DEMONSTRATING DEEP ROW PLACEMENT OF BIOSOLIDS IN COAL MINE LAND RECLAMATION

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ABSTRACT

When the Philadelphia Water Department needed an innovative biosolids management alternative that would utilize biosolids during winter months, the idea of growing hybrid poplars to reclaim mine lands presented many benefits. A similar operation in Maryland has been recognized as a successful approach to biosolids recycling and reclamation. The project places biosolids in deep row troughs that can be installed during winter seasons. This application technique supplies nitrogen for the establishment and maintenance of a hybrid poplar tree plantation over an eight year growing cycle. After two growing season at the mine site, this approach to reclamation has stabilized the disturbed site, has supported strong sapling growth, and resulted in no apparent adverse environmental impacts.

The deep row placement of biosolids is a concept developed by ERCO, Inc. (ERCO), for supplying nutrients at degraded sites over time for deep-rooted tree clones. In this approach, the deep rows are dug to a depth of approximately 30 inches (76 cm) and a width of approximately 42 inches (107 cm). Biosolids are placed into these rows at a depth of approximately 18 inches (45 cm) and the row is then filled with the excavated material. After biosolids application, stecklings from hybrid poplar, Populus spp., are planted on ten-foot centers.

The preliminary findings show that the hybrid poplar trees fertilized with biosolids grow faster during the first two years after planting than un-fertilized poplars. The deep row method can reduce or eliminate the occurrence of off site odors. When incorporating biosolids into a tree plantation using deep rows, the usual assumptions about mineralization rates used when biosolids are surface applied and incorporated are not usually applicable, and loss of nitrogen is minimal. During the first 2 years of growth, no significant difference in performance of the two clones of trees used in the demonstration was observed. Planting location (between the rows or directly above the deep rows) did not result in significant growth rate differences.

KEYWORDS

Biosolids, land application, hybrid poplars, reclamation, deep row, biomass, odor control, demonstration, nitrogen

BACKGROUND

Conventional Use of Biosolids for Reclamation

The Philadelphia Water Department has used biosolids for the reclamation of mine lands in Pennsylvania for nearly 30 years, and the history of this program, in which approximately 1 million tons have been used to treat nearly 5,000 acres, has been described elsewhere (Toffey 2003). This program emerged with the kind of biosolids products available in the mid 1970s, prior to modern centrifuge equipment and before the full benefits of industrial pretreatment had been realized. Nevertheless, with a collaboration of researchers and governmental offices, an effective program was developed, based on sound scientific findings of the risks and benefits to the environment and human health (Sopper and Kerr 1982; Sopper and Seaker 1983; Sopper and Seaker 1990; Anonymous 2004; Jenness August 2001).

The Philadelphia Water Department produces 170 Dry Tons Per Day (DTPD) of anaerobically digested and dewatered biosolids. The biosolids are classified as a Class B product with respect to pathogens, as a high quality biosolids with respect to metals, and as compliant with vector attraction reduction standards. Biosolids use in coal surface mine reclamation has been practiced by Philadelphia since the late 1970s as one of several beneficial use programs. For over twenty years, reclamation with biosolids occurred in bituminous coal mining areas, where the cycle of mining and reclamation occurs over relatively short three or four years. Since 2001, biosolids have been surface applied to anthracite coal mines in Schuylkill County, Pennsylvania. Reclamation in this coal region is made challenging because most mines were opened before environmental reclamation laws were in place, so few mines today retain stockpiles of topsoil. Closure of mines in Schuylkill County make use of surficial material for which the term “soil” is misleading, as the material is extremely stony and contains very little organic matter.

The conventional procedures for use of biosolids on coal mine lands in 2007 remain virtually the same as originally developed in the 1970s. After the mine surface has been brought to final contours and raked to remove large rock fragments, and after an adequate dose of agricultural lime is applied (typically over 5 tons per acre), then dewatered biosolids cake is applied at rates up to 60 dry tons per acre (DTPA) using conventional manure spreading equipment. Large plows make several passes over the land surface to attempt maximum incorporation into the surface 6 to 12 inches, although the rocky nature of typical overburden makes thorough incorporation difficult to achieve. The next step is seeding the surface with a mix of grass and legumes to achieve first a quick vegetative establishment and then a dense cover that resists erosive forces. While trees may be planted, the dense herbaceous cover usually impedes tree establishment. These processes have been described in previous papers (Sopper 1993; Toffey 2003).

The lessons learned about the benefits of biosolids for large-scale land reclamation have been also applied to hard mining lands, fire-scarred forests, and air-deposition contaminated sites with similarly effective results (Mathias, Bennett et al. 1979; Brown, Henry et al. 2003; Brobst, Meyer et al. 2004). In the research behind these projects, the potential for nitrate release was evaluated and determined to be a minor effect, even in soils of a sandy and gravelly consistency (Daniels, Evanylo et al. 2003). The deep row placement of biosolids is an innovative approach for sandy site developed in Maryland that enables application of high rates of nutrients to support hybrid poplar tree cultivation, while creating negligible nuisance odors and reducing to a minimum the risk of nitrogen loss (Pepperman 1999; Van Ham, Lee et al. 2000).

