Energy Performance Systems, Inc.

Owner & Developer of the Whole Tree Energy™ Technology

Project Title: **"Improving the Efficiency of Planting, Tending and Harvesting Farm-Grown Trees for Energy"**

Contract Number: RD-50 Milestone: 26 Report Date: January 13, 2013

Principal Investigator: L. David Ostlie, 763-428-0646

Congressional District: 3 (Corporate Office; Rogers, MN)
Congressional District: 7 (Farm Location; Graceville, MN)
Congressional District: 6 (Equipment Building Location; Big Lake, MN)

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MILESTONE 26 – SUMMARY REPORT
Harvest Trees to Obtain Yield and Cost Data

Executive Summary:

The final harvest with the Whole Tree Harvester™ proved to be a success. As in previous tests, the trees were cut cleanly and quickly (approximately 1.6 trees/s). The trees then traveled up the skid-pan, off of the harvester and onto the ground. Under normal operating conditions, the trees would be off-loaded onto a trailer pulled by the harvester. This would allow for the trees to be delivered to a biomass site with less dirt and debris, resulting in less abrasives and a cleaner fuel for the systems involved in conversion to power.

Although current harvest of row planted trees for paper, pulp and/or energy, usually involves 8-12 inches (dbh) trees, this test was performed with trees ranging from 2.5 to 5 inches (at the base). The Whole Tree Harvester™ performs best with larger trees. Design modifications would be necessary for the harvest of trees smaller than 3 inches (dbh). The most significant modification would involve adjusting the height of the skid-pan, such that the trees are supported in a way that allows them to stay upright as they travel up the skid-pan.

Costs associated with the harvest of trees from the production site for this project are shown at approximately $7.6 to $14.3 per ton (Figure 1). The chart shows the relationship between harvesting costs and productivity and is based on various tree sizes and harvesting speeds. Further details may be found in Table 2 and Appendix A. This data, combined with cost data from the EPS, Inc. Injection Planter, show that the viability of Whole Tree Energy™ (WTE) is great, particularly when compared to corn for Ethanol production, where conservative estimates show WTE costs ten-fold less than Ethanol.

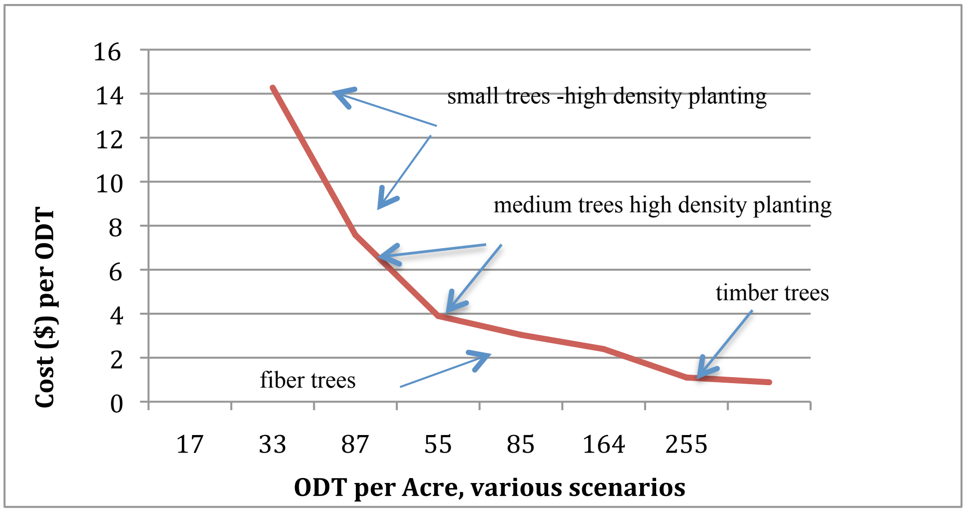

Figure 1. Harvester Cost Relative to Productivity

This project involved the use of high density plantings (1742 trees/acre) for the purpose of reaching maximum tonnage yield earlier. Typically forest resources are grown at rotation ages up to 30 years with wide spacing, which does not lend itself to energy production scenario. From an energy standpoint, tons per acre in a short time frame are the focus, rather than size and shape of the tree.

In addition to the last harvester test, the final yield results for the Graceville, MN production site as well as the Dumont, MN clone trials were gathered and analyzed. The Graceville trees performed well in certain areas of the site; however, many trees did not survive or grew slowly in the poorly drained areas of the site. Data collected over the six years of the Graceville West field study showed an overall yield of approximately 4.06 oven dry tons/acre/year (odt/ac/yr) or a total standing stock of about 24 dry tons on about 25% of the of the site at end of August. If the missed part of the 6th growing season (15% of total) is taken into consideration, the standing yields on the better part of the Graceville West field are closer to 25 dry tons/acre. The measured areas of the Graceville field represented the site quality envisioned to be available for ~ $100/acre at the time the proposal was written (2004). Some areas of initial slow growth showed accelerated growth in later years with dryer conditions. The best areas of the fields showed approximately 6 odt/acre/yr despite a widespread leaf fungal outbreak in Minnesota. The smaller Dumont production study averaged an age 5 standing yield (in late August) of 13.5 odt/ac over whole field and 16.7 odt/ac in best 5 plots when measured. Since the growth period does not actually end until early November, we estimated that final yields may have been closer to 14.2 and 17.6 dry tons/ac respectively based on degree day data showing that 15% of the growing season occurred after our measurements.

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The Dumont clonal trial included growth analysis of ten different clones, planted as 1 year old rooted cuttings, across in a range of soil drainage conditions. Of the clones evaluated, the DN2 clones performed the best, with yields (in small plots) of higher than 5 odt/acre/yr, followed by clones NE222 (4.9 odt/acre/yr), DN34 (4.1 odt/acre/yr) and finally NM6 (3.09). The results from the trial cannot be extrapolated to commercial conditions since they were planted with 1 year old rooted cuttings (at much higher cost) rather than unrooted cuttings as would be used commercially. While the interpretation and application of the results are limited, the trial did provide interestingly positive results in terms of the hardiness of clones such as DN2 and NE222 in poor soil conditions at specific sites. Evaluation of several clones for site-specific responses should be included when planning large-scale planting efforts.

Evaluation of the Whole Tree Harvester™ costs show that the harvester can be cost effective during the first year of use at relatively low prices paid to the harvester operator. If the price to the harvest operator is adjusted to account for tree sizes (higher prices for smaller trees), the harvest operation can still be profitable for trees as small as 3.5 inches in average diameter, even when using pricing that is less than half of the going rate in the industry. Because of the harvester high productivity rates, not currently existing in the industry, it became clear that the bottleneck for harvesting lies in the offloading of the loaded trailers. The Whole Tree Harvester™ can cut and offload a trailer full of trees faster than the time it takes to hook up a new trailer and haul it off. In order to account for this, an efficiency factor of 16% was utilized in the calculations. Finding ways to streamline the trailer off-loading could greatly increase the productivity of the harvester. Details are shown in Appendix A.

Assessment of the Cost of Production, Harvest and Potential Net Revenues

In order to estimate the overall costs of Whole Tree Energy™ , there are many factors that require evaluation. Included in these costs are production costs (such as land rent, tree slips, planting and site maintenance costs) as well as harvesting costs. Planting cost estimates assume that an injection machine can plant 7.2 million slips in a two month long planting season. This presumes a 10 hour shift where 6 slips are planted every 1.5 seconds with 8 hours of continuous operation per day at full capacity. Table 1 shows the breakdown of the planting costs.

Table 1. Planting Costs

Required Factors	**Estimated Costs**
Six general laborers	\$8/hr, 600 hrs each season = \$28,800
One skilled, trained, and certified operator	\$50/hr, 500 hrs each season = \$25,000
Fuel	\$12,000
Miscellaneous (i.e. maintenance, tires, etc.)	\$13,000
Estimated Annual Operating Cost	\$78,800
Machine Cost	\$90,000
Cost per Slip the First Year	\$.03
Cost per Slip After Initial Investment	\$.01

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Further cost analysis was completed after the Whole Tree Harvester™ production tests at the Graceville site. The harvester was designed to lower costs in both smaller tree, tighter spaced energy farms and larger tree fiber farms like those planted in the Southeast United States. Both of those cost scenarios are considered in Table 2 and illustrate the benefits of using the Whole Tree Harvester™. Further production statistics are included in Appendix A.

