United States
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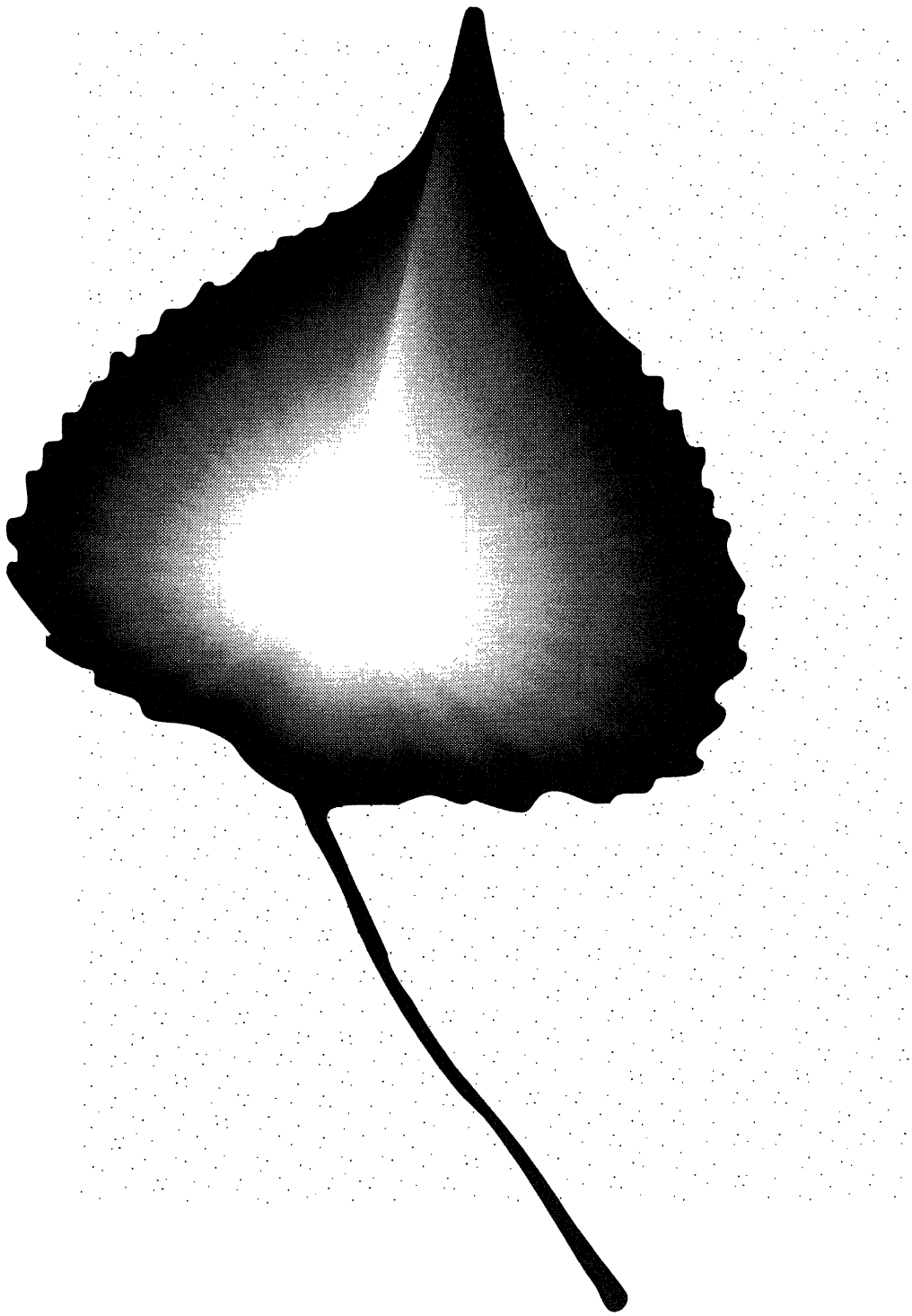
Research
Paper NC-309