Deep Row Use of Biosolids for Reclamation

Deep row placement has been practiced for twenty years in Maryland. This technology has been undertaken as a long term demonstration program. As such, a large data base of environmental factors has been created over the years, and a substantial body of research papers has been issued (Kays, Felton et al. 1999; Van Ham 1999; Kays, VanHam et al. 2001; Kays, Buswell et al. 2006). Notwithstanding the favorable results, reclamation with hybrid poplar planting is a biosolids utilization approach that has not yet been applied widely. But its applicability to reclamation of coal mine lands seemed plausible, particularly as a program that can handle biosolids year-round with low risk of community nuisance. Those considerations encouraged Philadelphia to support the use of this innovative biosolids approach within its mine reclamation program (Pepperman, Shrawder et al. 2004).

Table 1 lists the differences between conventional reclamation and deep row placement.

TABLE 1	**Comparison of Conventional and Deep Row Placement**
Reclamation using grasses and legumes	**Reclamation using hybrid poplars**
Biosolids surface applied and incorporated	Biosolids placed in deep rows ~12-32 inches beneath the soil surface
Biosolids/soil mixture subject to aerobic conditions, majority of nitrogen available over a period of 3 years	Biosolids remains in anaerobic conditions; nitrogen is slowly released over 6-8 years
Biosolids soil mixture subject to variations in air temperature. Warmer surface temperatures tend to increase the conversion of organic N to water soluble N	Biosolids remain in cooler temperatures resulting in less biological activity; this slows the conversion of organic N to water soluble N
Grass and legume mix has a N demand of up to 160 lbs/ac/yr	Hybrid poplars demand appears to be limited only by growth rate and availability of nutrients
Grass and legume crop purpose is to meet vegetative cover required for reclamation.	In addition to meeting reclamation criteria, hybrid poplars can be harvested in 6-8 years and sold for pulp and paper mill feed, woodchips and/or as a renewable fuel
Operations occur from April-October	Preparation of rows possible year round; application can occur during winter months
Carbon sequestration occurs primarily in the first 2-3 years	Greater carbon sequestration in the 6-8 year rotation
Odors may arise from inadequate incorporation and high rates; odors must be controlled with coal ash and other methods	Odors mitigated by covering the biosolids with soil in the deep rows

Comparison of Nitrogen Cycling

A key contrast between biosolids used in a conventional reclamation and deep row placement is in the nature of the nitrogen balance at play in field applications.

First, a larger nitrogen demand is created by the planting of hybrid poplar compared to a mix of grasses and legumes. The grass and legume mix used in reclamation has a nitrogen demand of up to 160 lbs/ac/yr. The hybrid poplar trees nitrogen demand is limited only by their growth rate and availability of nutrients (Cavaleri, Gilmore et al. 2004). A study was done in Quebec using biosolids in the growth of hybrid poplars. In that study, nitrogen was applied at rates between 1,711 pounds per acre and 2,414 pounds per acre (1,916 kg/ha and 2,703 kg/ha). Even at the higher application rates, nitrogen and phosphorus were determined to be growth limiting factors. This work suggested that poplars are capable of absorbing high rates of nitrogen, and that the growth rate of the poplars would increase as a function of higher amounts of nitrogen supplied through greater application rates.

Nitrogen mobilization is quicker with conventional reclamation than with deep row placement. When surface applied, the biosolids/soil mixture is subject to aerobic conditions, and obligate aerobic soil microbes convert organic forms of nitrogen to ammonia and nitrate nitrogen. Through this conversion process, the preponderance of the organic nitrogen in biosolids becomes available to plants typically over a three-year period. With deep row placement, the nitrogen is kept in mostly organic forms in anaerobic conditions, and thus the obligate aerobic microorganisms are not able to rapidly convert organic nitrogen.

A key factor in the contrast between the application techniques is temperature. The temperature regime of deep row placement conserves nitrogen for plant uptake. Soil microbial breakdown of organic matter occurs most efficiently when soil temperatures are at 50 degrees F or greater. At a typical biosolids surface application site in central Pennsylvania, soil temperatures would be expected to be at this level or higher generally from late April to October, and, thus, organic nitrogen conversion occurs throughout the growing season (Schwann 1986). Temperatures within the deep rows are anticipated to be ten to twenty degrees cooler than those on the surface. These cooler temperatures also serve to slow down the activity of the soil microbes within the deep row, thereby further limiting the production of ammonia and nitrates, and thus limiting the potential for loss of nitrates from the soil profile.

PROCEDURES

Application Area and Approach

The hybrid poplar demonstration is located within a portion of the Repplier surface mine. Mining activity is complete at this site, and conventional biosolids practices are being applied to most of the site for its reclamation. A portion of the Repplier mine was not treated with biosolids and was set aside for this demonstration with the approval of the Pottsville District Mining Office of the Pennsylvania DEP. This demonstration project is being conducted by the Philadelphia Water Department's contractor, Waste Management and Processors, Inc. (WMPI), who has a partnership with ERCO on this project. Lehigh Engineers is a sister company to

WMPI, and Garvey Resources is a biosolids consulting firm. A Temple University engineering student intern assisted with collecting and tabulating the data.

