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Species Trials for Biomass Production on Abandoned Farmland[1]

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ABSTRACT. As part of a nationwide study of the potential for woody crops to supply biomass for energy use, we evaluated seven hardwood tree species and six hybrid poplar clones on four different sites in Vermont, with three fertilizer treatments on some sites. Not all species were evaluated on all sites. Plots containing 25 trees were replicated three or four times at each site. Trees were planted at a spacing of 0.6 x 0.6 m or 0.9 x 0.9 m and grown for 3 years. The application of fertilizer did have significant effect on height, diameter, and stem weight. Species with high yields (about 16 oven-dry t/ha/year) included four of the hybrid poplars. Silver maple, black locust, and the other two hybrid poplars yielded about 10 oven-dry t/ha/year. Based on growth alone, these species and clones were recommended for short-rotation intensive culture in areas with similar climate and growing sites.

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The potential for increasing yields through short-rotation intensive culture (SRIC) of hardwood trees has been recognized as a source of energy and wood fiber (USDA For. Serv. 1980). Hardwoods are favored for their ability to coppice, avoiding replanting cost after harvest. They are also capable of fast juvenile growth and grow over a geographically widespread area.

The Short Rotation Woody Crop Program, sponsored by the U.S. Department of Energy and managed by Oak Ridge National Laboratory, consists of a number of projects nationwide which address all aspects of SRIC, including species selection; stand establishment and management; and collection, transportation, and storage strategies (Ranney et al. 1982). Several projects, including work reported here, involve species selection.

Hardwood species of the northeastern U.S. include several with possible value for SRIC. Work with hybrid poplar has shown promise for fast growth and high yields (Dawson et al. 1976, Zsuffa et al. 1977, Dickmann and Stuart 1983). However, other species remained untested, especially in SRIC plantations.

New England, because of changing agricultural methods and declining numbers of farms, contains large areas of land that were once farmed. For example, in Vermont in 1964 there were 9247 farms on 1.0 million ha; in 1979 there were 5900 farms on 0.7 million ha. Much of this abandoned marginal farmland is suitable for SRIC plantations.

Our objective was to test several hardwood species at close spacing in small plots on several sites to determine the species' potential for SRIC plantations.

METHODS

To evaluate growth rate and yield on several sites, plantings were established at four locations in Vermont in 1979, at elevations from 30 to 140 m and on different soils (Table 1). Seven species and six hybrid poplar clones were evaluated (Table 2).

All planting sites were clean cultivated using a combination of herbicides, plowing, harrowing, and rototilling (Hansen et al. 1983). Species plots of 25 trees, 5 rows x 5 trees, were planted. A 3-year rotation was chosen with 0.6 x 0.6 m or 0.9 x 0.9 m spacing to obtain canopy closure in that time period. Species were randomly planted within blocks. One or two rows of buffer trees were planted around each block. Blocks were replicated three or four times, as space and stock availability permitted. Experiment 3, site 3, had only one replicate because of unavailability of planting stock.

Experiment 1 tested the effects of different rates of fertilizer application confounded with methods of application on tree growth rates and yield. A soil analysis determined the fertilization rate for corn for each of three sites. All plots were fertilized to this control level. In addition, two other

Table 1. Plot site locations in Vermont: elevations, soils, and study specifications.

Site	Location (elevation)	Soils	Experiment number	Number of species/clones	Number of replicates
1	Burlington (30 m)	Limerick series: deep poorly drained, loam.	1	2	3
2	Bolton (110 m)	Hartland series: deep, well drained, loam.	3	4	3
3	South Burlington (85 m)	Adams series: deep, loose, excessively drained loamy sand	1	4	3
			3	5	1
4	Essex Junction (140 m)	Peru series: deep, stony, moderately well drained loam; fragipan starts at > 0.5 m.	1	8	4
			2	9	3

levels of fertilization were tested. A 20-10-5 (N,P,K) fertilizer pellet was placed in each planting hole on a third of the replicated plantings. Granular 10-10-10 was spread at the rate of 2.24 t/ha on another third of the replicates. Two species were planted on site 1, four species on site 3, and eight species on site 4. Sites 1 and 4 were planted at a 0.6 x 0.6 m spacing and site 3 at a 0.9 x 0.9 m spacing. In the split-plot design fertilizer treatments were main plots and species were subplots.

