	10.9 [ab]	12.1 [a]	9.5 [b]	0.006
N:P ratio Yr 2	15.0	15.7	16.1	15.3	0.57
%K Yr 1	2.1	2.0	2.0	2.4	0.10
Yr 2	1.6	1.6	1.6	1.6	0.83

Composite sample from 4 trees for each treatment sample.
Statistical analysis using Tukey test

The lower %P in year 1 resulted in a dramatic increase in the N:P ratio from one that is more balanced (ratio of 9 to 11) in year 1, to one that is very unbalanced (ration greater than 11) in year 2. Even with the lower level of %N in year 2 it is possible that the P amendments at the beginning of the growing season may have allowed for greater N uptake and continued growth increases.

One relevant result of the foliar data for year 1 was that the foliar levels of N, P, and the N:P ratio, were representative of the maximum values found in the literature. Maximum growth of hybrid poplar under fertilized conditions is thought to occur at 3.6% foliar nitrogen and 0.42% foliar phosphorous. However, fast growth is known to occur at levels above 3.0%. In year 1 the N and P values were at or near levels of maximum growth (greater than 3.6% N and 0.31%P), however, they declined considerably in year 2 to levels with %N just above 3.0 and %P around 0.20%.

Conclusions

After two years it appears that the height and diameter was affected in year 1 by the treatments but biomass was not. With low rainfall in year 2, height was unaffected by any treatments, but diameter and biomass did increase for the vegetation/phosphorous treatment compared to the treatments by themselves. The control was apparently not different from any of the treatments in year 1.

The lack of adequate rainfall in year 2 made comparisons difficult, however, it did indicate that the height, diameter, and biomass was 65% less than that reported for year 1 overall. Vegetation management does appear to be critical to sustaining higher levels of diameter growth during the period of drought in year 2, and during the periods of adequate rainfall of year 1.

The use of vegetation management and phosphorous additions during periods of adequate rainfall facilitates high foliar nutrient levels of N and P that are characteristic of maximum growth for hybrid poplar. The lack of rainfall dramatically reduces foliar nutrient levels for all the treatments and provides more justification for the use of irrigation. Drought reduced foliar P levels that are needed to sustain high levels of N uptake. There appears to be a direct connection between the lower levels of foliar nutrients and lower tree production measures.

The business model for deep row incorporation is to maximize growth and reduce rotation length so that fees paid for incorporation are maximized. It is clear from the study that during periods of adequate rainfall tree growth is increased by most of the treatments and maximized by the use of both vegetation and phosphorous amendments, and that drought reduces overall growth significantly. Rainfall appears to be the limiting factor to maximizing the growth of hybrid poplar at the ERCO site and this study suggests that the use of irrigation combined with the treatments will accomplish that goal. More long studies combined with cost-benefit analyses are needed to see if irrigation combined with the treatments used in this study are cost-effective.

OBJECTIVE 6. 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. Its feasibility relative to other biosolid disposal methods (or other reclamation activities) will be assessed.

Project 7 – Economic & Environmental Analysis of Deep Row Application

As more information is gained on the treatment effects, biomass production, rotation length and other factors, the economic analysis will be refined. The analysis will include a profit and loss estimate under different scenarios that exist in the operational environment. An environmental analysis will be developed as well to look at the larger impacts of the project. Project Leader: Dale Johnson and others.

Deliverable: Enterprise budget and profit analysis of deep row application under different research scenarios. Development of fact sheet. Environmental analysis.

Progress Update: *A fact sheet has been developed for the enterprise budget and profit analysis. However, the environmental analysis has not been done due to lack of sufficient funds in this grant. The investigators are working with campus faculty to see if some type of limited analysis can be completed to at least answer some basic questions.*