Mid-Rotation Yields Of Biomass Plantations In The North Central United States

Edward Hansen



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

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication October 26, 1992
1992

Mid-Rotation Yields Of Biomass Plantations In The North Central United States

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Interest is increasing in the concept of growing high yields of woody biomass as an alternative and renewable energy source because of its potential to ameliorate the increase in atmospheric carbon. The North Central Forest Experiment Station (U.S. Department of Agriculture-Forest Service), in cooperation with the U.S. Department of Energy, the Electric Power Research Institute, and Energy Performance Systems, has established and maintained a network of research and demonstration plantations throughout the North Central Region. These plantations, which contain large blocks of single clones, provide near commercial-scale information on biomass yields, and the economics of producing biomass for energy in addition to testing newly introduced hybrids. They also show farmers and other interested people that this new alternative agricultural energy crop is feasible. Mid-rotation yields from this research and development program are encouraging, and the concepts are beginning to be integrated into the Conservation Reserve Program. This report summarizes biomass yield and tree survival data of plantations halfway through an anticipated 10-year rotation.

METHODS

Hybrid poplar plantations were established at eight sites across four States: four in Minnesota, two in Wisconsin and one each in North and South Dakota (fig. 1). Plantations are 10 to 20 acres in size at most sites (table 1). Five acres were planted at one site in 1986, and 10 acres were planted at most sites in each of 1987 and 1988. Trees were planted as unrooted hardwood cuttings at 8- x 8-foot spacing for a projected rotation of about 10 years. Because information on suitable hybrids for the region was limited, the plantations at each site were subdivided into 10 smaller monoclonal blocks, each planted with a different hybrid, to reduce risk of extensive failure associated with planting only one hybrid at a site. Each block was 0.8 acre, large enough in which to obtain valid biomass yield data, conduct soil-tree growth investigations, and eventually conduct harvesting trials. Hybrid trials consisting of 40 to 80 hybrids in small contiguous blocks were also

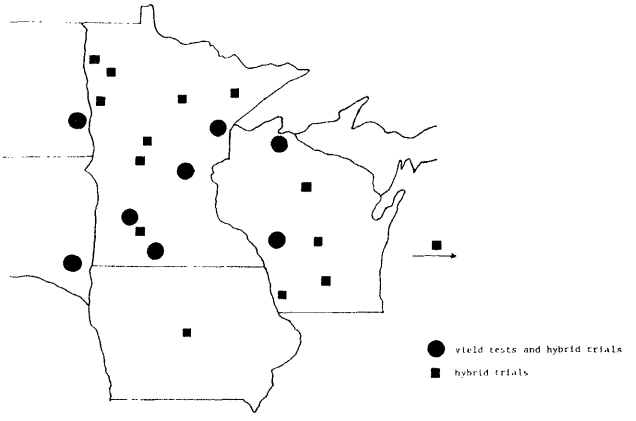

Figure 1.—*Hybrid poplar energy plantation network in the north central United States.*

Table 1.—*Acreage and location of established plantations remaining in 1991*

Location	Total acreage
Ashland, WI	20
Cloquet, MN	10
Fairmont, MN	15
Fargo, ND	20
Granite Falls, MN	15
Milaca, MN	15
Mondovi, WI	20
Sioux Falls, SD	20

Edward Hansen is a Silviculturist with the North Central Forest Experiment Station in Grand Rapids, Minnesota.

planted at each site. An additional 20 hybrid trials have been established by cooperators at other sites, including sites in Iowa and Michigan. These trials permit identification of new adapted clones with high productivity and pest resistance for each site.

Tree growth is determined in this study by measuring tree heights in 1- and 2-year-old plantations and diameters at breast height (DBH) in plantations 3 years and older. In the fall of 1989, 44 trees were selected over the network, cut at the ground line, and ovendried to obtain biomass weight (total above-ground ovendried tree weight minus leaves). Additional trees were harvested each succeeding year for a total of 119 trees to date. This data set is used to develop regression equations to calculate plot biomass yields based on tree diameter measurements. Biomass yield as used here is expressed as mean annual production (tree biomass per unit area divided by age).