Experiment 2 tested species effects on annual growth rate and annual yield. Fertilizer was applied, based on soil analysis, to the level for corn production. Nine species were planted at site 4 in three replicates at 0.6 x 0.6 m spacing. After the first growing season, after leaffall, one randomly selected row (five trees) from each of the three species plots was harvested to determine growth and yield. Two randomly selected rows (10 trees) were harvested each year from each species plot after the second and third growing seasons. Only the 3-year growth and yield are reported here.

Experiment 3 evaluated species differences in growth rate at two sites after three growing seasons. Four species were planted on site 2, 0.6 x 0.6 m spacing, and five on site 3 at 0.6 x 0.6 m spacing. Fertilizer was applied on all sites, based on soil analysis to the control level. There was only one replicate for Experiment 3 on site 3 because of the unavailability of planting stock.

Height and diameter were measured at the end of the third growing season in all plantings. Diameter was measured with calipers at 5 cm above ground level; height was measured as total height above ground level. Harvested stems were cut after leaffall at 5 cm above ground level and weighed. A section was cut from each stem and placed in a plastic bag. In the laboratory moisture content by weight for the sections was determined using ASTM D2016-74 (Am. Soc. for Testing Materials 1980). The moisture content was used to adjust the green weight of the stems to an oven-dry basis.

Omnibus species and fertilizer treatment differences were tested by the analysis of variance. Experiment 1, sites 1 and 4, were split-plot designs. Experiment 2, site 4, and experiment 3, site 2, were randomized block designs. Site 3 was a completely randomized design for experiments 1 and 3. Where more than one experiment was conducted on a site, independent replicates were used in the experiments. All differences were tested at « _ 0.05. Following a significant F-test, multiple comparisons were performed using Duncan's Multiple Range Test at the 0.05 level of significance (Chew 1976, Aleong and Howard [In press]).

Table 2. Species evaluated in growth and yield trials.

Common name	Scientific name
Silver maple	*Acer saccharinum L.*
Sugar maple	*Acer* saccharum Marsh.
Red maple	Acer rubrum L.
White ash	*Fraxinus americana* L.
Green ash	*Fraxinus pennsylvanica* Marsh.
Hybrid poplar nn[a]	Populus sps.
Hybrid poplar NE-41	Populus maximowiczii x trichocarpa
Hybrid poplar NE-209	Populus *deltoides x trichocarpa*
Hybrid poplar NE-353	*Populus deltoides* x 'Caudina'
Hybrid poplar NE-380	Populus 'Charkowiensis' x 'Caudina'
Hybrid poplar NE-388	Populus maximowiczii x trichocarpa
Black locust	*Robinia* pseudoacacia L.
Chinese elm	U/mus pumila L.

[a]A proprietary mixture of clones sold by Frye Nurseries for energy wood production, identified here as nn (no number).

RESULTS

Results of the three experiments for average height, diameter, and oven-dry stem weight for the 3-year period by species and site are summarized in Tables 3, 4, and 5. All species tested were not included. High mortality the first year for some species, including black, European white, and yellow birch, led to their exclusion from this evaluation.

All yields are reported as oven-dry stem weight. Based on results in all three experiments, the highest mean species stem weight was 2.86 kg for hybrid poplar nn (a proprietary mixture of clones sold by Frye Nurseries for energy wood production, identified here as nn or no number). Other hybrid poplars had mean stem weights that ranged from 1.40 to 2.24 kg.

Black locust and silver maple had high mean stem weights of 1.87 kg and 1.68 kg, respectively. The remaining species had high mean stem weights that ranged from 0.22 to 0.61 kg. This group included Chinese elm, green ash, red maple, white ash, and sugar maple.

In mid-May 1981 (start of the third and final growing season), overnight temperatures dropped to near -8°C for two successive nights. Silver maple, white ash, and green ash suffered some frost injury but demonstrated good recovery. However, black locust buds, which had just opened, were killed by the freeze. Subsequent growth was from dormant buds near ground level. This seriously affected data from this species, although the dead stems plus new sprouts still produced substantial yields.