Table 2. Whole Tree Harvester™ Cost Analysis Relative to Tree Size

Tree Size (dbh)	**3.5 (inches)**	**5 (inches)**	**8 (inches)**			**12 (inches)**		
Harvest Speed (fps)	8	6	4	6	8	4	6	8
Tree Spacing (ft)	5	5	10	10	10	10	10	10
Cut Rate (trees/sec)	1.6	1.2	0.4	0.6	0.8	0.4	0.6	0.8
Dry wt/tree (lbs)	38	100	250	250	250	750	750	750
lbs/s	60.8	120	100	150	200	300	450	600
Oven Dry Tons Per Hour	109	216	180	270	360	540	810	1080
Oven Dry Tons Per Year	72,843	143,770	119,808	179,712	239,616	359,424	539,136	718,848
Loading Downtime (%)	84%	84%	84%	84%	84%	84%	84%	84%
Power (%)	27%	28%	15%	23%	31%	20%	30%	41%
Fuel Cost @ $3.50/gal	$67,449	$70,610	$38,217	$57,326	$76,435	$50,416	$75,624	$100,832
Operator	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000
Maintenance Lbr & Parts	39,267	40,450	35,033	42,950	50,867	51,700	67,950	84,200
Capital Cost	$370,000	$370,000	$370,000	$370,000	$370,000	$370,000	$370,000	$370,000
Price $/odt	$8.00	$7.50	$7.00	$6.50	$6.00	$5.50	$5.00	$4.50
Annual Rev ($/yr)	$582,746	$1.08 mil	$838,656	$1.17 mil	$1.44 mil	$1.98 mil	$2.70 mil	$3.23 mil
Harvesting Cost ($/Yr)	$551,716	$556,060	$518,251	$545,276	$572,301	$547,116	$588,574	$630,032
Harvesting Cost per ton	$7.6	$3.9	$4.3	$3.0	$2.4	$1.5	$1.1	$0.9
Net Before Taxes (NBT)	$31,030	$522,212	$320,405	$622,852	$865,395	$1.43 mil	$2.11 mil	$2.60 mil

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Additional cost analyses were performed using a cash-flow Net Present Value model created by Bill Berguson of UM/NRRI with EPS actual and estimated cost inputs and modified to more closely represent EPS project costs (Tables 3 & 4). Table 3 shows only the variable input costs for the production of the wood. This is provided to show the differences in inputs between the high density plantings used in the EPS experiment and the inputs most commonly used in current commercial plantings in Minnesota, as represented by the 12 year plantings at 10 x 10 feet.

Table 3. Cash Flow Analysis of Hybrid Poplar Production Inputs[1]

Cost Type	One Harvest, 6-year, EPS Costs 5 x 5 ft	Two Harvests, No replant, 12 year EPS costs 5 x 5 ft	One Harvest, 12-year, NRRI Costs 10 x 10 ft
Burn-down Herbicide	NA	NA	$13.5
Primary Tillage (Chisel Plowing)	$10.00	$10.00	$14.1
Secondary Tillage Disking	$9.00 (1x)	$9.00 (1x)	$34.2 (3x/11.4 each)
Marking	NA	NA	$15
Cuttings	$174.20 (1740/ac @ $0.10)	$174.20 (1740/ac @ $0.10)	$45 (450/ac @ $0.10)
Planting	$52.26 (1740/ac @ $0.03)	$52.26 (1740/ac @ $0.03)	$22.5 (450/ac @ $0.05)
Pre-emergent Herbicide	$40.02	$40.02	$86 $43 each – 3 yrs
Post-Plant Weed Control (cultivation and/or mowing)	$28.07	$28.07	$46.5 $9.3 each - 5 times
Post-emergence Herbicide	NA	NA	$129 $43 each – 3 yrs
Shield or spot spray herbicides	NA	NA	Not given
Fertilizer	$82 $41 each - 2 applications	$246 $41 each – 6 applications	$114.6 $38.2 each – 3 applications
Maintenance (Insect Control)	$15.00	$15.00	NA
Total discounted cash flow per harvest at $0.04 discount rate	$486.72	$351.6	$750.24

[1]Cash flow model provided by Bill Berguson of UM – NRRI and developed in collaboration with fiber industry.

Table 4 uses the input costs with land rent and harvest costs to calculate a breakeven cost for the wood at the farmgate, then adds haul costs for an average 37 mile haul to estimate delivered price to an energy facility.

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Table 4. Cash Flow Analysis of Delivered Costs at Utility Gate[2]

Cost Type	One Harvest, 6-year, EPS Costs	Two Coppice Harvest, 12-year- EPS Costs	One Harvest, 12 year NRRI assumptions	One Harvest, 12 year NRRI assumptions w EPS harvester
Land Rent	$660.00	$1,320.00	$1,320.00[2]	$1,320.00[3]
Discount rate (4% per year for inflation)	$0.04	$0.04	$0.04	$0.04
Harvest Yield per rotation (dry tons/acre)	24	24 + 28.8	48	48
MAI (dry tons/ac/yr)	4.0	4.4	4.0	4.0
Total discounted cash flow of wood production per harvest	$486.72	351.6	$750.24	$750.24
Farmgate Discounted Breakeven Price per ton (with rent)	$50.68	$40.95	$53.73	$53.73
Harvesting Cost per ton[4]	$8	$8	$25	$3
Farmgate Price per ton	$58.68	$ 48.95	$78.73	$58.23
Haul cost for 37 mile average haul[5]	$7.40	$7.40	$10.36	$10.36
Delivered Price $ per dry ton	$66.08	$56.35	$89.09	$65.63
Delivered Price ($ per MBtu)[6]	$3.79	$3.24	$5.12	$3.77

[2] Cash flow model provided by Bill Berguson of UM – NRRI and developed in collaboration with fiber industry.
[3] Land rent assumption were not provided by NRRI, but EPS land rent costs were assumed for comparison purposes
[4] Harvester costs are significantly lower for larger trees and for whole tree rather than chip production and loading
[5] EPS haul assumptions are $2.50 per loaded mile, 25 wet tons per haul and 37 mile average haul of whole trees. NRRI haul assumptions are $3.50 per loaded mile, 25 wet tons and 37 mile average haul of wood chips.
[6] Assumption of 17.4 million Btu (MBtu) per ton of wood.

At an assumed yield at harvest of 24 dry tons, land rent of $110 per acre and discount rate of $0.04, the breakeven price per ton was $50.68 using a single harvest scenario and $40.95 using a two-harvest, 12 year coppice scenario where trees automatically sprout from the stumps following harvest. Addition of the harvest cost to the breakeven stumpage price resulted in energy prices of $3.79 and $3.24 per MBtu, respectively (assuming 17.4 MBtu per ton of dry wood). Addition of the estimated haul cost increases the delivered price on the first rotation to $3.79 per MBtu. Of course, it is unlikely that the tree crop would be replanted after the first rotation, so we have added the scenario that includes two harvests with only one planting. In research results from many places in the US, the second (coppice) rotation increases in yield by about 20%. If we add the two rotations together, the average harvested yield is 26.4 dry tons and with only a small addition in input costs, the farmgate price is $40.95 per dry ton and the delivered price is $56.35 or $3.24 per MBtu.

Comparison of model results with values published in 2010 by Berguson for a 12 year rotation with the same annual yield, but using wider spacing and standard planting and harvesting technology resulted in a delivered energy price of $5.12 per MBtu. Of course, if the EPS harvesting technology were to be applied to the 12 year, wider-spacing scenario, the energy price would be reduced to $3.77 per MBtu.

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If we assume the same input costs but a higher yield result of 5 odt/ac/year in the first 6 year harvest then the energy price for a single 6-yr rotation using EPS technology reduces to $2.90 per MBtu at the farmgate, and all other scenarios show similar reductions in price. These results emphasize both the importance of yield, harvest and land costs.