Regression equations of the form Log_e Dry Weight = a + b(Log_e DBH) were computed for each clone and site. Tests for significant differences between regressions showed significant site differences but no significant clonal differences. Consequently, clones were pooled, and a separate regression was calculated for each site. R^2 values for the individual clone and site regression equations ranged from 0.92 to 0.98. The R^2 values for the regression equations for the Milaca and Mondovi sites (the two sites with the highest yields) were 0.97 and 0.98, respectively.

RESULTS AND DISCUSSION

Biomass Yield

The fastest growing clones attained yields greater than 3.0 ton/acre/year (TAY) in 4- and 5-year-old plantations (table 2), up considerably from the greater than 1 TAY reported previously for these plantations at 3 years of age (Hansen 1990).[1] Overall, the five best clones had average yields across the region ranging from 1.2 to 2.2 TAY. The mean of the best five clones at the best site (Milaca) was 2.7 TAY. The maximum biomass attained by a single clone was 3.7 TAY for hybrid DN-34 in the 4-year-old plantation at Mondovi.

These yields are plotted against the production trend of the *Populus* hybrid "Tristis" in figure 2. The Tristis data are from an 8 x 8 foot-spaced, irrigated, and fertilized research plot at Rhinelander, WI. The biomass production was 1.1 TAY at age 5, and peaked at 4.2 TAY at 12 years. These Tristis data are used for comparison 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 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 1976). The plantation yields for many clones are expected to continue increasing for at least a few more years. The year that a particular clone reaches its peak biomass will define the rotation for that clone at that site. The current "best clone at Milaca" is clone NE-308. It, along with NE-54, is heavily infested with Septoria canker and is apparently approaching it's peak yield (table 2—5-year plantations). Other clones at that site are expected to continue accelerating growth and eventually surpass NE-308 and NE-54 yields.

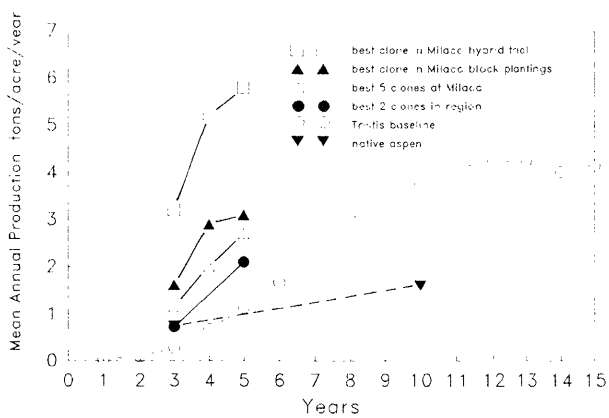

Figure 2.—*Biomass yields from the north central hybrid poplar plantation network.*

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

Table 2.—*Biomass production in 4- and 5-year-old plantations in the fall of 1991 (actual standing biomass)*

4-YEAR-OLD PLANTATIONS

	Site						
Clone	**Ashland**	**Cloquet**	**Fairmont**	**Granite Falls**	**Mondovi**	**Sioux Falls**	**Average**
	Tons/acre/year						
DN-1	*	*	*	*	*	*	
DN-17	1.0	0	1.6	2.0	1.8	0.8	1.4
NE-19	*	0	*	1.9	*	*	
DN-34	2.0	1.3	2.0	2.0	3.7	1.5	2.1
NE-41	*	*	*	0	0	0	
NE-47	*	*	*	*	0	*	
NE-54	1.1	0	0	0	0	0	
DN-182	2.0	1.2	2.2	1.8	2.7	1.4	1.9
NE-299	1.3	0	0	0	0	0	
NE-308	1.4	1.4	2.0	2.5	2.0	1.2	1.8
NE-387	1.1	0	0	0	0	0	
SIOUX	2.0	0	1.6	1.6	*	1.4	1.7
NC-5260	0	0	0	0	0	0	
							$\overline{X}$ = 1.78

* Clone not planted.
0 Measurements terminated because of poor growth.