Experiment 1

Site 1—Data were collected on

Table 3. Three-year height, diameter, and oven-dry stem weight by species and fertilizer treatment for experiment 1.

	Site 1			Site			Site 4		
	H[a]	D[b]	W`	H	D	W	H	D	W
Species									
Hybrid poplar									
NE-388	554.2A[d]	5.02A	2.24A						
nn				397.4A	4.95A	1.67A	520.5A	4.95A	1.90A
Silver maple	404.48	4.15B	1.47B	320.2A	4.01A	1.29A	306.08	3.63B	0.838
Black locust				344.7A	4.88A	1.87A	341.08	3.53B	1.12B
Green ash							220.9CD	2.52C	0.40CD
Chinese elm				238.08	3.66A	1.15A	188.5E	2.52C	0.33E
White ash							233.6C	2.63C	0.45C
Red maple							207.6DE	2.69C	0.37DE
Sugar maple							187.2EF	2.01D	0.22E
Fertilizer treatment									
Control	496.8A	4.60AB	1.79A				259.6B	2.96B	0.59B
10-10-10 Granular spread	485.8A	5.07A	2.29A				297.8A	3.33A	0.90A
20-10-5 Pellet	447.98	4.13B	1.55A				275.08	2.846	0.59B

'Height (cm).
'Diameter (cm).
`Oven-dry stem weight (kg).
'Means within columns are not statistically different at the 0.05 level of significance if followed by the same letter.

silver maple and hybrid poplar NE-388 (Fig. 1). The results of the analysis of variance indicated that the species were significantly different for 3-year height, diameter, and weight. Al-though the hybrid poplar clone yielded more biomass than did the silver maple, both species produced promising yield estimates.

The fertilizer treatment was statistically significant for height and diameter (Table 3). For the granular spread, height and diameter were not significantly greater than the control height and diameter but were greater than the height and diameter with pellet application. The difference between the mean control diameter and the mean diameter with pellet application was not significant. However, the mean height for the control was significantly greater than the mean height for the pellet treatment. There were no statistically significant inter-actions.

Site 3-Fertilizer treatments were confounded with replicates and so could not be evaluated. Four species were evaluated on this site. The species differed significantly for 3-year height but not for diameter and weight.

The mean height for Chinese elm (238.0 cm) was significantly less than for the three other species on the site (Table 3). There were no significant differences among the mean diameters, which ranged from 4.95 cm for hybrid poplar nn to 3.66 cm for Chinese elm. There were no differences among the four species for mean stem weight, which ranged from 1.15 kg for Chinese elm to 1.87 kg for black locust.

Site 4-Data were collected on eight species and results indicate that species differences and fertilizer treatments were statistically significant for 3-year height, diameter, and weight (Table 3). There were no statistically significant interactions. Hybrid poplar nn attained the greatest mean height (520.5 cm), diameter (4.95 cm), and weight (1.90 kg) on this site. The multiple range test next grouped silver maple and black locust means for height, diameter, and yield. The multiple range test identified statistically

Fig. 1. Experiment 1, site 1, silver maple and hybrid poplar NE-388 after 3 years' growth; length of rod is 6.5 m.

significant differences among means for the remaining five species, but their mean heights, diameters, and weights were so much less than those of the top three species that the differences were of little practical importance.

Mortality was not a problem in this experiment. The greatest mortality rate was observed on site 3 for black locust (16%). Mortality was not greater than 10% for any other species.

Experiment 2

This experiment was conducted entirely on site 4 and nine species were evaluated. The plots in experiment 2 were treated differently than were those in the other two experiments. A sample of trees was harvested from each plot to determine growth and yield at the end of the first and second growing seasons. This reduced competition for some of the trees for part of the growing season. However, coppicing was not discouraged, so that sprout growth quickly replaced the harvested stem in most cases. The data presented here are only an evaluation of the 3-year-old trees harvested in the last year of the experiment.

The analysis showed that species differences were statistically significant for 3-year height, diameter, and yield (Table 4); The two hybrid poplars, NE-380 and -209, were grouped with silver maple and black locust for height by the multiple range test. As a group, they averaged 385 cm in height. The same four species were grouped together for average diameter and yield. The mean weights for silver maple. black locust, and the two hybrid poplars ranged from 1.71 kg (beck locust) to 1.40 kg (hybrid poplar NE-209). Although there were statistically significant differences among means for diameter and stem weight for the remaining five species, they were of little practical interest.

