United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

Research Note NC-353

1990

Early Yields of Biomass Plantations in the North-Central U.S.

Edward Hansen

Research partially funded by the Department of Energy under Interagency Agreement #DE-AI05-890R21871

ABSTRACT.—A network of hybrid poplar short-rotation plantations was established across the north-central region of the U.S. during 1986-1988. This paper documents the greater than expected early yields from these plantations and discusses potential yields and uncertainties surrounding potential yield estimates.

KEY WORDS: Intensive culture, energy plantations, hybrid poplar, hybrid trials.

Interest is developing in the concept of growing high yields of woody biomass as an alternative and renewable energy source that can help ameliorate the increase in atmospheric carbon. The North Central Forest Experiment Station (U.S. Department of Agriculture, Forest Service) is cooperating with the U.S. Department of Energy and private industry in establishing and maintaining research and demonstration plantations throughout the north-central U.S. These plantations provide data for calculating biomass yields and cost of producing biomass for energy. They also demonstrate the feasibility of the concept to farmers and other private landowners who might be interested in growing high yields of woody biomass for energy. Early yields from this research and development program are encouraging, and the practice of growing short-rotation tree crops is beginning to be integrated into the Conservation Reserve Program.

Ed Hansen is a Silviculturist with the North Central Forest Experiment Station, Grand Rapids, MN.

METHODS

Hybrid poplar plantations were established at nine sites across four states: five in Minnesota, two in Wisconsin and one each in North and South Dakota (fig. 1). In general there are 10 to 20 acres in plantations per site (table 1). Five acres were planted at each of three sites in 1986, and 10 acres were planted at most sites in each of 1987 and 1988. Trees were planted at an 8- x 8-foot spacing for an anticipated rotation of about 10 years. Because information on suitable hybrids for the region is limited, the plantations at each site were subdivided into smaller monoclonal blocks to test several hybrids and to reduce risk of extensive failure due to planting only one hybrid at a site. Each monoclonal block

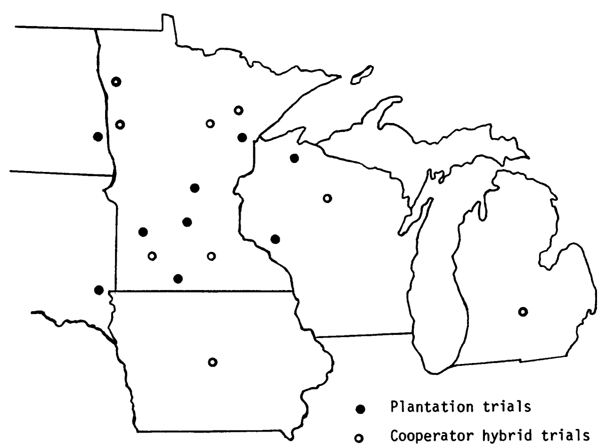

Figure 1.—*Regional plantation network.*

Table 1.—*Acreage and location of established plantations remaining in 1990*

Location	Code	Total acreage
Ashland, WI	ASH	20
Cloquet, MN	CLO	10
Fairmont, MN	FAI	15
Fargo, ND	FAR	20
Granite Falls, MN	GRF	15
Howard Lake, MN	HLK	5
Milaca, MN	MIL	15
Mondovi, WI	MON	20
Sioux Falls, SD	SXF	20

was 0.8 acre, large enough to obtain valid biomass yield data, conduct soil-tree growth investigations, and eventually conduct harvesting trials. Hybrid trials consisting of 40 to 100 hybrids in small contiguous blocks were also planted at each site. In addition, hybrid trials were established at nine other sites (including the States of Iowa and Michigan) by cooperators. These trials will help us identify new adaptable clones with high productivity and insect and disease resistance for each site. Economic data are being collected on cultural treatments applied to entire 10-acre plantations.

Tree heights were measured in 1- and 2-year-old plantations, and diameters at breast height (DBH) were measured in 3-year-old and older plantations. In the fall of 1989, selected trees were cut at the ground line to obtain biomass weight (total aboveground, oven-dried tree weight minus leaves). Forty-four trees were harvested. Five trees with diameters systematically spaced over the observed range were harvested for each of the four fastest-growing clones at Ashland, Wisconsin (a northern site) and at Granite Falls, Minnesota (a southern site). An additional four trees were harvested from a 4-year-old plantation at Fairmont, Minnesota.

Regressions were computed for each clone at the Ashland and Granite Falls sites. The regressions were generally of the form Log_e dry weight = Log_e DBH (table 2). Regressions not significantly different were pooled. Trees at Granite Falls were lighter than similar-size trees of the same clone at Ashland; consequently, regression equations developed from Granite Falls data were used for all sites except Ashland to give conservative yield estimates. A separate regression equation was calculated for the 4-year-old trees harvested at Fairmont.