During February, March and April, 2005, Philadelphia biosolids were delivered to the site and placed in deep rows that had been prepared using heavy-duty mining equipment. The existing soil was extremely stony and contained virtually no organic matter and only low levels of macro nutrients. The soil is so poor that establishment of sustainable vegetative cover without the use of biosolids would be very difficult. In late May and early June of 2005, WMPI planted fourteen acres of hybrid poplar trees in test plots at the Replier Mine site in Schuylkill County, Pennsylvania. Two control plots were planted without any biosolids; the other plots were planted with loading rates of 60, 72, or 100 dry tons of biosolids /acre (DTPA). Two other variables were tested in this project; the hybrid poplars were planted either between or on top of the deep rows, and two clones of hybrid poplars were planted.

Surface mine with deep rows prepared for biosolids placement. May, 2005

A backhoe is used to prepare the deep rows.

Because hybrid poplars are sterile crosses of native clones, the trees must be propagated vegetatively (i.e. they do not produce seeds). Stecklings, or cuttings from mature trees, are about ten inches in length and approximately half of an inch in diameter. To plant these stecklings, one end is inserted into the ground so that approximately 1 - 2 inches of the steckling remains exposed, and the soil around the base of the tree is compacted to give a firm rooting medium.

The pictures below show the hybrid poplars fertilized using the deep row method, at the Repplier site at the end of the first growing season. Pictured is Joe Brennan, Biosolids Utilization Manager, WMPI.

Table 2 provides a summary of the plots planted in 2005, loading rates, clones, placement of the stecklings with respect to the deep rows, and acreage.

Table 2 - Variables Tested in Each Plot								
Plot	A	B	C	D	E	F	G	H
Biosolids Loading Rate (DTPA)	0	0	60	72	100	100	72	60
Clones*	DN	OP	OP	DN	DN	OP	OP	OP
Planting Location	N/A	N/A	on top	on top	between	between	between	between
Acreage of Plot	0.36	0.3	1.63	2.96	2.45	2.8	1.97	1.78

* Dn 182 & OP 367

Environmental and Performance Monitoring

Monitoring for the project consists of sampling the biosolids, soil, groundwater, trees and foliage. The buried biosolids were tested in early summer by digging into the deep rows and testing for total nitrogen, ammonia, total solids, volatile solids and total phosphorus. The results of this testing are intended to demonstrate how quickly the nutrients become available to the trees. The tree heights and the diameters at chest height were recorded. Also, the average weight, including leaves and roots, for a sample of three trees for each plot was measured, recorded and analyzed. A key indicator as to the performance of the trees with respect to their uptake of nitrogen is foliar nitrogen concentrations. During the late summer, mature leaves from the trees in each plot were sampled and analyzed. This is useful in assessing the relative "fertility" of each plot and this measure also provides a gauge of tree performance. Foliar samples were analyzed for eleven additional elements (P, K, Ca, Mg, Mn, Fe, Cu, B, Al, Zn and Na).

Additional plots of hybrid poplar were planted in 2006, but the results will not be available until the end of 2007.

The groundwater at the Repplier site is sampled quarterly as part of a larger, on-going monitoring program, but because the demonstration area constitutes so small a portion of the drainage-shed, the groundwater monitoring results are not expected to be affected by the demonstration project.

Table 3 shows the sampling plan and the measurements and tests that were conducted, as well as the planned frequency over the demonstration project.