Mortality was not a serious factor but was somewhat greater than in experiment 1. Black locust had the greatest mortality at 33%, followed by red maple at 27%. Mortality for the other species did not exceed 20%.

Experiment 3

Site 2—Data on four species were collected. The species differences were significant for 3-year height, diameter, and stem weight (Table 5). Hybrid poplar NE-41 had greater mean height, diameter, and weight than the other three species. Black locust had greater mean height, diameter, and weight than the two maples. The mean stem weight for hybrid poplar NE-41 was 2.20 kg, almost twice as great as that for black locust (1.22 kg).

Site 3—Three hybrid poplar clones, red maple, and Chinese elm were evaluated. There were statistically significant differences among the species for height, diameter, and weight. The site continued to demonstrate the superior yields from the hybrid poplars.

The multiple range test indicated that the three hybrid poplars had height, diameter, and weight means greater than those of red maple and Chinese elm. The highest mean stem weight for the study, 2.86 kg, occurred on this site for hybrid poplar nn. The other two hybrid poplars, although less productive, had mean stem weights of about 2 kg.

The mortality in experiment 3 was a problem in evaluation of hybrid poplar nn on site 3 because there was only one replication and 47% mortality after 3 years. This resulted in a plot with significantly greater spacing. Sugar maple on site 2 experienced 44% mortality, but because its yield was low, the practical consequences are nil.

DISCUSSION

The results of this study show that the most rapidly growing species produced the greatest mean stem weights. Among the consistently high producers were the six hybrid poplar clones, silver maple, and black locust. As a group, averaged over all sites and experiments, mean stem weight was 1.7 kg. The highest mean stem weight observed was 2.86 kg for hybrid poplar nn and the lowest, 0.83 kg for silver maple. The other species evaluated consistently produced inferior yields. This group includes Chinese elm, red maple, white ash, green ash, and sugar maple.

The results of the fertilizer trials on mean yields are not easily generalized. On the two sites (1 and 4) where it was tested, fertilizer was found to be a statistically significant treatment. On site 1, however, the 10-10-10 granular spread and the control were not statistically different treatments for height, diameter, and yield means. The 20-10-5 pellet treatment means were significantly lower for height, not significantly different from the control for diameter, and not significantly different from control and the

Table 4. Three-year height, diameter, and oven-dry stem weight by species for experiment 2, site 4.

Species	Height	Diameter	Weight
	------------------ cm	------------------------------	kg
Hybrid poplar			
NE-380	444.7M	4.72A	1.70A
NE-209	385.6A	4.95A	1.40AB
Silver maple	334.4A	5.36A	1.68A
Black locust	375.2A	4.10AB	1.71A
Green ash	210.5B	2.91 BC	0.61 BC
Chinese elm	209.9B	2.79BCD	0.58CD
White ash	165.3B	2.63CD	0.35CD
Red maple	180.5B	3.16BC	0.52CD
Sugar maple	157.7B	1.85D	0.12D

[a] Means within columns are not statistically different at the 0.05 level of significance if followed by the same letter.

Table 5. Three-year height, diameter, and oven-dry stem weight by species for experiment 3.

Species	Site 2			Site 3		
	H[a]	D[b]	W`	H	D	W
Hybrid poplar						
NE-41	550.9A[d]	5.58A	2.20A	544.1A	5.03A	1.91A
NE-353	—	—		495.1A	5.41A	2.00A
nn	—	—		487.0A	6.09A	2.86A
Black locust	337.9B	3.94B	1.22B	—	—	—
Chinese elm	—	—	—	258.3B	2.83B	0.50B
Red maple	148.6C	2.59C	0.21C	158.0B	1.95B	0.20B
Sugar maple	121.1C	1.68D	0.11C	—	—	--

'Height (cm).
[b] Diameter (cm).
`Oven-dry stem weight (kg).
[d] Means within columns are not statistically different at the 0.05 level of significance if followed by the same letter.

10-10-10 granular spread for yield. On site 4, it was clear that 10-10-10 granular spread applied at 2.24 t/ha gave consistently greater mean heights, diameters, and yields than did the pellet control. But application method was confounded with fertilizer level, so observed differences could not be attributed to either level or method.