Land cost is the main driver of the break-even price/ton. This is mainly due to the opportunity cost (loss of potential revenue from other crops) to the farmer. Appendix B and associated figures show that land costs went up dramatically just prior to beginning this project and that producing corn for ethanol was a major factor. Currently, corn for ethanol is using approximately 30% of the total land available for corn production. That said, the current Ethanol energy price of $39.42 per MBtu is more than ten-fold the price of using whole trees for energy.

Final Yield Discussion

All regular plots and several additional plots were measured on the 40 acre hybrid poplar production test field near Graceville, MN, which was also used for testing the planter and the harvester. This milestone report summarizes the survival and growth of the trees from the beginning of the project up to the time of harvest on all production testing sites. Results from 2012 measurements on the Dumont clonal trial follow those from the production site (Graceville west field).

First Year Survival and Height Growth of Hybrid Poplar Clone NM6 in Four Production Trials

This analysis is included in order to provide some perspective on the quality of the soils at the East and West Graceville sites relative to the Glencoe and Dumont sites. Charts of percent survival in fall of first growing year, average first year height attained, and best plot average height are shown below. First year data from the Glencoe, MN site is included along with data from the East 40 Field near Graceville, MN and the 10 acre hybrid poplar production test near Dumont, MN. Only the hand planted rows from the Graceville West Field are considered in the fall survival percentage shown in Figure 2 since that is more comparable to the data collected from other sites. Fall survival in the machine planted area could not be assessed in the same manner since the data collected included skipped rows as well as planted rows. However, inspection of adjacent machine and hand planted rows (1900 feet long) in July 2007 (~ 2 months after planting) indicated that sprouting of machine planted cuttings was about 96% (where it was obvious that a cutting had been planted) and sprouting of hand planted cuttings was 99%. All mortality in the machine planted area was associated with cuttings with a small diameter that had not penetrated the soil very deeply and which were broken. This did not happen with cuttings that were 5/16 inches in diameter or larger. Lack of sprouting of hand planted cuttings was more likely to be a result of micro-site soil differences or failure to completely “close” the planting hole. The additional mortality by fall, of cuttings at both of the 40 acre Graceville sites, is most likely due to several pockets of highly alkaline soils at those sites.

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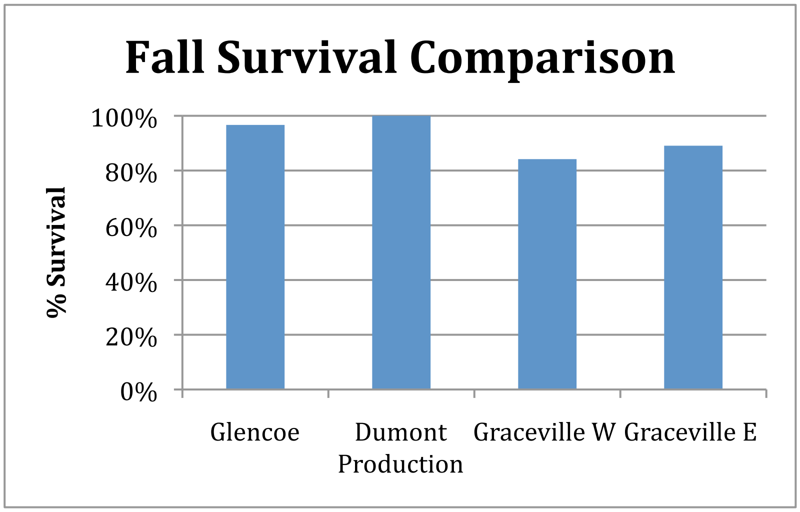

Figure 2.
Percent of planted trees surviving in fields at the end of the first growing season.

The average height comparisons are based on measurement of 30 plots across 69 acres in Glencoe, 15 plots across 10 acres at the Dumont Production site, 41 plots across 40 acres each at the Graceville East and West sites.

Overall average first year heights and best plot heights show a similar pattern among the 4 sites established. While trends are apparent, the great variability in heights on all sites renders the results not statistically different. Even though the data is insufficient for statistical comparisons, the differences in average and maximum heights may be attributable to soil characteristics or nutrient differences.

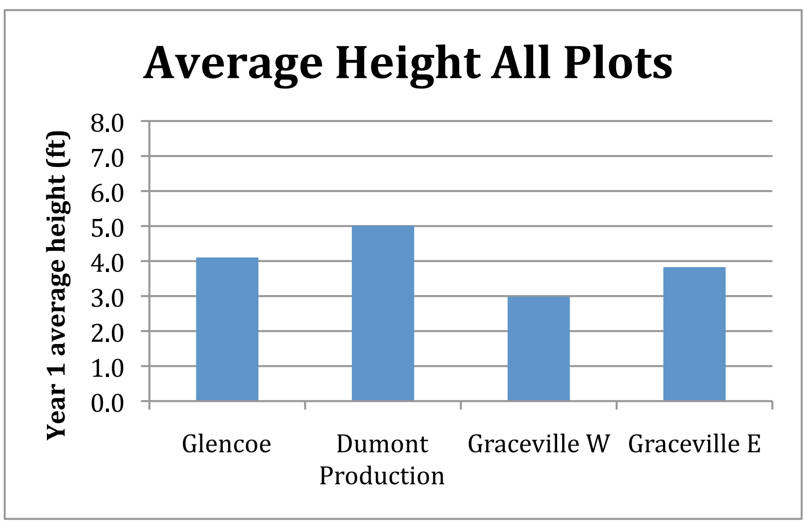

Figure 3.
Average height of trees in all measured plots at the end of the first growing season.

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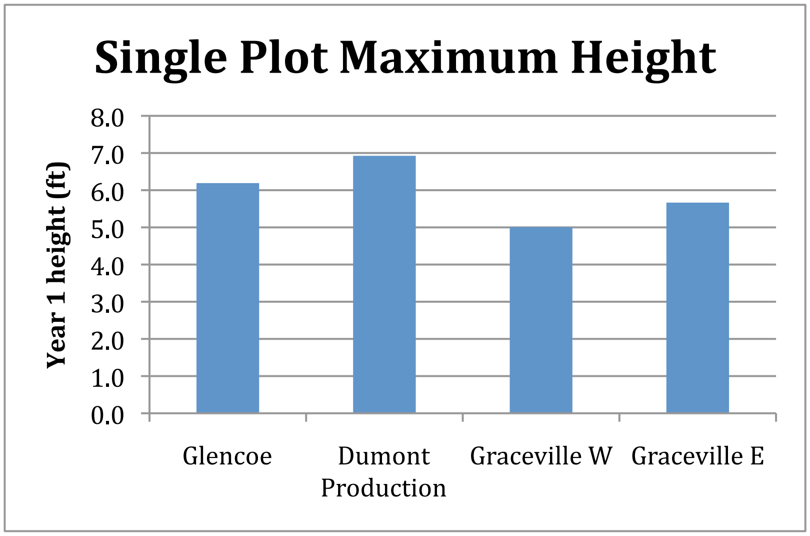

Figure 4.
Average height of trees in the single plot with the best heights at the end of the first growing season.

The aforementioned comparisons of first year survival and height growth suggest that the site chosen for testing of the harvester, is inherently a little less productive on a whole field basis than other cropland sites with potential for producing hybrid poplars in Minnesota. Following this first year assessment of the Graceville sites, the project team made the decision to not continue growth measurements across the whole field since the time required for measurement and analysis was much greater than the anticipated value of the data. Thus the growth measurements for years 2-5 represent only the better areas of the field, areas felt to be more representative of the type of land where production of hybrid poplars in Minnesota is most likely to be economically viable.

Hybrid Poplar Yields

At the time of the first trial of the EPS Whole Tree Harvester™ in August 2012, an additional measurement of growth (not required by the Xcel contract) was undertaken in order to gain an understanding of whether the stand was actually near its optimum growth stage for harvest. The project greatly appreciates the time put into this effort provided by Dan Buchman, whose time, travel and hotel expenses were covered by of the University of Minnesota’s Natural Resources Research Institute. The information obtained was very useful for understanding the growth dynamics of stands planted at 5 x 5 ft spacing.