Table 2.—*Regression equations developed from clones harvested at Ashland and Granite Falls*

Site	Clone	Equations[1]	R^2	Application
Ashland	DN-34 DN-182	$\text{Log}_e DW = 2.05(\text{Log}_e DBH)-1.06$	0.953	All clones at Ashland except DN-17 and NE-308
Ashland	NE-308 DN-17	$DW = 4.16(\text{Log}_e DBH)-1.86$	.975	DN-17 and NE-308 at Ashland
Granite Falls	NE-308	$\text{Log}_e DW = 2.29(\text{Log}_e DBH)-2.36$	.999	NE-308 and NE-19 at all sites except Ashland
Granite Falls	DN-17 DN-34 DN-182	$\text{Log}_e DW = 1.74(\text{Log}_e DBH)-1.36$	.980	All remaining clones at all sites except Ashland
Fairmont	Sioux.	$\text{Log}_e DW = 2.11(\text{Log}_e DBH)-1.70$	.994	Siouxland at Fairmont

[1]/DW = dry weight in kg
DBH = diameter breast height in cm

Most of this report is based on biomass yield after the third growing season of a projected 10-year rotation. Yield here refers to mean annual biomass production (total dry weight of above ground wood plus bark per unit area divided by age). The calculated yield is based on the surviving trees.

RESULTS

Biomass Yield

The fastest growing clones attained yields greater than 1.0 ton/acre/year (TAY) in 3-year-old plantations at three of the six sites and 0.98 TAY at a fourth site (table 3).[1] Overall, the best two clones (NE-308 and DN-17) had an average yield across the region of 0.7 TAY. The mean of the best five clones at the best site (Milaca) was 1.2 TAY. The maximum biomass attained by a single clone was 1.6 TAY for hybrid NE-308 in the 3-year-old plantation at Milaca.

[1]*For comparison, 1 ton is equivalent to 1 cord (90 cubic feet solid wood) of oven-dried aspen with a specific gravity of 0.36.*

Table 3.—*Biomass production in 3-year-old plantations*

Clone	Site: ASH	FAR	GRF	MIL	MON	SXF	Ave.
	- - - - - - - - *Tons/acre/year* - - - - - - - -						
NE-308	0.23#	0.25	0.86#	1.61	0.59	1.06	0.77
DN-34	.15#	.22	.53#	.31	.34	.75	.38
DN-182	.15#	.42	1.17#	.60	.34	.56	.54
NE-19	*	.34	*	*	*	*	
DN-17	.15#	.23	.67#	1.34	.98	.75	.69
SIOUX	.09	.05	.48	.51	*	.31	.29
NE-54	.04	0	.18	1.60	.09	.26	.36
NE-387	0	0	.51	.66	.16	0	
NE-299	0	0	0	.14	0	0	
NC-5260	0	0	0	.17	0	0	
DN-1	*	*	.58	*	*	*	
NE-41	*	*	*	0	0	0	
NE-47	*	*	*	*	0	*	

* *Clone not planted.*
0 *Measurements terminated because of poor growth.*
\# *Trees harvested for biomass regression development.*

These yields are plotted against the production trend of *Populus* cultivar Tristis in figure 2. The Tristis data are from an 8- x 8-foot-spaced, irrigated and fertilized research plot at Rhinelander, Wisconsin. The biomass production (mean annual increment) reached 0.3 TAY at 3 years and peaked at 4.2 TAY at 12 years. These data are used for comparison here because they are the only regional biomass data for hybrid poplar at an 8- x 8-foot spacing (the same as in these trials) for an entire 10+ year rotation. Although the Tristis biomass production in this data set peaked at only 4.2 TAY, this clone has produced as much as 7 TAY when grown at close spacing (1 x 1 foot) under a 4-year rotation (Ek and Dawson 1975).

For an additional comparison, total above ground biomass of aspen from ages 3 to 10 years growing on good to excellent sites is also plotted. The aspen yield data were obtained from equations derived from extensive field productivity data (Perala 1973). The data suggest that yields from hybrid poplar lag behind yields from aspen for the first few years. This is to be expected because young aspen coppice stands may have as many as 80,000 or more stems per acre; the hybrid poplar data plotted in figure 2 is from plantations with 670 stems per acre. After the first couple of years, yields from hybrid poplar far surpass those from native aspen stands on even the best sites.

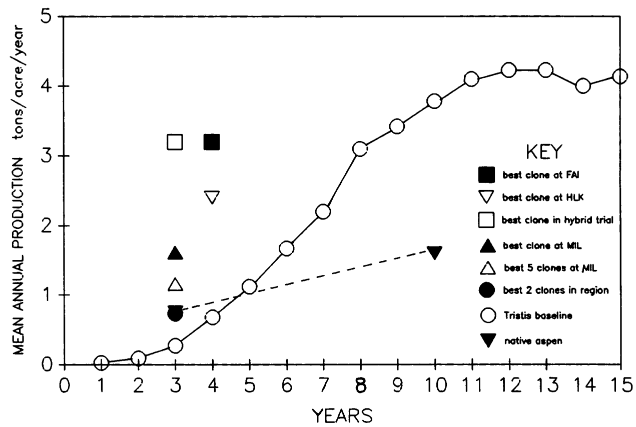

Figure 2.—*Third-year biomass yields compared to production trend of* Populus *Tristis.*

Yields at the end of the third year for the best two clones in the region, the best five clones at Milaca, and the best clone at Milaca are 2.7, 4.3, and 6.0 times greater than the Tristis baseline data, respectively (fig. 2). Limited data from 4-year-old plantations based on the best clone 'Siouxland' planted at a 6- x 6-foot spacing at Fairmont showed a yield of 3.2 TAY at a calculated equivalent spacing of 8 x 8 feet. Similarly, a 4-year-old plantation of NE-54 at Howard Lake had a yield of 1.6 TAY at a spacing of 10 x 10 feet or an equivalent yield of 2.4 TAY at 8 x 8 feet. Calculation of yield for a tree spacing other than what was planted may introduce some bias because of competition differences. In this case the Fairmont yield data would tend to be biased low and the Howard Lake data biased high.

Clonal Stability

Another interesting early trend is an apparent stability of clonal ranking between sites across the region (table 4). Both clone and site were highly significant (p = 0.01) in an ANOVA analysis of 2-year-old height growth. This finding has important ramifications in that the best clones for the region are also the best adapted clones for most sites; however, the same analysis based on 3-year-old biomass yields failed to show significant clonal differences (table 3). This failure was believed due to a combination of not measuring the poorer growing clones, thus circumscribing the data range, and more within-site variability due to poorer site tending the first year of the program (clone confounded with micro site).

Table 4.—*Tree heights in 2-year-old plantations*

Clone	Site: ASH	CLO	FAI	GRF	MON	SXF	Ave.	Rank
	Feet							
NE-308	8.4	6.0	15.7	17.0	12.5	12.9	12.1	1
DN-34	8.4	5.4	15.0	12.1	15.2	13.0	11.5	2
DN-182	8.1	4.9	12.9	12.6	13.1	11.4	10.5	3
NE-19	6.9	7.1	11.8	13.4	12.4	10.2	10.3	4
DN-17	6.4	4.1	12.8	13.8	10.7	9.5	9.5	5
SIOUX	7.9	3.3	13.0	10.1	*	11.8	9.3	6
NE-54	6.5	5.5	9.8	0	11.8	7.8	8.3	7
NE-387	6.2	5.0	10.2	0	11.6	8.1	8.2	8
NE-299	7.1	5.2	8.9	0	10.5	7.4	7.8	9
NC-5260	5.0	3.0	6.4	0	7.2	6.1	5.5	10
Average	7.1	5.0	11.6	11.3	11.7	9.8	9.3	

* *Clone not planted.*

0 *Measurements terminated because plots were destroyed.*

NOTE: treatments not bounded by a common line are significantly different; Fisher LSD test (p = 0.05).

DISCUSSION

These data show that early yields from the plantation network exceed by several times the yields previously obtained from a Tristis clone at the same spacing that produced a maximum of 4.2 TAY. These plantation yields will probably continue to exceed the Tristis yield trend depicted in figure 2. It is difficult to estimate what the ultimate yield difference will be at the point of maximum mean annual production; but if final yields were double that of Tristis, they would be in the range of 7 to 10 TAY. Yields of 7 TAY have been obtained in a Tristis plot with close spacing, so these projections seem reasonable.

There is much room for further increase of even these high yields. These plantings were established during the record drought of 1987-1988. Due in large part to this drought, tree survival averaged only 58 percent in 1987 and 63 percent in 1988. However, mortality was not the same for all hybrids—faster growing hybrids generally had better survival. For example, the best two clones had 80 and 94 percent survival for the same 2 years. In any case, survival was poorer than that normally obtained in poplar plantations. If survival had been in the more normal 95+ percent range, yields would have been greater.

Further yield increases may also be achieved with new, faster growing hybrids. For example, the fastest growing 3-year-old clone (DN-2) in the hybrid trial at Milaca had a yield of 3.2 TAY or nearly **12 times** the yield of Tristis at the same age (fig. 2). This yield is based on only four trees centered in a 16-tree plot—a very limited data set. Nevertheless, it suggests large yield improvements are possible from testing and identifying fast-growing hybrids. When these faster growing hybrids in the hybrid trial program are available for large-scale plantings, yields should increase over what we are presently observing in the block plantings.

It is possible that the biomass regressions are underestimating yield on some sites. Although 44 trees were harvested, the sample is still small considering the total number of sites, hybrids, and tree sizes. The more conservative Granite Falls regression equations were applied to all sites except Ashland. If some of those sites have tree size/weight relations that are more like those at Ashland, then their true yields are underestimated.

Several factors may reduce future yields. The yields reported here were achieved during record warm, dry weather. Hybrid poplar growth is positively related to temperature; consequently, on those sites where water was available, the reported yields may be greater than what would occur during cooler/wetter growing seasons. A survey of soil characteristics in the summer of 1990 will help interpret observed yield differences between sites. In the absence of detailed soil data, we believe that yields were severely limited at Fargo, Sioux Falls, and Mondovi, primarily by drought. Yields at Granite Falls and Milaca were not nearly as limited by drought because of deep soils at Granite Falls and a shallow water table at Milaca. If this is the case, a return to cooler, wetter weather will tend to increase yields at Fargo, Sioux Falls, and Mondovi, relative to yields at Granite Falls and Milaca.

Another factor that could eventually reduce yields is disease. We have observed serious leaf diseases on NE-308. If these continue, growth rates will no doubt decline. Note that NE-308 is also prone to the canker disease *Septoria musiva* and should NOT be planted in commercial plantations in the region at this time; however, most of the faster growing hybrids listed in table 2 have been grown successfully in shelterbelts in the region for several decades, so they may have sufficient disease resistance when planted more extensively in plantations.

The poor performance of some hybrids should not detract from the overall positive results of this testing program. In planning this program, it was recognized that several hybrids were high risk performers. It was decided to include more hybrids to increase information for future use, and eventually concentrate data collection on the best half of the hybrids. We have now dropped three to four hybrids at most sites from further analysis.

The large yield increases in this test as compared to that of the Tristis baseline clone data from Rhinelander are due primarily to two factors: (1) Tristis is a slow-growing clone, particularly in the first few years; and (2) soils are better and growing seasons are longer for most of the sites in the plantation network. Over the years we have observed the early slow growth of Tristis in numerous comparative trials of hybrids, including its last-place ranking in these trials (table 4). Evidence that yield differences are due to improved site quality is that yield data for the Ashland site (which is climatically most similar to Rhinelander) is much more comparable to the Tristis baseline yields. The average yield of the best four hybrids at Ashland was only 0.17 TAY (table 3) as compared to 0.27 TAY for Tristis at age 3 (fig. 2). Correcting for the high mortality at Ashland improves yield to 0.31 TAY, similar to that of the 3-year-old Tristis with 100 percent survival. The other network sites reported in this paper were all south and west of Ashland (warmer) on better agricultural soils and had greater yields. These relative yield increases occurred with no irrigation or fertilization except at one site (potassium at Cloquet), whereas the Tristis baseline data were obtained by using both those cultural treatments throughout the rotation.

SUMMARY

Maximum biomass yields from tree energy plantations with an 8 x 8 foot tree spacing in the north-central U.S. are 0.7 to 1.6 TAY at age 3 and 2.4 TAY at age 4. The average yield of the best two hybrids at age 3 over the entire region is 0.7 TAY. These yields are 3 to 4 times higher than the Tristis baseline data and suggest that harvest yields will eventually be quite high, perhaps as much as 7 to 10 TAY. Unknowns of weather, site factors, hybrid potential, and disease make it difficult to estimate future yields. These factors interact and to some extent compensate each other so that the final yields may be below or above the estimated 7 to 10 TAY. The performance of individual clones in these trials should not be used as a sole criterion for clonal selection. More years of observation and results from other regions are needed when making selections for extensive plantings.

ACKNOWLEDGMENTS

This report is the product of the North Central regional plantation network established and maintained through the support of Lynn Wright of the Short Rotation Woody Crops Program (Department of Energy), Dave Ostlie of Energy Performance Systems, Wendell Johnson of the University of Minnesota, and EPRI (Electric Power Research Institute). Plantation establishment in 1986 was directed by Bill Berguson of the Minnesota Natural Resources Research Institute. Subsequent plantation establishment and tending were managed by Dan Netzer, and field data collection and analysis were carried out by Dave Tolsted and Terry Strong of the North Central Forest Experiment Station.

LITERATURE CITED

Ek, A.R.; Dawson, D.H. 1976. Actual and projected growth and yield of *Populus* 'Tristis #1' under intensive culture. Canadian Journal of Forest Research. 6: 132-144.

Perala, Donald A. 1973. Stand equations for estimating aerial biomass, net productivity, and stem survival of young aspen suckers on good sites. Canadian Journal of Forest Research. 3: 288-292.

★ U.S. GOVERNMENT PRINTING OFFICE 1990—555-247