5-YEAR-OLD PLANTATIONS

	Site						
Clone	**Ashland**	**Fargo**	**Granite Falls**	**Milaca**	**Mondovi**	**Sioux Falls**	**Average**
	Tons/acre/year						
DN-1	*	*	1.2	*	*	*	
DN-17	1.6	1.9	1.5	2.8	2.8	1.3	2.0
NE-19	*	0	*	*	*	*	
DN-34	0.6	0	1.6	1.3	2.1	0.8	1.3
NE-41	*	*	*	0	0	0	
NE-47	*	*	*	*	0	*	
NE-54	1.6	0	0	3.1	1.7	0	
DN-182	0.7	1.8	1.8	2.2	2.7	1.2	1.7
NE-299	1.5	0	0	0	0	0	
NE-308	1.7	0	1.2	3.0	1.8	1.9	1.9
NE-387	1.2	0	0	2.2	1.9	0	
SIOUX	0.5	1.2	1.0	1.9	1.7	0.7	1.2
NC-5260	0	0	0	1.6	0		
							$\overline{X}$ = 1.62

* Clone not planted.
0 Measurements terminated because of poor growth.

For an additional comparison, total aboveground biomass of aspen from age 3 to 10 years growing on good to excellent sites is also plotted (fig. 2). The aspen yield data were obtained from equations derived from extensive field productivity data (Perala 1973). These data suggest that yields from hybrid poplar lag behind aspen for the first year or two. This lag 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 are from plantations with 670 stems per acre. However, after the first couple of years, yields from hybrid poplar far surpass those from native aspen stands on even the best sites.

In addition to the maximum biomass yield, we are also interested in the frequency of high yields. These plantations were established with the anticipation that a significant number of the untested clones would fail. Therefore, we decided at the outset that only the best half of the clones at any one site would be measured throughout the plantation rotation. The other half of the clonal plots that had poor to marginal performance due to high mortality, slow growth, poor winter hardiness, or severe disease incidence would not be measured after the first 2 years. The distribution of yields from all the measured 4- and 5-year-old clone-site combinations of the 0.8-acre plots are plotted as histograms. The data show that many plots have yields in the 2.0 to 3.0 TAY range, and a few plots have yields greater than 3.0 TAY (fig. 3). This range is a good indicator of yields attainable in 4- to 5-year-old commercial plantations with trees spaced at 8 x 8 feet on good sites in this region. Yields, when harvested at rotation, should be even higher than these early results.