Table 3: Monitoring Program Overview

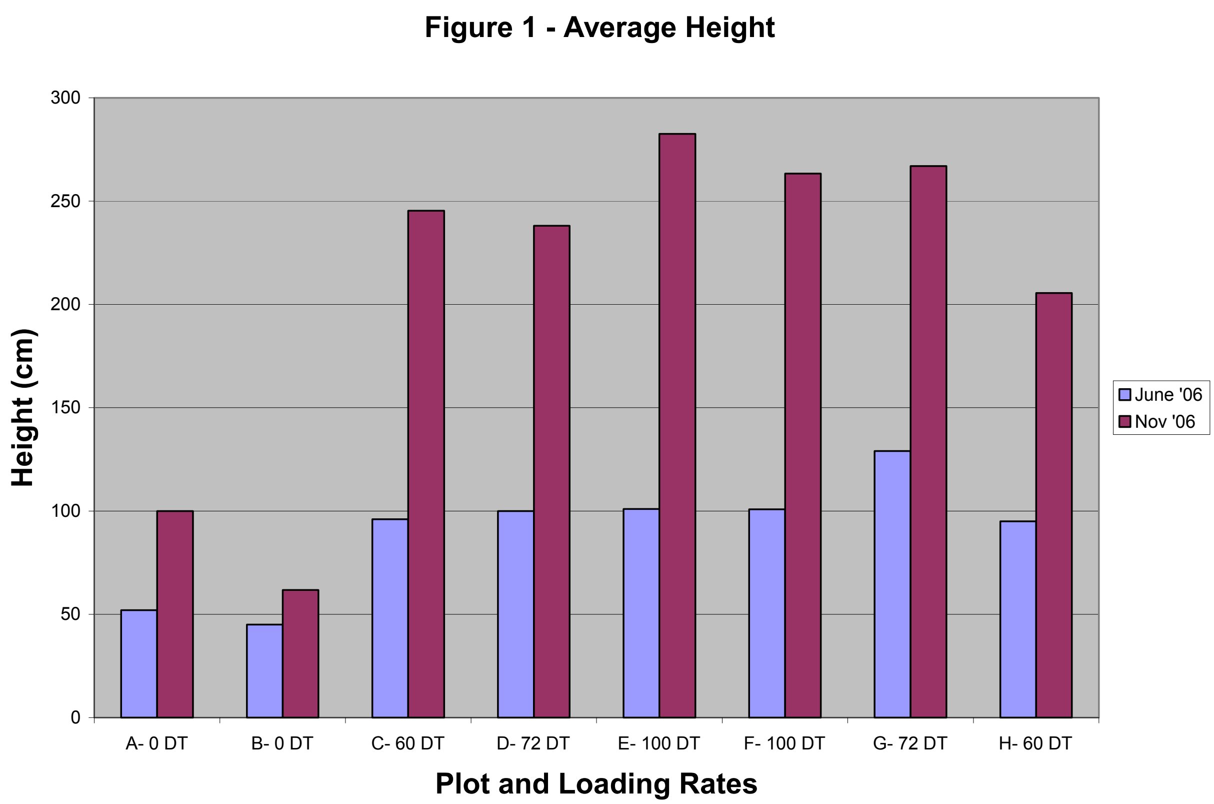
Materials Sampled	**Sampling Frequency**	**Sampling Location**	**Parameters Tested**
Biosolids	Monthly	Phila. Water Dept Southwest Water Pollution Control Facility	Metals, PCB's, Nutrients, TS, TVS
Biosolids	Spring and late summer for 6-8 Years	Deep rows for each loading rate	N, NH4, TKN, TS, TVS, P, P2O5
Background Soils	Once at the beginning of the project	Each test plot	Metals, Nutrients
Water	Partial Analysis* Quarterly, Full Analysis Annually	Pine Knot Drainage Tunnel	pH, Alkalinity, Specific Conductance, Acidity, Fe, Mg, Al, SO_3, TSS,* NO_3, NO, SO_4, As, Bo, Ca, Cd, Cu, Pb, Mn, Hg, Mo, Ni, Se, Zn, Chloride
Water	Quarterly	Lysimeters	Same as above
Trees	Spring and late Summer	Each test plot	Height, Weight, DBH
Tree Foliage	Once per year in August or September	Each test plot	P, K, Ca, Mg, Mn, Fe, Cu, B, Al, Zn, Na

*Full analysis includes all parameters listed; quarterly analysis includes those parameters up to and including TSS.