Project 8 – GIS Map to Identify Deep Row Application Sites and Market

Another project initiated under this continuing research will be to use geographical information systems (GIS) to build a database that will provide an estimate of the potential acreage available for deep row application in the three county region of Charles, Prince George's and Anne Arundel. Geologic data, locations of sand and gravel mines, and other information will be entered into a GIS database to provided acreage estimates of sand and gravel spoils that may have the proper geology to be candidates for site investigation for deep row application. These estimates can be used to determine market development and potential for an industry based on this application method. Further, the maps generated can be used for educational programs and publications. Project Leader: Jonathan Kays and Gary Felton.
Deliverables: GIS database and accompanying maps that show locations of potential deep rows sites, acreage, and potential application under different research scenarios.
Project Update: *The PI's have met and communicated with the Maryland Department of Natural Resources and Maryland Geologic Survey professionals to gather existing GIS data which should provide needed information for the Prince George's and Charles County area. We are discussing the best way to use this data and put it into a format that will serve our purposes.*

OBJECTIVE 7. Educate state and local environmental professionals about the use of deep-row biosolid applications to develop sustainable forest crops and simultaneously rehabilitate disturbed soils, and draft regulations based on research results.

Project 9 – Annual Field Day

The annual October field day will be offered each year to educate those interested in this technology. This has been a successful program and has led to investigation of new ideas and networks. Project Leader: Eric Flamino
Deliverables: October Field Day
Progress Update: *Field day was held October 5, 2006 and attended by about 35 professionals from industry, government, regulatory agencies, university, and other. No field day is scheduled for October 2007 since other educational and policy venues are being considered by the partners.*

Project 10 – Draft Regulations

The research will be used to draft agronomic rates for deep row application that could be used for regulatory legislation that would protect the environment while providing a known permitting procedure. At the present time all work at ERCO is done under a special research permit with monitoring and operating conditions under the total control of the Maryland Department of Environment (MDE). If the use of this technique is to expand, potential business operators must be able to calculate cost for monitoring and operation that are known. Drafting of agronomic rates and regulations based on the research will be done in cooperation with the project partners. Project Leaders: All Principal Investigators.
Deliverables: Agronomic recommendations for deep row application for use in COMAR regulations.
Progress Update: *Efforts to communicate and involve MDE has improved with a meeting on August, 2007 with the Deputy Secretary of MDE, other high level MDE administrators, and project partners. Reports are now being sent directly to the Deputy Secretary of MDE and*

the Division head for review. When the project is over in July of 2008, project leaders and cooperators will meet with MDE to discuss future steps. .

Project 11 – Fact Sheet Series for the Public, Regulators, & Industry Education

Implementing deep row application on other sites requires that citizens, regulators, policy makers, and industry leaders understand the process, potential impacts, and other aspects. Knowledge gained from the research will be used to produce a series of fact sheets that can be used for educational purposes, including the annual October field day. Project Leader: Jonathan Kays & other Principal Investigators.

Deliverables: Fact Sheet Series available at:
http://www.naturalresources.umd.edu/Publications.cfm#biosolids

Progress Update: *A fact sheet format series entitled "Biosolids & Forests" has been developed that will enable the reporting of research results on specific projects that have to do with deep-row application as well as surface applications, which is now being addressed. At this time five fact sheets have been reviewed and finalized. They are all available online.*

- Biosolids Fact Sheet Series: Use of Deep Row Incorporation to Grow Forest Trees.
- Biosolids Fact Sheet Series: Effect of Deep Row Incorporation on Water Quality.
- Biosolids Fact Sheet Series: Site Preparation and the Effect of Subsoiling on Survival and Growth of Hybrid Poplar
- Biosolids Fact Sheet Series: Hypothetical Business Scenario for Deep Row Biosolid Incorporation for a Hybrid Poplar Forestry Operation
- Biosolids Fact Sheet Series: Five-Year Results of Hybrid Poplar Clonal Study Using Deep Row Incorporation

2) ADDITIONAL RESEARCH PROJECTS AT SITE

This project has resulted in the completion of other research that expands our knowledge base but is not paid for by project funds. They are listed below:

- The development of a method to assess foliar nutrient levels through the use of field based spectrophotometry. Investigators: Drs. Gary Felton and David Tilley. Graduate Student is Tommy Griffith. The project is funded through the University of Maryland, Environmental Science and Technology Department.
- Saturated hydrologic conductivity of soil core samples from the ERCO site. This research will provide needed data on how water moves through the soils. Part of project by a high school student. Investigator: Dr. Gary Felton