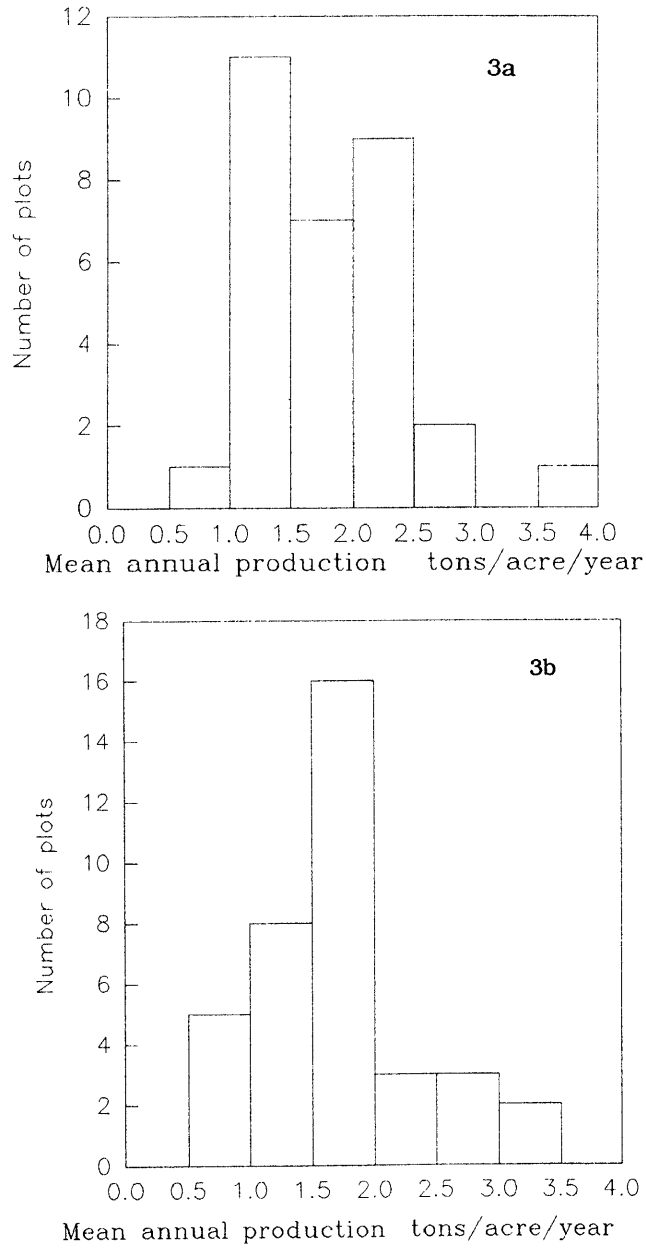

Figure 3.—*Histogram of biomass yields for 10 clones planted at eight sites across the north central United States (3a = 4-year-old plantation, 3b = 5-year-old plantations).*

Mortality

Essentially all tree mortality to date has been due to cutting mortality early in the establishment year (fig. 4). Data shown are for Sioux Falls (a dry site) and Milaca (a wet site), both planted in 1987. Due to severe drought during the establishment year, none of the clones planted at Sioux Falls had survival greater than 90 percent. On the other hand, several of the clones at Milaca had survival greater than 90 percent due to better soil moisture, even though weed competition was quite severe at times. There has been almost no subsequent tree mortality since planting, even though 1987-1989 was a period of historical record drought.

The high initial mortality was due to a number of reasons, some of which varied from site to site. The plantation program was initiated without adequate time for site preparation; weed control was not consistent due to the extensive network; some clonal planting material was of

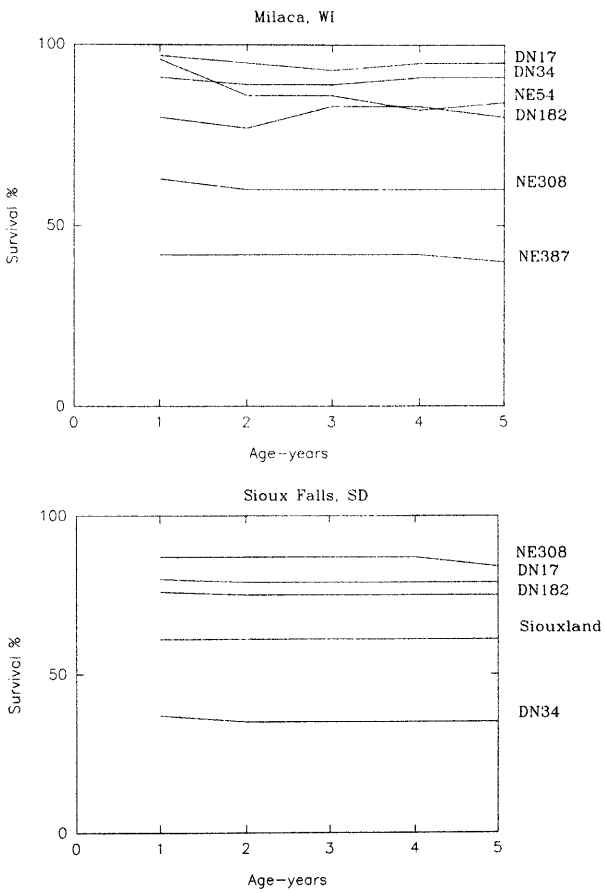

Figure 4.—*Hybrid poplar survival with advancing tree age for 2 of 8 plantations in the north central plantation network.*

poor vigor (see DN-34 clone in fig. 4); and the drought affected some clones and sites more than others, specifically where tillage practices did not adequately conserve soil moisture. Correcting several of these deficiencies led to slightly improved survival in the second year (63 vs. 58 percent) despite a worsening drought. With good tillage practices that conserve soil moisture, vigorous cuttings, and good weed control, establishment year survival can be high even with drought. Once the cuttings are rooted well, drought during the first 3 years of plantation growth has little effect on tree survival.

Mortality Effects On Biomass Yields

The large and variable mortality associated with plantation establishment strongly influenced biomass yield within the clonal plots at all sites except Granite Falls. Tree mortality accounted for 71 percent of the variation in biomass between the various clonal plots at Milaca (fig. 5). Similar regressions of plot yields to survival gave R^2 values that ranged from 0.53 to 0.63 for the other sites except Granite Falls.

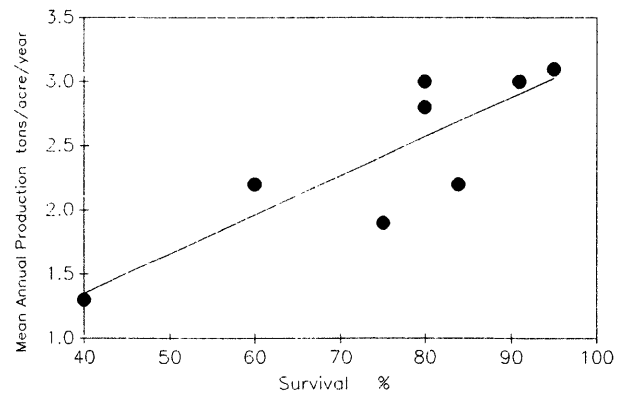

Figure 5.—*Survival effect on biomass yields at Milaca. Each data point is a different hybrid plot. Regression R^2 = 0.71.*

Biomass Adjusted For Mortality

The biomass regressions were used to estimate biomass yields at 100 percent survival. First, the mean tree weight of all living trees on a plot was calculated, and then the adjusted plot biomass was calculated using the mean tree weight and assuming 100-percent survival. These estimates were calculated for each plot at all 5-year-old plantation sites. This procedure tends to overestimate plot biomass somewhat because surviving trees tend to grow larger than they otherwise would. Consequently mean tree weight will be biased high. Nevertheless, despite this bias, it is informative to examine the calculated distribution of plot biomass assuming no mortality. A histogram of these calculated biomass yields shows that nearly all mortality-adjusted plots would lie between 1.5 and 3.5 TAY with a much larger representation of plots above 2.5 TAY (compare figure 6 with figure 3b). This indicates that with good first year survival, yields of 2.5 to 3.5 TAY could be

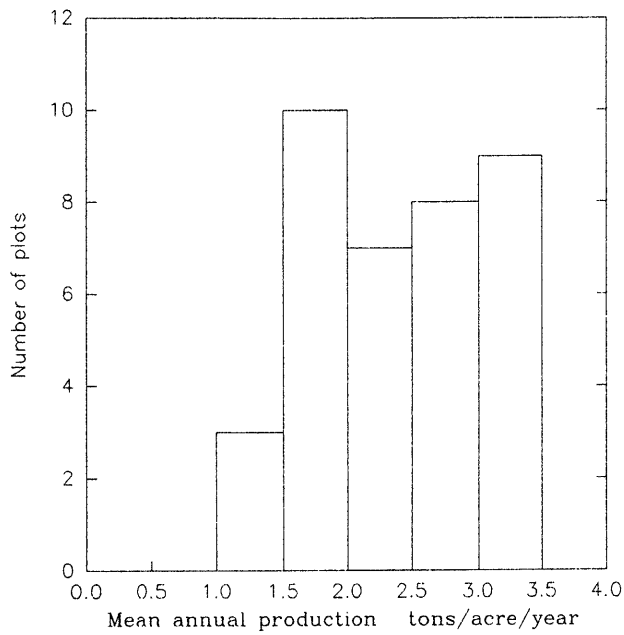

Figure 6.—*Histogram of mortality-adjusted biomass in 5-year-old hybrid poplar plantations for 10 clones at six sites across the north central United States.*