Several different commonly used measures of growth are summarized graphically below. Stem diameter is the actual measure used for calculating the weight of individual trees based on equations that describe the diameter to weight relationship. Basal area and total stand biomass are calculated based on assumptions about the relationship of tree diameter at 4.5 ft height (dbh) to dry weight (see Appendix C). The average stem diameter is about 1 inch lower than the average dbh used to determine harvest costs since some of the trees had 2 or more stems per tree. The weights of each stem are added together to result in total tree weight.

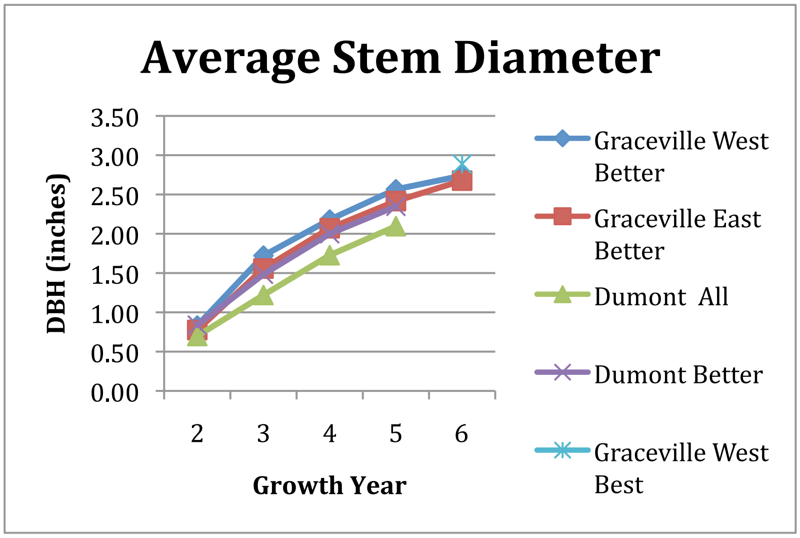

Figure 5.
Average stem diameter on five plots selected for better growth at the Graceville sites and the Dumont production site. The average at all plots at the Dumont Production site is also shown to indicate that yields are reduced by only ~ ½ odt/ac/year when all plots are considered.

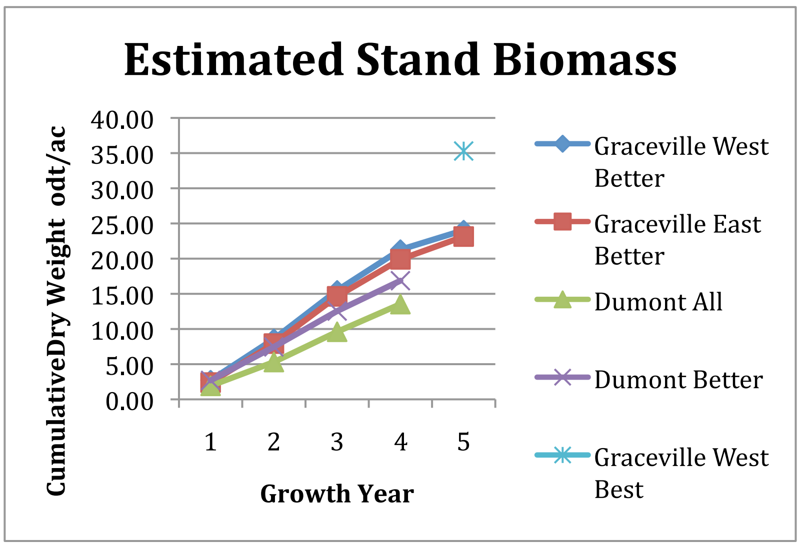

Figure 6.
Estimated stand biomass in the better areas of the Graceville harvest site was close to 25 dry tons/acre, very best single plot had estimated yeilds of 35 dry tons/acre.

Additional plots were measured on the Graceville sites to better sample the variability on the site. The bar chart below shows the variation in average stem dbh (diameter at breast height or 4.5 feet above the ground) among several areas of the field. (1.7 to 2.9 inches). The worst growth areas of the field were not measured. However the smallest trees in the harvest rows had stem dbh values in the range of 1 to 1.5 inches, not that much smaller than the average stem dbh. It should be noted, that stem dbh is a single stem, if a single tree had 2 stems, then they were counted as 2 stems.

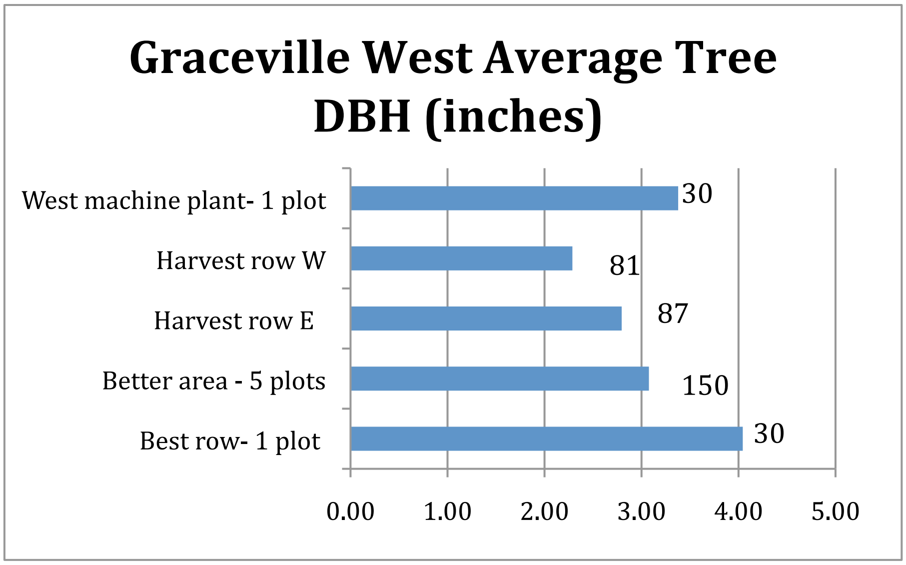

Figure 7. Average stem dbh from 5 locations on the Graceville west field (Numbers in parentheses indicate the number of trees measured in that area. Minimum number of trees measured was 30).

Photo 1 shows the variation in tree size in the harvested rows where average standing biomass was estimated to be ~13 to 16 dry tons. Alternatively, Photo 2 shows the somewhat larger tree sizes and generally greater uniformity in areas of the field represented by the "better plots" with estimated standing biomass of 20 to 25 dry tons. The "best plot " was a plot of very uniform trees measured a month later than the other plots, possibly accounting for the larger estimated biomass. The estimated yield based on that best row, measured only in year 6, is shown by the asterisk in Figure 6.

Photo 1. Example of Tree Size Variation

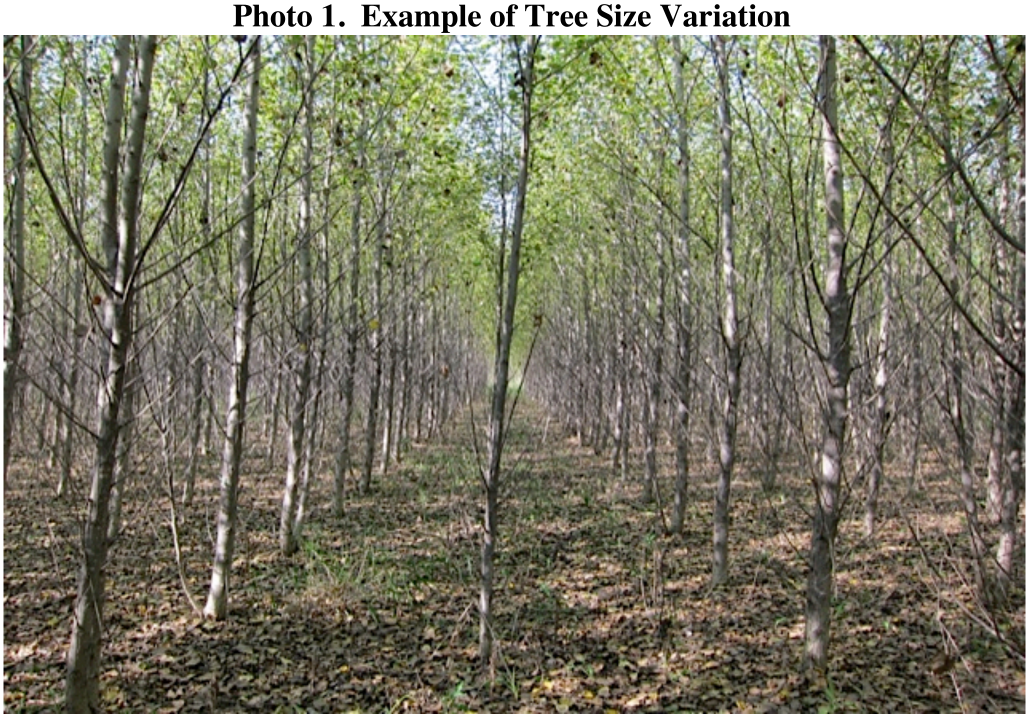

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Photo 2. More Uniform Tree Size

