Biomass Production Study of Hybrid Poplar Grown on Deep Trenched Municipal Biosolids

Biosolids, formerly known as "sludge," refer to the residual materials removed from sewage during the wastewater treatment process. They usually contain from 1-4% nitrogen and are a valuable source of fertilizer for agriculture and forest crops. The utilization of biosolids using short rotational crops of hybrid poplar trees solves many of the problems associated with traditional biosolids application methods and holds great promise for our region.

Land application of the solids produced from municipal waste water treatment plants has become a preferred option for large-scale nutrient recycling when compared to landfilling because it utilizes the nutrient value of biosolids for growing crops. It has become increasingly difficult to apply these biosolids on land due to accelerating land prices, the disappearance of farm land, and social issues surrounding odors.

In the Washington, D.C. metropolitan area, much of the biosolids are hauled in trucks over long distances to southern Virginia at high cost and increasingly expensive diesel consumption. To offer a more sustainable solution, a local mining company (ERCO, Inc. of Brandywine, MD) developed a local solution that applies the municipal biosolids to underground trenches in the heavy clay mining spoils of a former sand and gravel mine. Short rotation crops of fast-growing hybrid poplar trees are grown in the biosolids and subsequently harvested and chipped for the local plant nursery industry.

This study was initiated because of the interest in wood energy, utilization of non-agricultural lands, and the concern of odor. The goal of this study was to develop a method of calculating biomass production of hybrid poplar trees grown on municipal biosolids. Hybrid poplar (Populus spp.) is among the fastest growing trees in North America.

Figure 1. Excavated trench and a load of municipal biosolids

University of Maryland Extension, the Washington Sanitary Suburban Commission (operator of the 500 million gallons-per-day Blue Plains waste water treatment facility in Washington, D.C.), and ERCO, Inc. coordinated a beneficial re-use of biosolids reclamation project in Prince George's County, Maryland (Figure 1) to demonstrate how deep row application of biosolids could be used to produce hybrid poplar trees in a six- year rotation (Kays et al., 2000). This production system has the potential to supply wood as lumber, pulp, and mulch to local industries, or supply chips for thermal energy production and future cellulosic

ethanol processing plants, while restoring life to mining spoils and avoiding land-filling.

Silvicultural businesses must be able to inventory their woody crops using calculations based on measurements that are easily made in the field. Through this study, formulas were developed to estimate tree wood biomass from simple field measurements.

Site Description
The study site was located within Prince Georges County, Maryland, in the Washington D.C. metropolitan area. About six meters (20 feet) of sand and gravel were mined from the site between 1972 and 1983, which left behind a substrate consisting predominantly of clay.

Land preparation began with the excavation of trenches in which biosolids were buried (Figure 1). By covering the biosolids with 20 to 30 cm of overburden (spoil left after mining), odors are prevented from escaping. The biosolids application rate typically ranges between 422,000 to 725,000 dry kg per hectare (171 to 294 dry tons per acre). The biosolids were entrenched which maintained them in a fairly stable anaerobic environment for a year prior to planting. The site was then planted with hybrid poplar trees, the roots of which provide a natural recycling system that utilizes most of the nutrients in as few as six years (Felton et al, 2005). The tree farm management was "low-intensity;" no herbicide, irrigation, or fertilizer was applied. The understory spaces were mowed 2-3 times per growing season during the first two years of the rotation to suppress plant competition.

Experimental Design
In 2005, samples were randomly selected from stands planted in 1999, 2000, 2001, 2002, and 2003 using the same clone, OP367 (Figure 2). At each stand, approximately five trees were randomly selected for sampling, except for the 2001 stand

where a total of nine samples were selected due to the large area it covered, and the 2003 sample where only three samples were collected because it was very sparse.

Data Collection
The diameter at breast height (DBH) which is 1.4 meters from the ground, was taken for each sample tree. Trees were measured with a standard DBH tape at the end of the growing season in September 2005.