quite common in 5-year-old plantations. Two plots with a mean survival of 93 percent had an unadjusted biomass of 3.0 to 3.5 TAY in figure 3a, confirming that high initial survival can result in yields of that magnitude. Based on experience with these plantations, we anticipate that survival of 90+ percent can be achieved in commercial plantations.

Potential Yields

Mid-rotation yields from the plantation network greatly exceed yields previously obtained from Tristis at the same age and spacing that eventually produced a maximum of 4.2 TAY (Strong and Hansen, in prep.). These plantation yields should continue to exceed the Tristis yield trend depicted in figure 2.

There is potential for further increase of these yields. These plantings were established during the record drought of 1987-1988, and managed under difficult scheduling conditions associated with an extensive network. Due in large part to the drought, tree survival averaged only 58 percent in 1987 and 63 percent in 1988. If survival had been in the more normal 90+ percent range, maximum yields would have been somewhat greater, and just as important, the frequency of high plot-yields would have been much greater. It should also be noted that yields in 4-year-old plantations equal if not slightly surpass the yields in 5-year-old plantations (fig. 3). This is attributed to better survival and improved culture in the 4-year-old plantations.

Further yield increases may also be achieved with new, faster growing clones in the hybrid trials. For example, the fastest growing 5-year-old clone in the hybrid trial at Milaca has a yield of 5.8 TAY (fig. 2). This yield is based on a very limited sample—only 4 trees centered in a 16-tree plot. Nevertheless, it (and yields of other new clones now being tested) suggests that substantial yield improvements are possible from new faster growing hybrids.

Several factors may also reduce future yields. The yields reported here were achieved during a period of record warm-dry weather. Hybrid poplar growth is positively related to temperature; and where soil water was available during the drought, the reported yields may be greater than what would occur during cooler/wetter growing seasons. We believe that yields at Fargo, Fairmont, and Sioux Falls were severely limited, primarily by drought. Yields at Granite Falls, Mondovi, and Milaca were not nearly as limited by drought because of deep soils at Granite Falls and Mondovi and a shallow water table at Milaca. If these apparent relations are true, then a return to a cooler-wetter climate will tend to increase yields at Fargo, Fairmont and Sioux Falls, relative to yields at Granite Falls, Mondovi, and Milaca.

Water Requirements

Soil water availability appears to be the key to high yields from woody biomass plantations. In an irrigation study at Rhinelander, WI, consumptive water use (precipitation plus irrigation) required to maintain soil moisture tension higher than -0.03 MPa averaged 5.5 inches per month during the June-August growing period

(Hansen 1988). Normal precipitation during June-August averages less than 4.0 inches per month for much of Wisconsin-Minnesota. This means that there is a water deficit of approximately 5.0 inches (with normal precipitation) during the average growing season. This deficit could be offset by either a shallow water table, or a deep soil mantle that can store an equivalent amount of soil moisture from overwinter recharge. Without this alternative source of soil moisture, the trees will be drought stressed **in a normal precipitation year**. The plantation network described in this paper lies west of Rhinelander and receives progressively less precipitation as one traverses west. For example, Sioux Falls, SD, has 7 inches less precipitation (annually) and Fargo, ND, has 10 inches less precipitation than Rhinelander. Therefore, a soil- or ground-water supply to supplement precipitation becomes more important in a westerly direction.