RESULTS

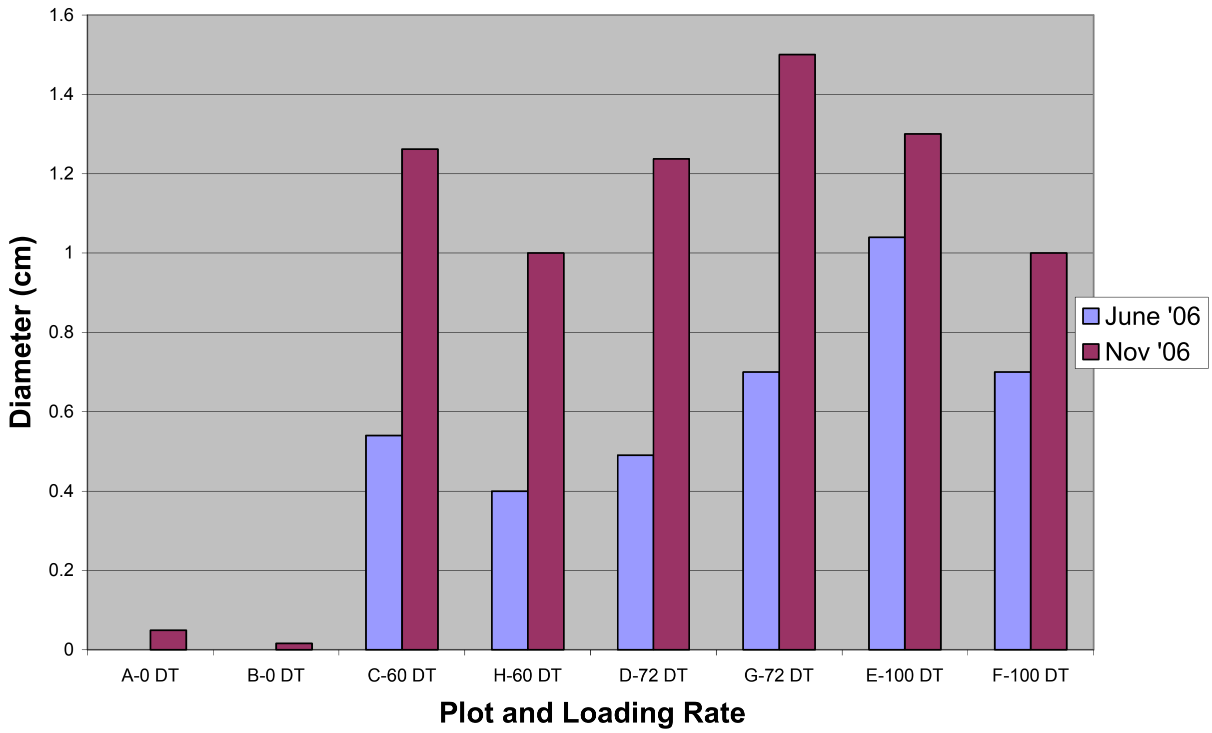
Tree Growth Measurements

The trees in the control plots were smaller in height, lower in weight and had the smallest root systems out of all of the plots based on the monitoring of the trees in plots A-H during 2006. Figure 1 shows the average height of the trees in the various plots at the beginning and at the end of the second growing season. For this phase of the trees' growth, the trees fertilized with biosolids grew to a greater height, two to three times higher, than those in the control plots A and B.

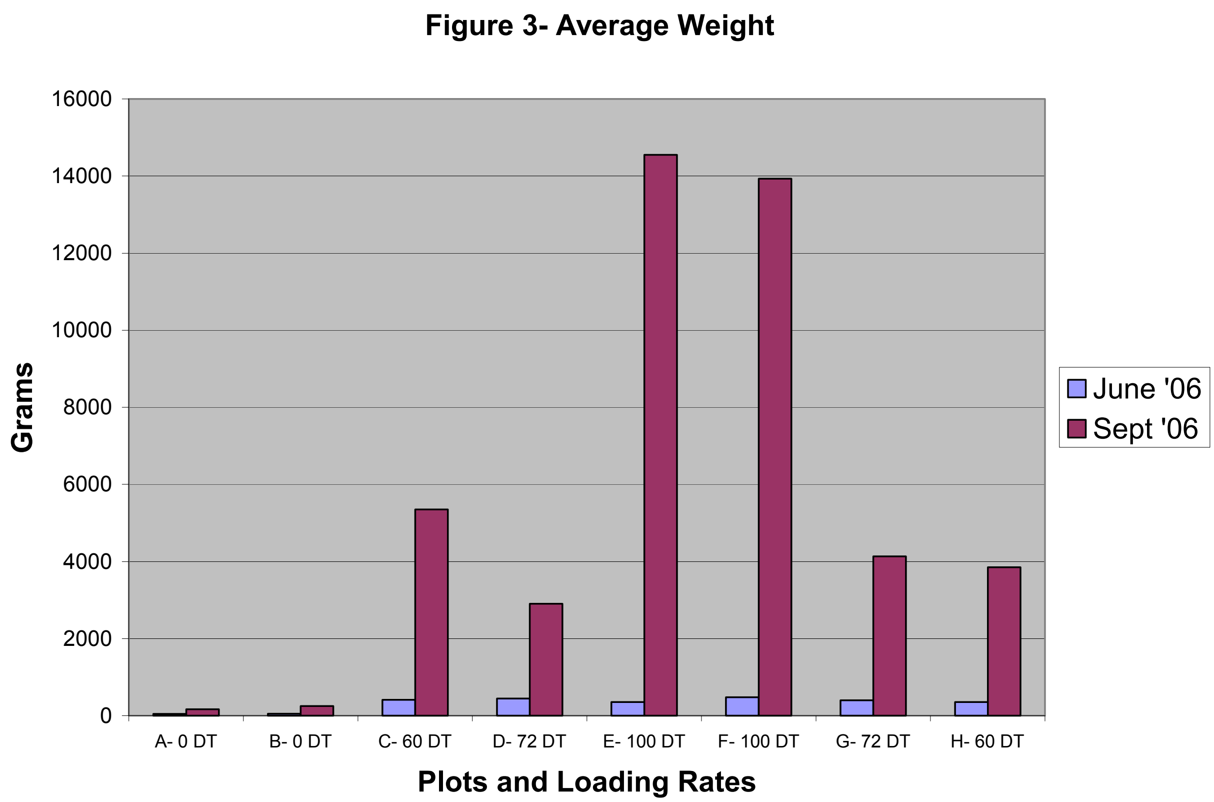


Diameter at breast height (DBH) was measured in June and November of the second growing season on trees that had reached 50 inches. Figure 2 shows the average DBH for each plot. Trees less than 50 inches tall were assigned a DBH of zero in the calculation of the plot average. DBH in the control plots was significantly less than in the plots fertilized with biosolids. However, DBH was not a good indicator of relative tree mass since some trees had only one stalk that was more than 5 feet tall, while others had several stalks of similar diameter.

Figure 2 -Average Diameter



The difference in weight further illustrated the impact of biosolids application. Again, trees fertilized with biosolids grew much better than the trees in control plots A and B. At the end of the second growing season, the trees in the 100 DTPA plots had average weights nearly 10 times that of the control. Figure 3 shows the average weights that were measured.