3) RESEARCH AT OTHER SITES DIRECTLY ATTRIBUTABLE TO RESEARCH AT ERCO SITE

- Replicated study on 1.5 acres at the Wye Research & Education Center in Queenstown, MD, to assess water quality and growth effects of surface application of biosolids on hybrid poplar growth on the Eastern Shore. Research plot was planted with hybrid poplar trees in spring 2006 and it has had two growing seasons to develop. Soil and foliar samples have been taken each year, as well as growth measures for the trees. Funding is being sought to hire a graduate student to carry out the project. Principal investigator is Jonathan Kays. **(SEE APPENDIX B)**
- Hybrid yellow poplar has been planted on ten acres of rolling coastal plains soil at the USDA Beltsville Agricultural Research Center. A replicated study is underway to grow these trees using annual surface applications of poultry litter. Biomass fuel potential will

be evaluated annually. Economic and energy efficiency will be examined and compared to ethanol production and to the switch grass plots that have also been planted at BARC. We expect to demonstrate the value of utilizing a waste to generate energy. Nutrient status of the soil will be quantified using twice-a-year soil sampling. Principal investigator is Gary Felton.

- Eric Flamino has been actively involved with a deep row incorporation demonstration and research project on old anthracite coal mines near Pottstown, PA. Approximately 10 acres have been planted with hybrid poplar trees using deep row applications using difference biosolids application rates. The initial results of this effort were presented at the WEF meeting last spring. The soil conservation districts in western Pennsylvania have started a biomass initiative that includes the use of deep row application on coal mines in western PA. They have visited the ERCO site and research plots are being planned.
- Virginia Tech in the middle of a deep row incorporation study on an old sand pit in Virginia to assess the impact on growth and water quality. This is part of the Mid-Atlantic Water Quality project. The Principal investigator is Greg Evanylo from Virginia Tech.
- Mike VanHam of Sylvis, Inc, a firm in British Columbia, and cooperator on the deep row research, is moving forward to implement a deep row incorporation demonstration project with the government of British Columbia.

4) PRESENTATIONS, REPORT, AND PEER REVIEWED PAPERS

Peer Reviewed Papers

- Buswell, C. U., G. K. Felton, J. S. Kays, and E. J. Flamino. (2006). Water Quality of Deep Row Biosolids Incorporation on a Tree Farm. In Proceedings of the 2006 American Society of Agricultural and Biological Engineers Conference, July 9-12, 2006. Portland, OR.
- Kays, J. S, G. K. Felton, C. U. Buswell, and E. J. Flamino. (2007). Deep Row Incorporation of Biosolids to Grow Hybrid Poplar Trees on Gravel Spoils in Southern Maryland. Water Practice, Volume 1, Issue 1. Available at: http://www.wef.org/ScienceTechnologyResources/Publications/WaterPractice
- Felix, E., D. R. Tilly, and G. F. Felton. (2006). Biomass production of hybrid poplar (Populus spp.) grown on municipal biosolids. Department of Environmental Science & Technology, University of Maryland, College Park. Undergoing peer review.

Fact Sheets

- Kays, J. S., E. Hammond, G. Felton, E. J. Flamino. (2006). Biosolids Fact Sheet Series: Use of Deep Row Incorporation to Grow Forest Trees. Keedysville, MD: MCE. [Online]. Available at: http://www.naturalresources.umd.edu/Pages/Biosolids_overview.pdf
- Kays, J. S., E. Hammond, G. Felton, E. J. Flamino. (2006). Biosolids Fact Sheet Series: Effect of Deep Row Incorporation on Water Quality. Keedysville, MD: MCE. [Online]. Available at: http://www.naturalresources.umd.edu/Pages/Biosolids_Water_Quality.pdf
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APPENDIX A FIELD LOG FROM GEOTECHNICAL EXPLORATION

Geotechnical Exploration Notes - 3/23/06

Location (aka site A) is on the road right through the middle of section 9. Continuous cores were collected from a depth of 5' to 25' using a Laske sampler and the University of Maryland Biological Resources Engineering drilling rig. Saturated hydraulic conductivity and texture analysis will be done on various samples throughout the depth. As the cores were collected and cuttings were examined, the following is the profile we found:

0-2.5'	Mixed gravel, soil, clay	
2.5'-5'	Yellow clay with traces of pea gravel	
5'-10'	Clay with pea gravel	$9.0X10^{-7}$
10-15'	Clayey sand, the sand is very fine	$6.1X10^{-4}$
15'-22'	Clayey sand or sandy clay, the sand is very fine	$1.6X10^{-6}$
22'-25'	blue-gray marine clay	$1.7X10^{-5}$

3/24/06 Returned to hole. No water in hole. Re-filled the hole with bentonite at bottom, dirt in approximately 6' lifts, interrupted with 3 more bentonite plugs to a depth of approximately 5'. Finished last 5' with more dirt.

Geotechnical Exploration Notes - 4/06/06

Location (aka site B) is midway on the road between the experimental plots and Section 4. Continuous cores were collected from a depth of 5' to 25' using a Laske sampler and the University of Maryland Biological Resources Engineering drilling rig. Saturated hydraulic conductivity and texture analysis will be done on various samples throughout the depth. Three days after 1" rain. About 60°F. Partly cloudy.

As the cores were collected and cuttings were examined, the following is the profile we found:

0-5'	Mixed gravel, soil, clay	
5'-6'	Sand	
6'-8'	Wet sloppy mud, sand, and clay	
8-10'	Yellow sandy clay	$4.3X10^{-6}$
10'	Blue-grey marine clay	$1.8X10^{-6}$
10+ - 15'	Lost core, cuttings were hard blue-grey clay	
15-17.5'	Sandy mud	
17.5-20'	Blue-grey marine clay	$1.6X10^{-6}$
20-21'	Wet, runny marine clay	
21-23'	Marine clay with sand	
23'-25'	Marine clay	$1.7X10^{-5}$

4/7/06 Returned to hole. Water found at 15 feet. Re-filled the hole with bentonite at bottom, dirt in approximately 6' lifts, interrupted with 3 more bentonite plugs to a depth of approximately 5'. Finished last 5' with more dirt.

Geotechnical Exploration Notes – 4/06/06 PM

Location (aka site C) is midway on the road between the Sections 6 and 8. Continuous cores were collected from a depth of 5' to 25' using a Laske sampler and the University of Maryland Biological Resources Engineering drilling rig.

0-5	Gravel and sand remnants	
5'-10'	Lost core, wet yellow sand and mud	
10-15'	Water, under pressure, sand and mud	$3.2X10^{-5}$
15-17'	Mixed mud	
17-20'	Marine clay	$2.7X10^{-6}$
20-22'	Yellow clay	$1.2X10^{-5}$
22'-25'	Marine clay	$1.2X10^{-5}$

4/7/06 Returned to hole. Water in hole up to 5'. Re-filled the hole with bentonite at bottom, dirt in approximately 6' lifts, interrupted with 3 more bentonite plugs to a depth of approximately 5'. Finished last 5' with more dirt.

Geotechnical Exploration Notes – 4/20/06

Location (aka site D) is on the edge road in Section 5. First attempt was hard gravel and lifted the drilling rig. Moved a few feet and started over. Continuous cores were collected from a depth of 5' to 25' using a Laske sampler and the University of Maryland Biological Resources Engineering drilling rig.

0-5	Sand and gravel remnants	
5-10	Mostly gravel. Lost part of sample	
10-15	whitish-grey clay	$1.5X10^{-7}$
15-20	whitish-grey clay, 17-18' had orange streaks	$4.1X10^{-5}$
20-25	whitish-grey clay to 24', green clay 24'-25'	$4.4X10^{-4}$

4/21/06 Returned to hole. No water in hole. Re-filled the hole with bentonite at bottom, dirt in approximately 6' lifts, interrupted with 3 more bentonite plugs to a depth of approximately 5'. Finished last 5' with more dirt.

Geotechnical Exploration Notes – 6/8/06

Location (aka site F) is in Section 1 almost on the property line. Started at 11:00 AM. Sunny about 75°F. South side of boarder road. Continuous cores were collected from a depth of 5' to 25' using a Laske sampler and the University of Maryland Biological Resources Engineering drilling rig.