Photo 3. Example of Multiple Stems

Estimated Average Yield over Entire Graceville East and West Fields

The estimation of average yield over the entire Graceville East and West fields must take into consideration several factors that we believe would not necessarily be true of commercial fields planted by experienced woody crops managers. For example, because these fields were planted within the constraints of the time and money available from the Xcel Energy RDF grant projects, we did not have much time to search for the site quality that we would have preferred. A discussion of the socioeconomic climate constraining our choices is explained in Appendix B. The areas of the Graceville fields with few, if any trees (especially the East Field, shown in Figure 8) is a result both of natural mortality related to unsuitable soil conditions and removal of the trees by the landowners.

The estimate of average standing biomass across the entire Graceville East and West fields was obtained by using a combination of the information derived from measurements of standing biomass yields in reasonably well stocked portions of the Graceville site and aerial photographs (shown in Figure 8 and Figure 9 and infrared photographs not shown) which show the areas of the fields with little or no trees standing. A grid was overlain over one set of the aerial photographs and our judgment was used to determine the portion of the grid covered with trees integrated with our assessment of the quality of the growth of the standing trees. The higher growth estimates of 20 to 25 odt/acre, tended to offset the lower estimates of 0 to 5 odt/acre to result in field averages of 12.1 oven dry tons for the West Field and 12.2 oven dry tons for the East Field. Our analysis of the economics of producing and harvesting hybrid poplar for this project will consider those numbers along with higher field averages. It is our belief that much better field yields can and will be obtained under commercial conditions when newer and better clones and good quality sites are used for hybrid poplar production.

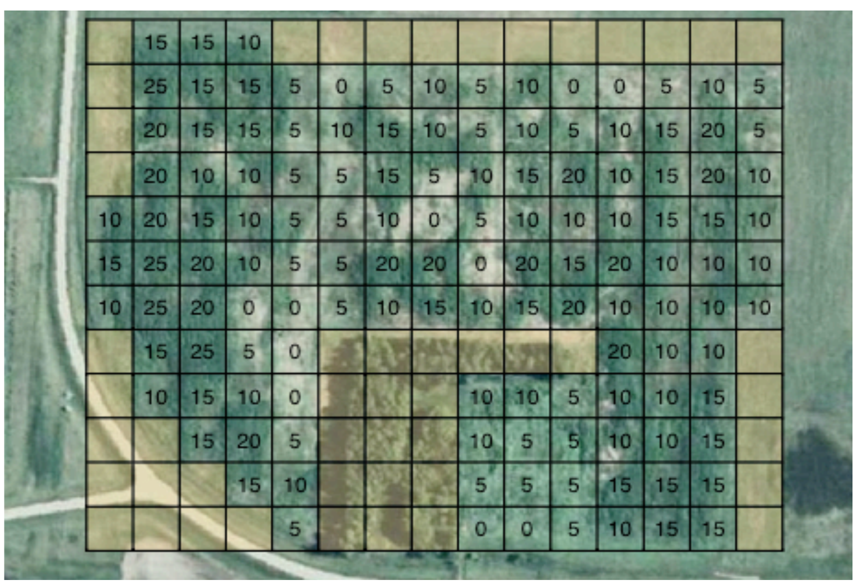

Figure 8. East Field Aerial Photo

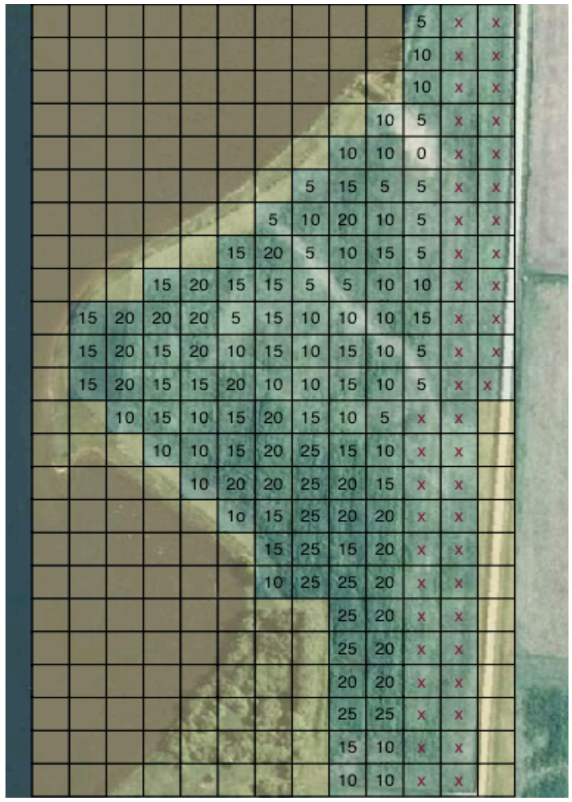

Figure 9. West Field Aerial Photo

Readiness of Project Tree Stands for Harvest

One of the goals of the EPS project was to attempt to get the stand to its optimum harvest age within the maximum time frame of the Xcel Energy RDF Grant projects (5 years). This was also a reasonable goal for production of trees primarily intended for energy production and also because most landowners would prefer to earn profit sooner rather than later from land suitable for growing crops. Normally the optimal harvest age would be at age when a maximum growth rate is expected (based on prior experience). According to the mean annual increment graph, the appropriate harvest age appears to be between years 5 and 6 (Figure 10).

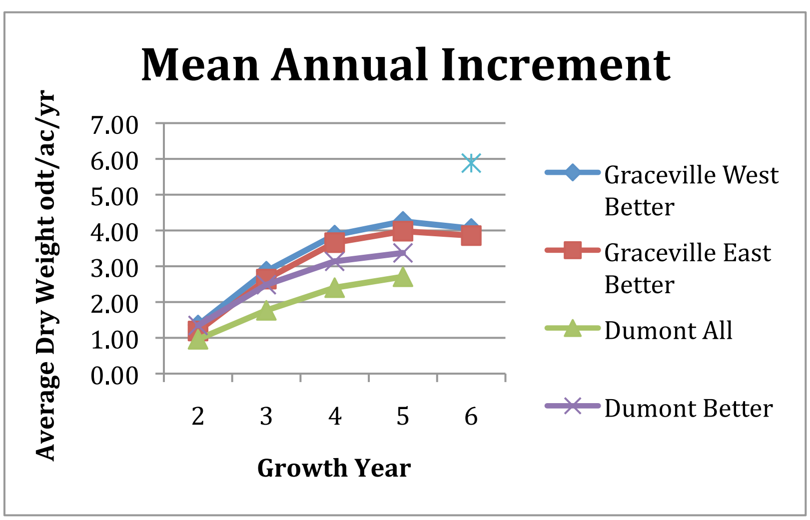

Figure 10. Mean annual increment progression of stands in oven dry tons (ODT)/acre.

Based on experience by researchers at the University of Minnesota with NM6 growth in others parts of Minnesota (Figure 11), and growth of other clones and woody crop species in many parts of the US recently assembled by Lynn Wright, some problem with the growth of the stands is likely occurring. The measurements in 2012 were taken at the end of August (when the harvest actually occurred). That was about 6 weeks before the end of the growth season so they may have not captured the full growth increment between years 5 and 6. The observation of a thin crown and many fallen leaves with black spots on the ground by the end of August was most likely indicating that the trees were stressed due to fungal attack (Photo 2). Other observations as far away as Grand Forks, ND suggested that the same things were happening to native cottonwoods that were never seen before.