Observation of the root systems in the plots with 100 DTPA loadings showed larger and farther reaching root systems than the other plots. This photograph shows how the largest roots grew in the direction of the biosolids in the deep row. It also shows the large diameter of the trunk and the root.

The photograph to the right shows roots of a hybrid poplar tree grown in deep rows with 100 DTPA biosolids.

The two pictures on the next page show the difference in appearance between a tree removed from the control plot and one removed from the 100 DTPA Plot. Not only were the trees grown in biosolids taller, but they had many more branches and a more extensive root system.

Poplar Grown Without Biosolids　　Poplar Grown With Biosolids

Foliar Samples and Foliar Analysis

Leaf samples were collected from trees within each plot in September of 2006. Fifteen leaves or more were collected from each plot. The 7th or 8th leaf (with the stem) from the top of fifteen or more average size trees in each plot was collected. The selected leaves were photosynthetically active (vibrant green). Penn State Lab (Agricultural Analytical Services Laboratory) tested each sample for N, P, K, Ca, Mg, Mn, Fe, Cu, B, Al, Zn and Na. The results are shown in Table 4. Leaves from the control plots averaged 1.83 % N while the biosolids amended plots averaged 2.7% N.

Table 4 - Poplar Foliar Analysis

Plot	Loading	N	P	K	Ca	Mg	Mn	Fe	Cu	B	Al	Zn	Na
	(DTPA)	%					ug/g						
A	0	1.53	0.13	0.56	1.49	1.02	1037	88	3	27	23	320	29
B	0	2.12	0.18	1.22	1.10	0.66	180	55	5	36	18	447	21
C	60	2.25	0.15	0.71	1.11	0.88	2634	109	6	26	57	663	45
D	72	2.99	0.20	0.85	1.13	0.93	483	87	8	28	12	318	25
E	100	2.68	0.17	0.97	1.24	0.81	410	90	6	30	11	376	33
F	100	3.07	0.21	1.50	0.89	0.64	691	92	10	37	21	396	29
G	72	2.71	0.18	1.23	0.93	0.70	309	83	8	41	16	359	27
H	60	2.49	0.17	0.95	1.10	0.71	588	105	7	30	17	503	38
AVG	**no biosolids**	**1.83**	**0.16**	**0.89**	**1.30**	**0.84**	**609**	**72**	**4**	**32**	**21**	**384**	**25**
AVG	**biosolids**	**2.70**	**0.18**	**1.04**	**1.07**	**0.78**	**853**	**94**	**8**	**32**	**22**	**436**	**33**

This shows that the trees fertilized with biosolids were healthier than those without biosolids. The general literature suggests foliar nitrogen content in hybrid poplars with access to unlimited nitrogen would be about 3% to 4%. This finding suggests that the trees in the plots fertilized with biosolids could likely utilize additional nitrogen.

Soil Sampling and Analyses

Surface soil samples from the top 2 inches (5.08 cm) in each of the test plots were collected and analyzed for basic fertility, sieve analyses and aluminum toxicity. As expected, the organic matter in the control plots (background) was very low, 0.7 - 0.8 percent. Organic matter in the plots receiving biosolids ranged from 1.4 - 2.2 percent. This higher level of organic matter in the plots receiving biosolids could be due in part to biosolids left at the surface during the original placement, but leaf fall from the trees and earthworm activity may also contribute. The surface soil pH is higher in the plots where biosolids was used, even though all plots were treated with lime. But the reason for this is not known.

Table 5 **Soil Results December 2006**

Test		**A**	**B**	**C**	**X**	**D**	**E**	**F**	**G**	**H**
Loading Rate		0	0	60	60	72	100	100	72	60
pH		4.7	4.7	6.9	5.6	5.8	6.1	5.8	6.7	6
P	lb/A	30	6	62	22	34	20	16	54	50
Acidity	meq/100g	3.9	8.1	0	6.3	3.9	3.9	2.2	2	2.8
K	meq/100g	0.1	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.2
Mg	meq/100g	2.3	1.6	3.3	6.3	5	4.7	4.3	5.3	5.7
Ca	meq/100g	2	1.4	3.8	3.5	3.9	3.3	3.9	5	4.4
CEC	meq/100g	8.3	11.1	7.3	16.2	13.1	12	10.6	12.5	13
K	% Sat of the CEC	1.1	0.6	2.9	0.9	1.6	1.4	1.7	1.3	1.2
Mg	% Sat of the CEC	27.5	14.1	45.5	39.7	38.5	39.2	40.6	42.5	43.4
Ca	% Sat of the CEC	24.2	12.5	51.6	21.5	30	27.1	37.1	40.2	33.9
Organic Matter	%	0.7	0.9	1.4	1.4	2	2.1	1.6	1.7	2.2
***X- this was an area in plot C**										

The Penn State Agricultural Analytical Soils Laboratory analyzed the soil samples and interpreted the results. The sieve analysis showed that once the rocks were removed, the soils fell in the category of sandy loam and sandy clay loam. Magnesium levels in all of the soil samples were above optimum levels. This presents a risk that plants will absorb magnesium instead of calcium and there will be a calcium deficiency. Soil samples were collected and composited from an area within plot C where no plants grew, and the sample was labeled "X." Soil fertility and an aluminum toxicity test were conducted, but the analytical results did not appear to be significantly different from the other soil samples collected in test plots.