0-5	Gravel and Clay	
5-7'	Gravel and clay	$8.3X10^{-7}$
7'-10'	Clay, grading yellow to grey	
10-14'	Sandy clay, yellow	$1.8X10^{-4}$
14'-15'	Grey sandy clay	
15'-20'	Grey sandy clay	$5.0X10^{-6}$
20-24'	Grey clay with yellow fingers	$3.7X10^{-3}$
24-25'	Moist clay with some sand	

Next day, no water, no marine clay

Geotechnical Exploration Notes – 6/15/06

Location (aka site G) is At the edge of Section 6 on the center access road. Continuous cores were collected from a depth of 5' to 25' using a Laske sampler and the University of Maryland Biological Resources Engineering drilling rig.

0-5	Gravel and Clay	
5-6'	Biosolids and clay	
6-9'	Yellow Clay	$3.5X10^{-5}$
9-10'	Marine Clay	
10-15'	Marine clay, slightly drier than at other drilling sites	$8.7X10^{-6}$
15'-19'	Marine clay, same as above	$9.1X10^{-5}$
19-20'	Marine clay but slightly bluer material	
20'-25'	Marine clay, same as above	$5.5X10^{-7}$

Next day, about 3' of water in bottom of hole

Geotechnical Exploration Notes – 11/15/06

Location (aka site H) is at the edge of Section 8 on the edge of the property. Continuous cores were collected from a depth of 5' to 25' using a Laske sampler and the University of Maryland Biological Resources Engineering drilling rig.

0-3	Gravel and Clay
3-5'	Biosolids and clay
5-6'	Hard sand and gravel. Lifted drilling rig. Had to move and change bits. Trace of free water.
8-8.5	Lost core
8.5-10	white sand and gravel. Hit water.
10-12'	More dense sand and gravel. Hole was bored to 15', but no more than 2' of sample will go up into the Laske tube, due to friction, density, and consistency of sand and gravel.
15'-16'	Sand, gravel, 2" rock. Sample only 1' long.
16-18'	Drilled gravel and rock without taking sample.
18'	Dropped the *!#@$ auger flights down the hole. Had to go fishing. Retrieved the flights on 11/16/06. Pouring rain, will return another day.
18-25'	More gravel and rock. Got 2' of core in a 5' sample tube.

No hydraulic conductivity data were collected for site H. The constant head permeameter set up was not set up to handle such high flow. Essentially the water moved too fast to obtain an accurate and believable time and the brass rings would not properly contain the gravel. The result would bee too disturbed and any data would not be valid.

11/16/06 Returned to hole. No water in hole. Re-filled the hole with bentonite at bottom, dirt in approximately 6' lifts, interrupted with 3 more bentonite plugs to a depth of approximately 5'. Finished last 5' with more dirt.

APPENDIX B - EFFECT OF SURFACE APPLICATION OF BIOSOLIDS ON HYBRID POPLAR GROWTH & WATER QUALITY

Principal Investigator: Jonathan Kays
Co-Principal Investigator: Gary Felton

Objective:

- Determine the effect of different biosolid surface applications on hybrid poplar growth, biomass production, and water quality.

Justification:
Available agricultural land to apply biosolids has become increasing difficult to find for many reasons, leading to the need for more beneficial techniques to utilize the nutrient value of these products. Landfilling of nutrient rich material and trucking long distances with the associated environmental impacts are not desirable options.

The use of short rotational woody crops (SRWC) such as hybrid poplar show great promise due to their ability to take up large amounts of nutrients and produce biomass that can be used for pulp, bioenergy, cofired generation, compost and other purposes. The application of biosolids to hybrid poplar plantations that matches the trees uptake abilities (350 lbs/N/yr/ac) is a mainstay of the Pacific Northwest and provides much of the raw material for the pulp industry.

This study will apply prescribed amounts of biosolids on two-year old hybrid poplar seedlings to measure the impact on growth, biomass production, and water quality, while demonstrating how SRWC plantations can help reduce the acreage necessary to utilize biosolids.

Project Description:
In spring 2006 a 1.5 acre research plot of OP367 hybrid poplar clones was planted on a 12' X 12' spacing and divided into three blocks for replication. Each tree was protected from deer browsing by a 4-foot tree shelter and the tree rows were sprayed with Goal herbicide to manage unwanted vegetation. Each block has 3 treatments (control & two biosolids application treatment levels) that have been randomized as much as possible given operational constraints. For the first two years the growth of the trees will be measured, foliar samples will be taken to assess nutrient uptake, and soil nutrients will be assessed to determine levels of P. This will provide a good baseline of measurements upon which the treatment impacts can be assessed.

After two growing season, application of lime-stabilized biosolids from a nearby generator will be made with a manure spreader followed by disking to incorporate the material. The operational spacing of 10'X10" that is typically used in poplar planting was expanded to accommodate the available manure spreader which is 8.5 feet wide. The standard is one foot of spacing for each year of plantation rotation age, so this is a 12 year project.

The applications will be matched to the uptake capabilities of the trees which is about 350 lbs/N/yr/ac. Research on this topic from the Northwest Biosolids Management Association has found the about 37% of the applied biosolids are actually available for tree growth (PAN), which means that approximately 1000 lbs/N/yr/ac is needed annually. Virginia has found similar percentages for PAN. According to accepted practice in the Pacific Northwest, the total annual application will be equally split (500 lbs N/ac) between two times of the year: once just prior to leaf out when roots are actively growing, and once in the fall near leaf fall when roots again are still actively growing.

After each growing season diameter and height measures will be taken to assess growth, survival, and biomass production. Foliar nutrient levels will be taken in mid-August according to accepted protocols to determine the fertility status of the trees and how it relates to growth measures.

Survival and Growth Results – First Growing Season (2006)
After the first growing season the following results were obtained (Table 8). While they are reported by treatment, there are no significant differences since no treatments have been applied. The survival is excellent at 99%. The tree shelters will be removed in spring 2008, prior to the beginning of the third growing season.

Table 8: First year growth of hybrid poplar at Wye Research & Education Center (2006) prior to any applications

	Control	Low Application	Medium Application	High Application
Survival	98.2%	98.8%	98.8%	98.9%
Total Height (m)	1.74 (se 0.07)	1.82 (se 0.05)	1.89 (se 0.06)	1.82 (se 0.06)
Basal Diameter (cm)	0.98 (se 0.04)	1.0 (se 0.03)	1.1 (se 0.04)	1.0 (se 0.04)

Foliar Nutrient Results – Two Growing Seasons (2006-2007)
Foliar nutrient samples were taken in August at the end of the first (2006) and second (2007) growing season to assess nutrient uptake by the trees (Table 9). The most revealing number is the percent N, which averaged 2.42% in first growing season and 2.14% in the second growing season. It is possible the higher value in year 1 was due to residual nitrogen from the previous row crop cultivation.

Table 9: Foliar nutrient levels for two years prior to any biosolids application

	%						
	N	S	P	K	MG	CA	NA
2006	2.42	0.35	0.28	1.92	0.45	1.03	0.01
2007	2.14	0.32	0.19	1.04	0.66	1.37	0.03

	ppm					
	B	ZN	MN	FE	CU	AL
2006	44	30	51	66	10	17
2007	40	53	106	86	8	40

Maximum growth of hybrid poplar under fertilized conditions is thought to occur at 3.6% foliar nitrogen and 0.42% foliar phosphorous. However, maintaining a 3% foliar N concentration is desirable for fast growth. As would be expected, the foliar nutrient levels fall short of what would be expected under fertilized conditions. This baseline of data indicates the plantation will respond vigorously to biosolids applications that provide needed nutrients, and this would be reflected in higher percent N levels at the end of the growing season.

Conclusions

The research site has undergone two years of growth which has allowed for establishment and good root development of the hybrid poplar trees. While height growth is acceptable, it is well below the capability of the species. Growth and survival for the second growing season are expected soon but observational data indicates there is little of the deformation of the stems found in fast growing plantations and the foliar nutrient levels are well-below levels expected in fast growing or fertilized plantations. A visit to the site in September 2007 found that two rows of trees close to an existing woods edge of mature oaks were completely dead, most likely from far reaching roots of the mature trees that were more capable of securing what little moisture fell during this year of drought. The experimental design will have to be slightly altered to take this into account.