Photo 4. 2012 Growth Spurt

Thus the most likely causes for the down turn in growth is the very wet and cold spring of 2011 and the resulting leaf fungal attack (believed to be Marssonina coupled with other fungi), followed by very dry conditions in August, September and October of 2011, and again followed by lower than normal rainfall and higher than normal temperatures throughout the growing season in 2012. The annual climate conditions affecting the trees are summarized in Appendix D. The trees could potentially recover from these 2 years of very stressful conditions and put on more growth in 2013.

One positive aspect of the dryer and warmer conditions in 2012, is that areas of the field that had suffered poorer growth during most of the years due to poorer soil conditions appeared to have a growth spurt in 2012 putting on 5 to 8 feet of additional height growth in some cases. Thus while the "better" plots that we have continuous measurements on over the years showed a decline in growth, we suspect that other parts of the field did some catching up in growth. We have a few pictures that show the increased height growth of some trees in 2012 (Photo 4) and one plot showing relatively good growth in an area of the field that had been observed to have poor growth in previous years.

Dumont, MN Clone Trial Final Results and Discussion

A trial including 10 clones in three N-S replicates (9 plots each) was established in 2008 in Dumont, MN on a five acre plot of land situated between a corn field to the west and a natural area to the east. The site was a perfect place to test the response of clones to soil drainage differences (well to poorly-drained soils). The poorly drained soils were typical of large areas in the larger 40 acre fields planted in 2007 in nearby Graceville, MN where NM6 and a few pure deltoides (cottonwood) showed very poor growth performance. The poorly drained soils exhibited high salt levels normally also associated with pH levels higher than normally preferred by most hybrid poplar clones. Such areas often resulted in iron chlorosis in the NM6 clone.

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The purpose of the trial was to determine which clones would show better tolerance to the range of soil types available in western Minnesota than the more widely planted NM6. Because some of the newer clones were not capable of rooting from cuttings and it was presumed that protection of the site from competing vegetation and deer browse would be difficult, all clones were planted as 1 year old rooted cuttings (steckings) rather than as unrooted cuttings. A gas powered auger was used to penetrate the soil hard pan for each planting. This is not a commercial process, at a cost of $2 per plant, but does remove some variables associated with rooting and soil types. As expected, high growth of herbaceous weeds (but generally not grass) and deer browse did occur. In order to make the yield estimates more comparable to sites planted with unrooted cuttings, 1 year was added to the tree age (from planting). Only the center 9 trees in the 25 tree plots were measured for height and yield calculations thus yields must be interpreted primarily as relative yields. Regardless of planting method, the response of the clones to their environment, is of great interest and may help lead to other clones with higher yields under more diverse conditions, which will lower costs associated with crop trees.

Table 5. Clones Demonstrating Best Growth by Age 6 in Dumont, MN Clonal Trial

Description	Clone Name (# replicates)	2012 Average (odt/ac/yr)	2012 SD (odt/ac/yr)	2009 Average Height (ft)
Best single plot	DN2 (1)	6.37	1.84	11.0
Best 2 plots	DN2 (2)	5.88	2.27	11.5
	NE222 (2)	4.86	2.51	10.3
Best yield average over all replicates	DN2 (6)	4.60	2.77	9
Most similar yield across all soils	DN34 (3)	4.06	1.71	9.8
NM6 yield [7]	NM6 (3)	3.09	1.29	9.9
D105 yield [7]	D105 (5)	3.32	1.79	9.2

[7]While the native cottonwood (Populus deltoides) clone 105 performed similar to NM6, neither clones were challenged by the worst soil conditions of the 5 acre site.

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Table 6. Effect of Field Position on Age 6 Yield Results in Dumont, MN[8]

N-S plot	Field position	2012 Yield Rep 3	2012 Yield Rep 2	2012 Yield Rep 1	Field position	Soil Drainage Type
1	W-N	4.93	5.26	2.16	E-N	Good
2	W-N	2.92	4.22	3.00	E-N	Good
3	W-N		3.90		E-N	Good
4	W-M	3.77	3.31	6.37	E-M	Medium
5	W-M	2.08	5.38	4.22	E-M	Medium
6	W-M	1.88	4.08	4.68	E-M	Poor to Med
7	W-S		3.54	4.09	E-S	Poor to Med
8	W-S	2.11		5.05	E-S	Poor to Med
9	W-S	3.72	3.05	4.45	E-S	Poor to Med

[8]The average plot yields include the zero values for the missing trees, however it should be noted that live trees next to a missing tree(s) were often much larger, thus potentially compensating for the missing tree(s). The colors relate to the following clones: yellow = DN2, green = NE222, orange = DN34, blue=NM6, and purple=D105 (a pure cottonwood, Populus deltoides). Plots with no results suffered more than 50% mortality of the measurement trees. Other plots (uncolored) with yield numbers are clones that had insufficient replication to evaluate. The southern end of the replicate 3 likely has the poorest soil conditions on the 5 acre site.

Deer browse, which varied considerably across the sites, presented complications that make statistical analysis difficult. Two relatively heavily browsed replicates (in the upper right hand corner of the site did have 22% to 66% mortality and one replicate in the middle south portion suffered 100% mortality. However the most heavily browsed plot (a DN2 clone) in the upper left corner has low mortality (11%) and produced one of the higher yields on the site.

While a number of extraneous factors (deer browse, flooding, vegetative competition, and drought) affected growth, at least one conclusion is clear. Clone DN2 performed reasonably, to very well under a range of soil drainage, deer browse, and vegetative competition conditions with 6 plots distributed over all soil drainage conditions. DN2 plots represented 2 of the 3 plots with yields higher than 5 odt/ac/yr and 4 of the 11 plots with yields higher than 4 odt/ac/yr.

Photos 5 and 6 show one of the larger DN2 trees at a dbh of 4.6 inches in the measurement plots, while Photo 7 shows the approximately 10 inch base of an even larger DN2 tree not in a measurement plot. However, DN2 did not perform well (2.11 odt/ac/yr) in an area of the trial known to have flooded in the first year of planting. The two plots of NE222 suggested the possibility for good yield performance but were not sufficiently well represented in the clone trial. Clone DN34 is the only clone that showed relatively similar growth in the good, medium and poorly drained areas. The growth clones DN34, NE222, and DN2 all exceeded the yield of NM6 on comparable soil types, while that of the pure cottonwood clone, D105 was very similar in growth. All other clones either had very poor survival or were represented too few times in the trial to merit discussion.

Photo 5. DN2 Clone Measurement

Photo 6. Close Up of Larger DN2 Measurement

Photo 7. Large DN2

Personal communication with Bill Berguson of the University of Minnesota/Natural Resources Research Institute indicated that they have observed excellent growth of DN2 in some locations, but it has not shown good adaptability over a range of site types. They report that a closely related clone, DN5, has shown better results across a wider range of site types. Clearly more work is needed to find clones adaptable to very poorly drained soils.

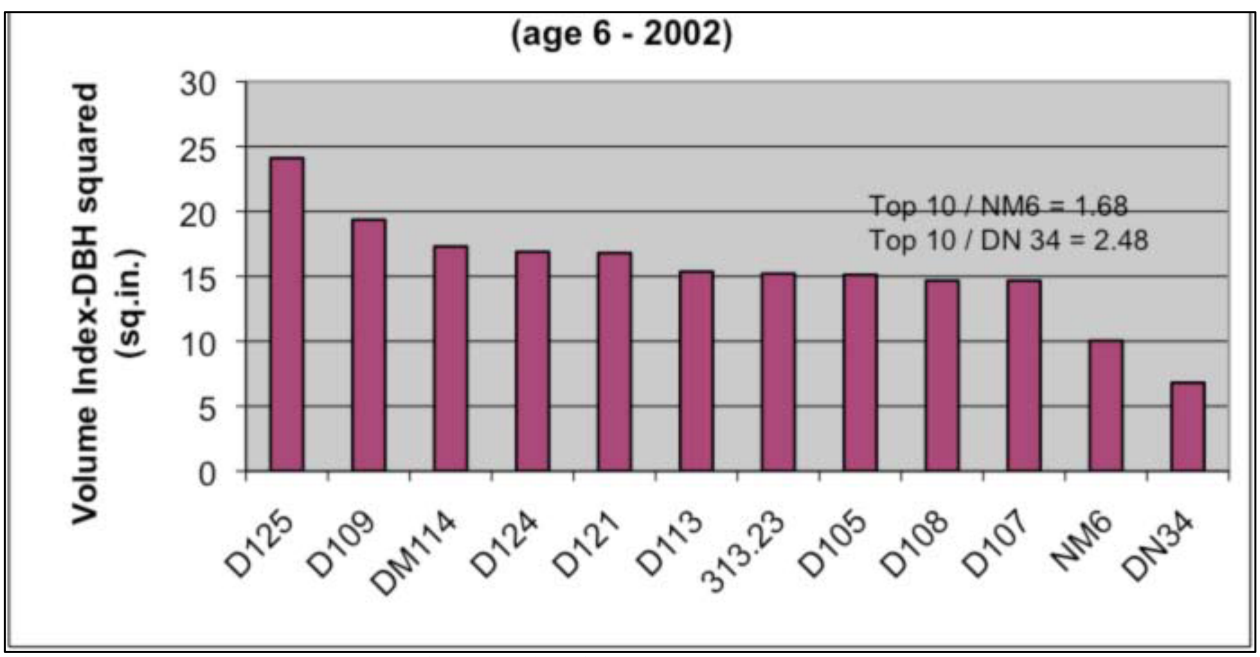

Figure 11. Growth of the ten highest-yielding poplar clones compared to the commercial clones NM6 and DN34 after six Years in northwestern MN. Source: Berguson et al 2010

Additional Milestones:

Work on Milestone 27, the final report, is currently in progress.

Project Status:

Report preparation is all that remains for the last milestone. All testing, data gathering and most analyses for this project are complete.

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Appendix A

Table 7. Estimated Harvesting Statistics

Tree Size (dbh)	3.5 (inches)	5 (inches)	8 (inches)			12 (inches)			24 (inches)
Harvest Speed (fps)	8	8	4	6	8	4	6	8	6
Green Tree Weight (lbs)	75	127	450	450	450	1,263	1,263	1,263	5,726
Spacing (ft)	5	5	10	10	10	10	10	10	20
Cut Rate (trees/sec)	1.6	1.6	0.4	0.6	0.80	0.40	0.60	0.80	0.30
Green tons per hour	215	367	324	486	648	909	1,364	1,819	3,092
ODT per hour	108	183	162	243	324	455	682	909	1,546
Trees per hour	5,760	5,760	1,440	2,160	2,880	1,440	2,160	2,880	1,080
Height (ft)	29	44	51	51	75	86	86	86	97
Peak Cutting Force (lbs)	428	873	2,234	2,234	2,234	5,026	5,026	5,026	20,102
Travel & Cut Avg Force (lbs)	9,467	9,499	9,550	9,550	9,550	9,787	9,787	9,787	10,797
Travel, Cut & Lift (lbs)	10,095	10,568	11,440	11,440	11,440	15,091	15,091	15,091	22,821
Net HP Used	147	154	83	125	166	110	165	220	249
Work MBTUs	373,748	391,264	211,769	317,653	423,538	279,365	419,048	558,730	633,694
Gross HP	244.7	256.2	138.7	208.0	277.3	182.9	274.4	365.9	414.9
Fuel Use (GPH)	18.0	18.8	10.2	15.3	20.4	13.4	20.2	26.9	30.5

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Appendix B

Socio/economic Climate at the Time Sites Were Rented for the EPS project

Due to the passage of the Renewable Fuels Standard in the Energy Policy Act of 2002, rapid changes were occurring in both agricultural and energy markets that made implementation of the project plan more difficult than anticipated. In 2004 the corn-based ethanol market was in its 3rd year of rapid expansion and most of the biorefineries were being located in the mid-western cornbelt including southern Minnesota (Figure 12 and Figure 13). Thus farmland prices were rising very rapidly by 2005 (Figure 14), when our project was funded and our search for suitable farmland began. This created a large hurdle for renting farmland especially at the rental rates used for the proposed research cost estimates (based on 2003 or earlier rates). In order to meet contract obligations, the project was ultimately forced to establish the hybrid poplar production trials on farm land of lower quality than had been assumed when establishing the yield goals and measures of progress for the project.

The Graceville fields were the only fields that we could locate within the time constraints of meeting the contractual obligations of the Xcel Energy RDF contract in 2007. While the landowner was very interested in and supportive of the project and donated many hours to the planting effort, the basic fact is that the only land he could reasonably take out of grain production for rent was likely the worst quality land within his large farmstead. The rental rates of $110 per acre were very reasonable given the rates on higher quality land, nevertheless that rate was at the upper end of the rental rates EPS had anticipated paying when the proposal was prepared in 2004.

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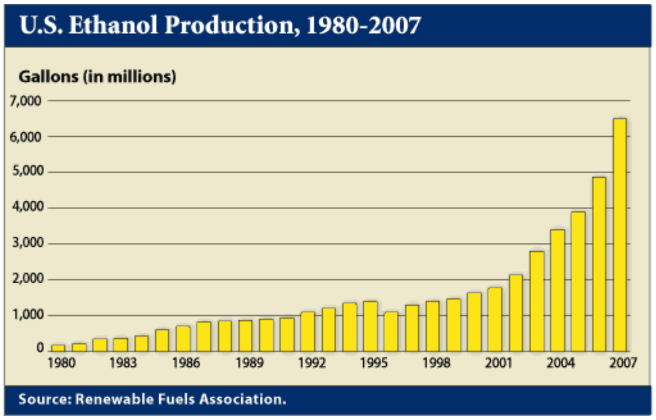


Figure 12.
U.S. Ethanol Production

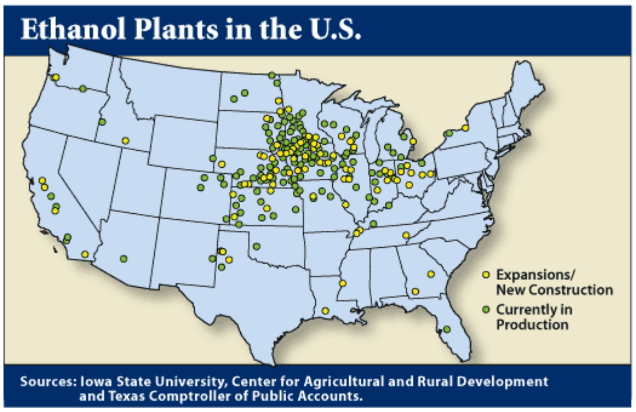


Figure 13.
Location of Ethanol Plants in the U.S**.**

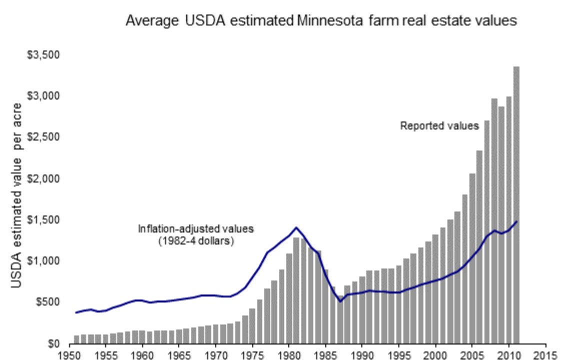


Figure 14.
Farm Real Estate Values
Source: Steven J. Taff, Department of Applied Economics, University of Minnesota from Minnesota Real Estate Sales, 2011.