Changes in Biosolids Characteristics in the Deep Rows

Biosolids in the deep rows were analyzed for nitrogen and phosphorus to see if there was a change from when the biosolids were initially produced. The results from the spring sampling were inconclusive. The data showed a change in total nitrogen concentration that ranged from a 7% gain to a 19% loss. Basing the results on one sample from each excavation did not prove adequate to identify trends in changes in nitrogen concentration, nor could it explain an apparent increase in biosolids nitrogen.

In the Fall round of sampling, three samples from each excavation (loading rate) were collected, and the PWD lab conducted the analysis of the samples. This is the same lab that tests the biosolids before it leaves the Water Pollution Control Plant (WPCP). Table 6 shows the results of the analyses of biosolids from within the deep rows and compares it to the average concentrations measured in biosolids from the Philadelphia Southwest WPCP during March, April and May, 2005, the period of time during which biosolids were shipped to the site.

Table 6	**Biosolids Samples from Deep Rows**				
	Collected Sept 2006				
			Total	Total	Volatile
Plot	Phosphorus	Ammonia	Nitrogen	Solids	Solids
	(mg/kg)	(mg/kg)	(mg/kg)	(%)	(%)
Biosolids					
Background (1)	23433	3480	34733	29.6	45.6
Avg Plot C	28500	5727	26167	33.7	38.5
Change	5067	2247	-8566	4.1	-7.1
Avg Plot D	25233	3883	23307	30.9	40.5
Change	1800	403	-11426	1.3	-5.1
Avg Plot E	26067	5913	28400	32.5	37.7
Change	2634	2433	-6333	2.9	-7.9
Avg Plot F	16767	2200	15000	43.8	24.5
Change	-6666	-1280	-19733	14.2	-21.1
Avg Plot G	22467	3063	19533	41.0	30.7
Change	-966	-417	-15200	11.4	-14.9
Avg Plot H	20533	2847	20467	42.0	29.5
Change	-2900	-633	-14266	12.4	-16.1

The change in total nitrogen concentrations shows that the nitrogen is being removed either by root uptake, leaching, conversion to nitrogen gas, or possibly dilution of the sample by soil. The levels of ammonia and phosphorus showed that, while in some plots the concentrations decreased, in other plots concentration increased. In all plots, testing showed that the total solids increased and the percent volatile solids (similar to organic matter content) decreased.

Interpretation of these analyses is made complicated by the difficulty in obtaining samples of biosolids from the trenches. Some of the collected samples may not have been exclusively biosolids. When the deep rows were backfilled, the rocks and soil became embedded in the layer of biosolids. The biosolids and the soil are the same color, so some of the biosolids sampled in the deep row may have contained soil.

Experience with the deep row technique at the ERCO site in Maryland showed that the nitrogen content of biosolids in the deep row varied from the top of the biosolids to the bottom of the biosolids. Because the loading rates at the WMPI site were lower (60, 72 and 100 DTPA compared to 171 and 342 at the ERCO site) and the mine site so rocky, the depth of biosolids was not always adequate to collect a pure sample from the bottom and the top of the deep rows.

In July of 2006, samples of the biosolids from the deep rows were analyzed for fecal coliform. Although this was not part of the planned monitoring, recent research by others raised a concern for re-growth of fecal coliform in stored biosolids. The results of the sampling from the deep rows showed the fecal coliform concentration from all three samples were less than 1000 MPN per gram solids and all were below the level of detection. These results indicate that not only was there no evidence of re-growth but fecal coliform continued to die off in the deep row environment.

CONCLUSIONS

Deep row placement of biosolids for reclamation of coal mines with hybrid poplar plantations has been successful in the first two growing seasons. The testing of the plots during two growing seasons has shown:

1. Hybrid poplar trees fertilized with biosolids grew faster than controls during the first two years when measured in terms of height and biomass; the contrast was several orders of magnitude higher biomass and height in the treated versus control plots.
2. No differences were observed in the growth of stecklings placed between rows of biosolids versus over the top of the rows.
3. No difference was observed in the performance of the two different clones.
4. The 100 DTPA rate of biosolids application gave the strongest biomass results of the three application rates.
5. Foliar analysis suggests that even higher application rates of nitrogen may be used, supporting future demonstration plots of higher application rates.
6. Soil sampling suggests a beneficial modification of the surface soil quality in the treated plots that may be occurring from leaf fall.
7. While sampling of the biosolids in the rows did not fully explain the nitrogen cycle at the plots, no evidence of significant nitrogen loss was seen.

8. Fecal coliform monitoring showed that bacterial counts dropped in the buried biosolids, and no re-growth was observed.

In addition, no odor complaints were received from the communities in the vicinity of the demonstration, suggesting that the deep row placement of biosolids mitigates odor risks.

The one operational challenge encountered in the deep row approach was the difficulty with creating straight rows through the extremely rocky and non-homogeneous surface. Boulders more than 1 meter (3.28 feet) in diameter were often encountered and the row was shifted to the right or left to avoid the boulders.