Figure 2. Hybrid poplar plantation on deep row site

In October 2005, sample trees were felled by cutting at the ground surface with a chainsaw. The height (HT) of felled trees was measured following cutting (figure 3). The green weight (GW) of the entire tree above ground including twigs and branches, was obtained by suspending the felled tree from a load cell (National Scale Technology, Huntsville, AL) attached to a steel tower (Figure 4). For each sample, disks 2-3 cm thick were cut from the tree base and every 1.6 m (5ft.) increment above the bottom. A minimum of three disks per tree were collected. The green weight of each disk was recorded. The disks were transported to a lab where they were oven dried at 70°C until reaching a

constant weight. Drying time required was from 3 to 5 days.

Figure 3. Measuring tree height after felling

Figure 4. Measuring green weight of the tree

The percent moisture content of each disk (MC_{disk}) was calculated using the equation:

MC_{disk} = 100 * (GW_{disk} – DW_{disk}) / (GW_{disk})

Where:

GW$_{disk}$ = green weight of tree sample disk (grams)

DW$_{disk}$ = oven dried weight of tree sample disk (grams)

Sample tree moisture content (MC_{tree}) was determined using the average of percent moisture content of each disk (MC_{disk}), which was then used to determine a tree's above-ground biomass (BM_{tree}):

BM_{tree} =(GW_{tree}) / (1 + MC_{tree} / 100)

Where:

BM_{tree} = above-ground dry biomass in grams

GW_{tree} = green weight of sample tree in grams

MC_{tree} = estimated percent moisture content of sample tree

Above-ground biomass per hectare of each stand (BM_{stand}) assuming no mortality of trees, was determined from the equation below. If mortality exists, BM_{stand} can be corrected by multiplying the value by the percent survival. Mortality trees can vary depending on many factors but some mortality occurred in the study areas.

BM_{stand} = s*BM_{tree} * (% survival/100)

Where:

"s" = planted stem density (number of trees per   ha)

BM_{tree} = Mean above-ground biomass per tree (grams)

% survival = number from 1 to 100

Data Analysis

The net production of mean above-ground tree biomass was found by fitting a straight line to a graph of basal area of the stand (BM_{stand}) as a function of stand age. The best fit line was found using simple linear regression.

Growth relationships predictive of BM_{tree} were determined for DBH and HT using a simple linear regression for each measure. Stepwise linear regression was used to explore whether a growth equation that combined both DBH and HT improved

stand estimates. Correlation between independent variables (i.e., DBH and HT) was determined to avoid statistical problems.

Figure 5. A sample stand.

Results

After six years of growth on trenched biosolids, the hybrid poplar plantation appeared healthy with a developing canopy and full understory (Figure 5).

The mean tree biomass, height, and DBH increased with stand age, except in the 2001 stand, which suffered from the combination of heavy deer grazing and drought conditions during the first growing season (Table 1). After six years of growth, trees averaged 20.5 kg in weight, 974 cm in height, and 11.7 cm in diameter (Table 1). Table 2 provides the same information in English units.

Growth Model

The growth relationships for the sample data showed that both DBH and height had strong linear relationships with wood biomass of individual trees during the first six years of growth. Equations were developed that found tree height was a strong estimator of tree wood biomass (WB_{tree}) as shown in this equation:

$$WB_{tree} = 0.0274 * HT - 8.1 \qquad \text{(Model 1)}$$

Where:
    WB_{tree} = tree wood biomass in kg predicted by Model 1

    HT = tree height in cm

The equation below estimated tree wood biomass as a function of DBH (cm), where DBH = diameter at 137 cm (4.5 feet)

$$WB_{tree} = 2.0 * DBH - 4.64 \qquad \text{(Model 2)}$$

Where:
    WB_{tree} = tree wood biomass in kg predicted by Model 2

    DBH = Diameter at 137 cm (4.5 feet)

Because DBH is an easier field measure to collect compared to tree height and it provided a good prediction of tree biomass, the equation was further developed. It was found that the relationship between tree biomass and DBH was not quite linear. There was an inflection point in the relationship at a DBH of 4 cm. It is likely that the young trees did not penetrate the 20 cm of trench cover to reach the fertile biosolids until they were greater than 4 cm in diameter, which would explain the inflection point.

To improve the precision of the growth model based on DBH, the data was divided into two sets based on whether DBH was greater or less than 4 cm to develop two equations.