The importance of supplemental water to biomass yields is illustrated by the Milaca site, which has a shallow water table and the overall highest yields. Measurements in 1991 with a piezometer transect across the Milaca plantation showed that the water table was initially at the ground surface in the spring, but declined underneath the plantation progressively throughout the summer to a depth of 3 to 4 feet (fig. 7). On either side of the plantation, the water table remained within a foot of the ground

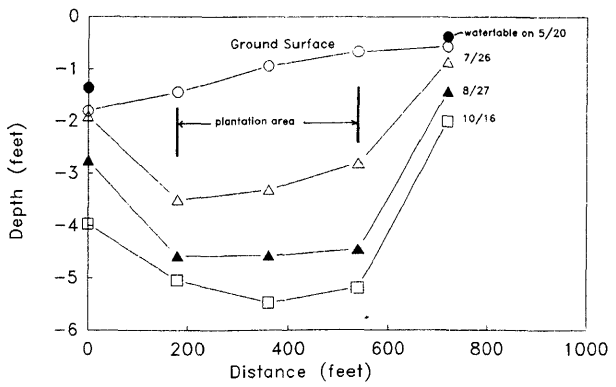

Figure 7.—*Water table depression at the Milaca site under a 5-year-old hybrid poplar plantation (1991).*

surface through August. During this same June-August period, precipitation averaged 4.25 inches/month (Department of Commerce 1991). The data suggest that the trees used the water from a 3+ foot zone of saturated soil in addition to the 4.25 inches of monthly precipitation. The conclusion is that fast growing hybrid poplars use much more water than is available in normal summer precipitation in this region.

Fertilization Requirements

Fertilization has not been required in most of these plantations. We monitor nutrient status of the trees by leaf tissue sampling and analyses each summer. Only two sites have been judged to require fertilization. Potassium was applied at 100 lbs/acre to the Cloquet plantation the year of establishment (based on leaf tissue analysis of a failed plantation the prior year), and nitrogen was applied at 150 lbs/acre to the two Mondovi plantations of ages 4 and 5. Therefore, fertilization has been required once on each of three plantations out of a total of 54 plantation-years of observation.

Clonal Performance

The best clones in the large-block trials in this plantation network are the same clones that have long been used in the region for shelterbelt and landscape plantings. The clones and their parentage are:

DN-17	Robusta	Deltoides x Nigra
DN-34	Eugenii	Deltoides x Nigra
DN-182	Raverdeau	Deltoides x Nigra
—	Siouxland (believed to be a naturally occurring DN clone)	

Other clones that we planted in large plots are slow growing, have failed, or are seriously diseased, with stems beginning to break from stem canker. These include all of the NE (Northeast) clones listed in table 2 and Tristis.

The same clones are generally the best performers at all sites and for both years of planting (table 2). This pattern was observed early in the program in both the large plots and in the hybrid trials (Hansen 1990). The hybrid trial

data containing 91 clones showed that consistency of clonal ranking over all sites was highly significant (Hansen *et al.* 1992). This was true both for all sites planted within a given year and for all sites pooled across years, indicating that clones that are best on one site tend to be among the best on all sites. For example, of the clones that ranked in the top 20 overall for the region, 6 clones were in the top 20 at six of the seven sites, and 18 clones were in the top 20 on four of the seven sites. These results show that most clones are broadly adaptable to the region, and clonal tests can be done at just a few sites to identify the superior clones for the region.

ACKNOWLEDGMENTS

This report is a product of the USDA Forest Service's North Central regional plantation network, established and maintained through the support of the U.S. Department of Energy's Biofuels Feedstock Development Program managed by Oak Ridge National Laboratory, Dave Ostlie of Energy Performance Systems, Wendell Johnson of the University of Minnesota, and the 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 of the North Central Forest Experiment Station.

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1992-756-200/60249

Hansen, Edward.
1992. **Mid-rotation yields of biomass plantations in the north central U.S.** Res. Pap. NC-309. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.

Summarizes biomass yield and tree survival data of short rotation hybrid poplar energy plantations halfway through an anticipated 10-year rotation.

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