Additional monitoring of these plots is warranted. Whereas only two growing seasons have occurred, no firm conclusion is possible yet about whether sufficient nutrients have been placed in the rows to support a multi-year growth cycle. Similarly, no conclusion can be yet drawn as to the habitat changes that may occur in the plot areas.

OBSERVATIONS

Deep row placement of biosolids for hybrid plantations is a biosolids utilization approach that offers a number of potential benefits. The Philadelphia Water Department looks forward to several advantages:

Year-round operations. Deep row trenches may be prepared during winter months, and biosolids may be hauled and utilized during the winter months when other land application programs are shut down. This serves not only the need of wastewater agencies for winter outlets, but allows the application contractors to make use of its staff and equipment through the winter.

Diversification of Outlets. This program may be run coterminous with conventional reclamation use of biosolids. The cost of operations is more cost effective than landfill disposal for off-season biosolids use.

Public support. This project has garnered public support when presented to the County Conservation District and local watershed associations.

Odor control. Deep row placement of biosolids mitigates the problems of off site odors during operations. The biosolids can be delivered to the site and placed in the deep rows in approximately 15 minutes. Compared to surface application, this greatly reduces the surface area of biosolids exposed to the atmosphere and the length of time biosolids are exposed to the atmosphere.

Higher application rates and operational efficiencies. The amount of biosolids that can be physically spread and incorporated in conventional methods is limited to a 2 - 3 inch layer, and even then the risk that some biosolids remains at the surface gives rise to odor nuisance potential. The deep row placement of biosolids may accommodate several times the guideline rate of 60 DTPA that is the limit for conventional methods. Deep row placement does not result in incidental exposure of biosolids at the soil surface.

Water quality improvements. Reclamation of disturbed mine lands is expected to gradually improve the quality of discharge water over the long term as hybrid poplars intercept a large portion of rainfall that otherwise recharges pools of acid mine waters.

Wildlife habitat enhancement. Hybrid poplars provide wildlife habitat and their uptake of biosolids-borne nutrients is returned to the soil surface as leaf fall that initiates soil forming processes supportive of diverse ecosystems. The trees also provide nesting sites for birds and grazing opportunities for deer. In addition, the plots are arranged with aisles between plots and space between the road and the plots. This combination of open space and trees creates ideal habitat for upland game birds. Space between the steckling plantings in the plots is seeded to grasses and legumes which provide food and cover for wildlife.

Optimized tree growth. The deep row method is ideal for tree planting because the trees do not compete with the weeds and grasses, as is the case with conventional reclamation methods. For this reason, the survival rate of tree saplings and the growth rate of trees is superior with the deep row method.

Benefits of using hybrid poplars. Hybrid poplar use has recently expanded from past traditional use in windbreaks to producing wood, fiber and fuel products and to remediating contaminated sites and treat waste. Poplars are among the fastest growing tree clones in North America, capable of accumulating enormous amounts of wood and biomass in a relatively short period of time. Use of poplars for waste management applications originally started with growing hybrid poplars for pulp in short rotations of six to eight years. Another prospective use for poplars is bioenergy, which is the use of vegetation for energy production. Poplar chips can produce a fast and hot burn and can be classified as a carbon neutral energy source. Hybrid poplars can be used to produce pelletized fuel. The branches and tops left from pulp harvests and even small, young material can be converted to pellets for pellet burning industrial boilers and thermostatically controlled home heaters. However, today, the trend is to grow the poplars at a wider spacing for 10 - 15 years, in order to produce solid wood products such as molding, paneling, furniture stock, veneer and veneer core. Sawmill tests show hybrid poplar wood equals or surpasses black cottonwood in quality, which is currently being exported for lumber.

Carbon sequestration. Deep row placement of biosolids for hybrid poplar plantations is a potentially significant means of accomplishing terrestrial carbon sequestration. The CO_2 equivalents (Green House Gas) produced or absorbed by a hybrid poplar project of 100 acres can be estimated using factors released by the US EPA (Anonymous 2006). The activities that generate CO_2 equivalents are the trucking of the biosolids from Philadelphia and the use of mobile equipment to prepare the deep rows and deposit the biosolids. The activities that sequester carbon are the growth of the trees and the increase of carbon in the soil. The full mass balance is included in a Garvey report to WMPI on the demonstration project and shows that planting 100 acres of hybrid poplar with 100 DTPA biosolids will result in a net decrease in CO_2 equivalents of nearly 34,000 tons CO_2. This is about 1 ton of CO_2 equivalents per wet ton of biosolids used.

ACKNOWLEDGEMENTS

The authors want to acknowledge the efforts of Joe Brennan, Biosolids Utilization Manager, WMPI, who manages all the daily operations at the reclamation site. Randy Lindenmuth, PE, at Lehigh Engineers was also instrumental in obtaining the approvals and environmental permits to operate the demonstration. Special thanks are extended to Daniel Koury, Pottsville District Mining Office, PADEP, for his help in planning the project and communicating with others in the PADEP, County Conservation District, local watershed associations and the general public.

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