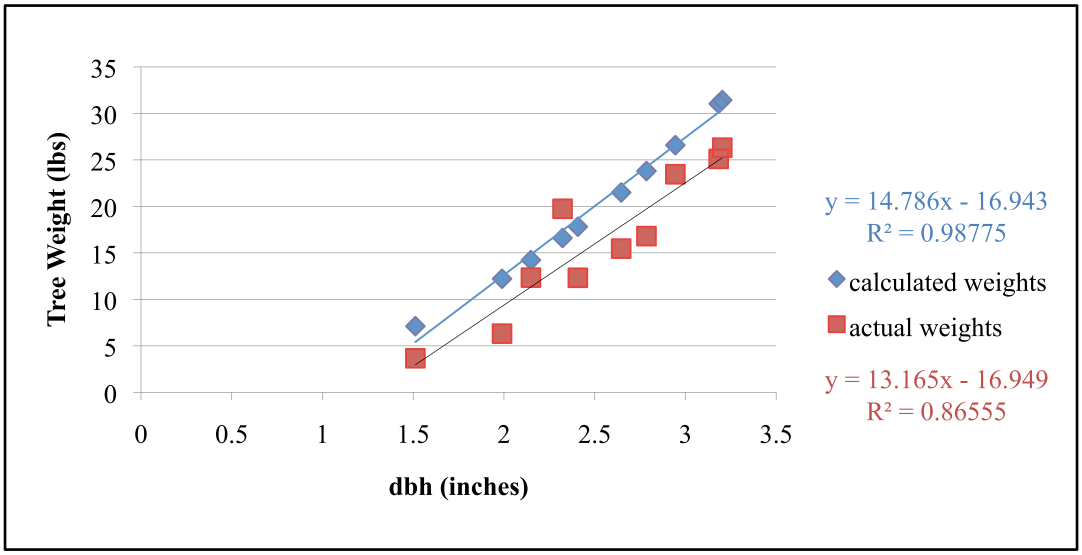
Appendix C

The dbh to dry weight relationship has been verified for the NM6 trees growing at Graceville based on actual field weighing of a sample of trees followed by drying wood samples to obtain the dry weight to wet weight relationship. A plot showing the verification measurements to the values estimated by using an equation provided by the University of Minnesota team at the Natural Resources Research Institute is shown below. The equation is as follows:

Dry Weight = $0.14+(3.05*dbh^2)$

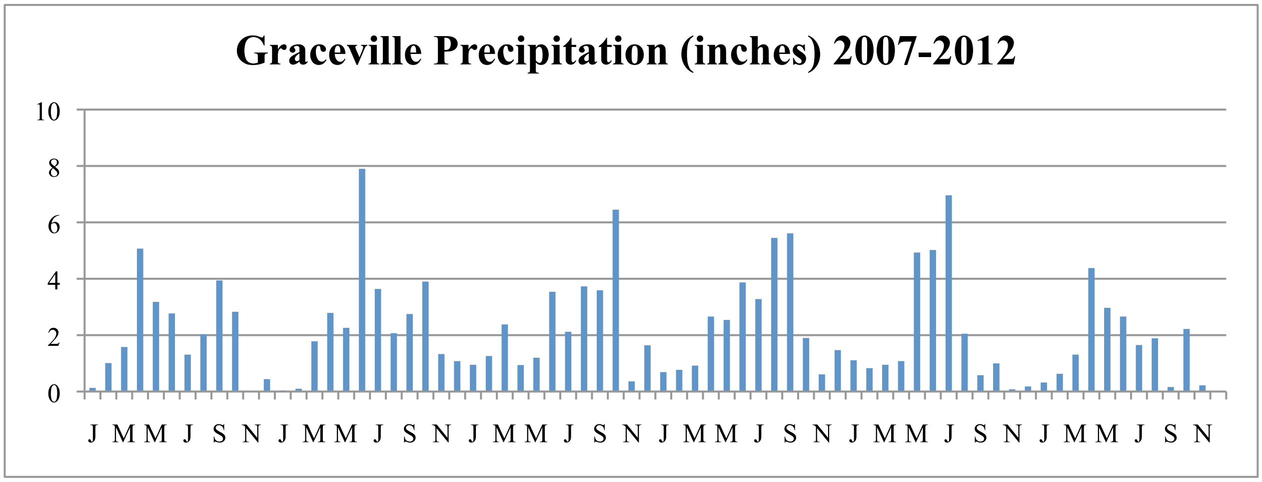
Dry weight is assumed to be 50% of wet weight.

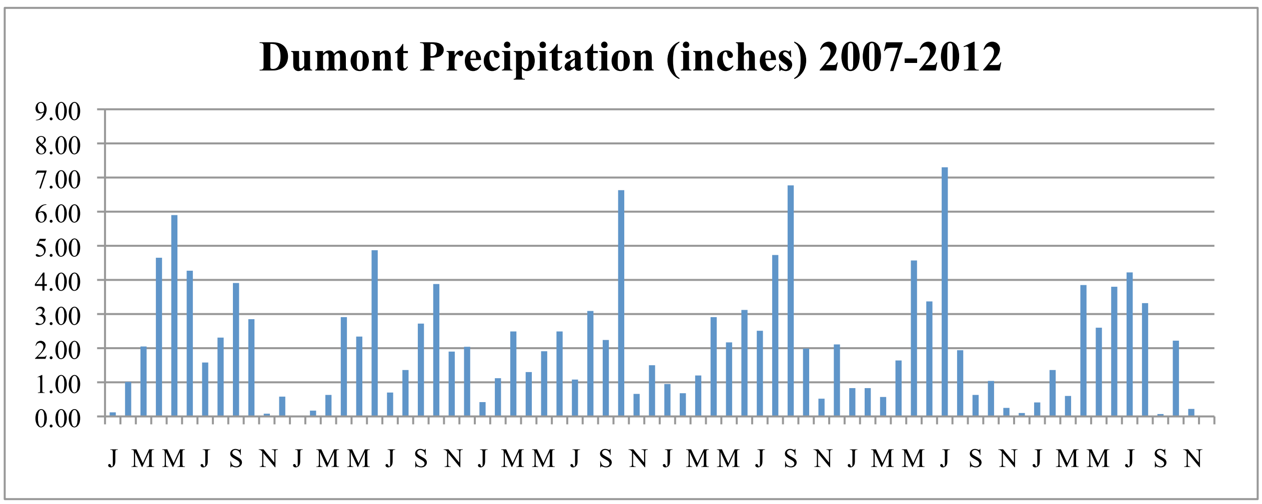
Figure 15. Plot of Calculated vs Actual Tree Weights

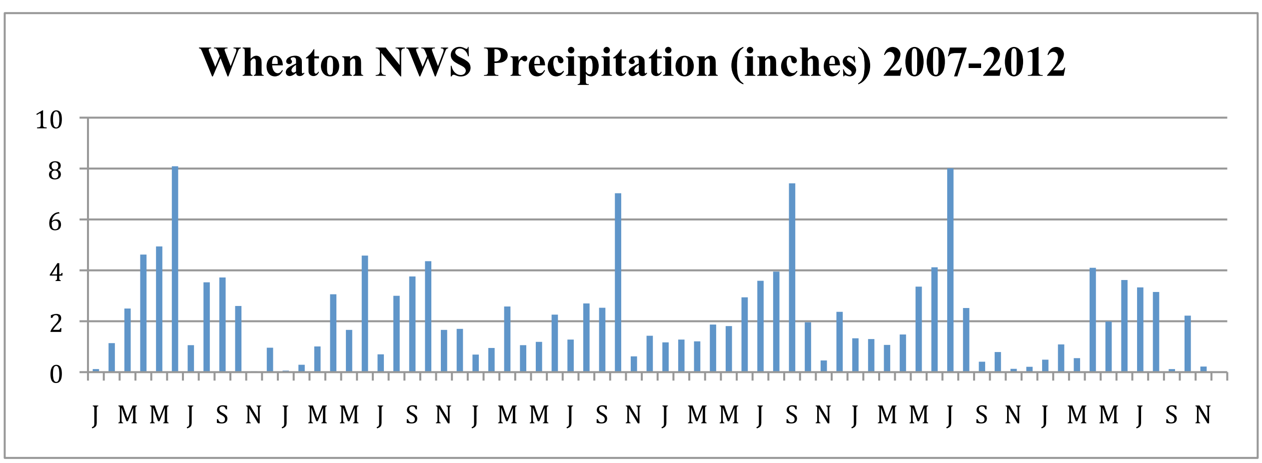


Appendix D

Historical Climate Data from the University of Minnesota Website
(http://climate.umn.edu/doc/historical.htm)







The growing Degree data was also obtained from the University of Minnesota climate data site using a custom table to look up monthly data for Wheaton, MN.