Net Wood Productivity

Conclusions

- A healthy hybrid poplar plantation was grown on the clay spoil of a former sand and gravel mine where a one-time application of municipal biosolids was applied in deep trench rows.
- The oldest tree stand, which was six years old had a mean standing wood biomass of 22,100 kg/ha (19,732 lbs/ac or 9.87 tons/ac).
- The mean net tree productivity of the hybrid poplar plantation during its first six years of growth was estimated to be 5450 kg/ha/year (4866 lbs/ac/yr or 2.43 tons/ac/yr)).
- The energy equivalent in BTU's of hybrid poplar wood chips at 50% moisture is 177.3 million BTU's for the six year old plantation. That is equivalent to 1,276 gallons of #2 fuel oil per acre.
- The most precise growth model for estimating above ground tree biomass used DBH. Tree height also served as a strong estimator of tree biomass. However, using DBH makes taking field measurement much easier and cheaper. Different equations are used for trees above and below 4 cm in DBH.
- The soils found at the sand and gravel mine are representative of thousands of acres of land in southern Maryland. Each site would need to be assessed individually for suitability for the deep trenching technique.
- The use of the equations for trees grown on intact or unmined native soils will need to be verified by destructive sampling of trees to see how accurately their biomass is predicted using the equations.
- Hybrid poplar trees grown using the deep trenched biosolid technique provide a renewable energy source (wood chips) that when burned using clean wood energy technology, produce Btu's for heating and cooling, which displaces fuel oil (Table 3).

References:

Felix E., D.R. Tilley, G. Felton & e. Flamino. (2008). "Biomass Production of Hybrid Poplar (Populus sp.) Grown on Deep – Trenched Municipal Biosolids," *Ecological Engineering*, Volume 33, Issue 1, May 2008, Pages 8-14. Available online at [http://www.naturalresources.umd.edu/Publications/BiosolidResearch/AuthorsCopyBiomassProduction.pdf]

Table 1. Metric dry weight, height and diameter at breast height (DBH) of individual hybrid poplar trees grown on trenched municipal biosolids in Maryland (USA)

Year of Planting	Age	Dry Weight (kg)		Height (cm)		DBH (cm)		No. of Samples
Year	Years	Mean	SD	Mean	SD	Mean	SD	n
2003	2	0.3	0.2	225	47	1.3	0.7	4
2002	3	4.6	4.5	494	188	5.0	2.7	10
2001	4	3.0	1.9	442	106	4.2	1.5	9
2000	5	14.9	6.7	844	91	9.5	2.5	5
1999	6	20.5	2.9	974	66	11.7	1.0	5

Table 2. English dry weight, height and diameter at breast height (DBH) of individual hybrid poplar trees grown on trenched municipal biosolids in Maryland (USA)

Year of Planting	Age	Dry Weight (lbs)		Height (ft)		DBH (in)		No. of Samples
Year	Years	Mean	SD	Mean	SD	Mean	SD	n
2003	2	0.7	0.4	7.5	1.6	0.5	0.3	4
2002	3	10.2	10.0	16.5	6.3	2.0	1.1	10
2001	4	6.7	4.2	14.7	3.5	1.7	0.6	9
2000	5	33.1	14.9	28.1	3.0	3.8	1.0	5
1999	6	45.6	6.4	32.5	2.2	4.7	0.4	5

Table 3. English dry weight per acre, BTU's and equivalent gallons of oil at a planting density of 10' X 10' (432 trees per acre) of hybrid poplar trees grown on trenched municipal biosolids in Maryland (USA)

Year of Planting	Age	Dry Weight Per Tree (lbs)	Dry Weight Per Acre (lbs/acre)	Wet Weight at 50% moisture (tons/acre)	Million Btu's Per Acre at 50% moisture	Equivalent Gallons of Fuel Oil per acre
Year	Years	Mean	Mean	Mean	Mean	Mean
2003	2	0.7	3183.8	0.3	2.7	19.7
2002	3	10.2	44.06	4.4	37.9	272.6
2001	4	6.7	2894	2.9	24.9	179.1
2000	5	33.1	14299	14.3	123.0	884.7
1999	6	45.6	19699	19.7	169.4	1218.8

Note: 4,300 BTU's/lb hybrid poplar wood @ 50% moisture. 139,000 BTU's/gallon

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