Assuming a mean stem weight of 2 kg in three growing seasons, 0.6 x 0.6 m spacing, and 80% survival, biomass yield would be about 16 oven-dry t/ha/year. This is the yield anticipated by Ek and Dawson (1976) for hybrid poplars in SRIC plantations. This yield was attained or exceeded in this study by the hybrid poplars NE-41, 388, 353, and nn.

Silver maple, black locust, and hybrid poplars NE-209 and -380 did almost as well overall as the best hybrid poplars. Based on the same assumptions, mean stem weights attained would yield about 10 oven-dry t/ha/year. The other species—green ash, Chinese elm, white ash, red maple, and sugar maple—would have yielded from 1 to 5 t/ha/year.

We did not assess species or clone susceptibility to insects and disease. During the short duration of this study, no significant problems were observed. However, in some continuing experiments, a stem canker, *Septoria musiva*, has been observed. Most of the hybrid poplars in this study are listed by Dickmann and Stuart (1983) as principal hosts for the canker.

The overall results for growth indicate that any of the hybrid poplar clones, silver maple, and black locust would be suitable for SRIC plantations on good sites. Hybrid poplars have exacting site requirements and to reach their full potential for growth need deep, well-drained soils of medium texture and granular structure (Dickmann and Stuart 1983, Demeritt 1983). The other species that we evaluated cannot be recommended for SRIC plantations based on our results.

The findings can be used by foresters or landowners wishing to select a species to establish a plantation of fast growing hardwoods for fiber or fuel use. The findings apply to Vermont and surrounding areas with similar climate and growing sites.

Research on SRIC has shown that wood fiber can be produced at high rates. Methods of site preparation, planting, and management of SRIC plantations have been developed (Dickmann and Stuart 1983, Hansen et al. 1983). However site specific problems, harvesting, insect and disease control, and markets, still leave many questions that must be answered before SRIC can be judged economically feasible in a specific situation. ❑

LITERATURE CITED

ALEONG, J., and D. HOWARD. [In press]. Extensions of the Duncan's Multiple Range Test for unbalanced data. J. Appl. Stat. 12(1).

AMERICAN SOCIETY FOR TESTING MATERIALS. 1980. Standard test methods for moisture content of wood. ASTM Part 22:622–636, Philadelphia, Pa. p. 622–636.

CHEW, V. 1976. Comparing treatment means: a compendium. Hortic. Sci. 11:348–356. DAWSON, D. H., J. G. ISEBRANDS, and J. C. GORDON. 1976. Growth, dry weight yields and specific gravity of 3-year-old populus grown under intensive culture. USDA For. Serv. Res. Pap. NC-122. 7 p.

DEMERITT, M. E., JR. 1983. Planting and care of hybrid poplar. USDA For. Serv., Northeast. For. Exp. Stn. NE-INF-48-83. 9 p.

DICKMANN, D. I., and K. W. STUART. 1983. The culture of poplars in eastern North America. McNaughton and Gunn, Inc., Ann Arbor, Mich. 168 p.

Ex, A. R., and D. H. DAWSON. 1976. Yields of *intensively* grown *Populus:* actual and projected. Pages 5–9 *in* Intensive plantation culture. USDA For. Serv. Gen. Tech. Rep. NC-21.

HANSEN, E., L. MOORE, D. NETZER, M. OSTRY, H. PHIPPS, and J. ZAVITKOVSKI. 1983. Establishing intensively cultured hybrid poplar plantations for fuel and fiber. USDA For. Serv. Gen. Tech. Rep. NC-78.

RANNEY, J. W., J. H. CUSHMAN, and J. L. TRIMBLE. 1982. The short rotation woody crops program: 1982 program summary. Oak Ridge Natl. Lab., Environ. Sci. Div. Pub]. No. 2036. 128 p.

USDA, FOREST SERVICE. 1980. Energy and wood from intensively cultured plantations: research and development program. USDA For. Serv. Gen. Tech. Rep. NC-58. 28 p.

ZSUFFA, L., H. W. ANDERSON, and P. JACIW. 1977. Trends and prospects in Ontario's poplar plantation management. For. Chron. 53:195–200: