United States
Department of
Agriculture

Forest
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North Central
Forest Experiment
Station

Research Paper
NC-320

Field Performance of *Populus* in Short-Rotation Intensive Culture Plantations in the North-Central U.S.

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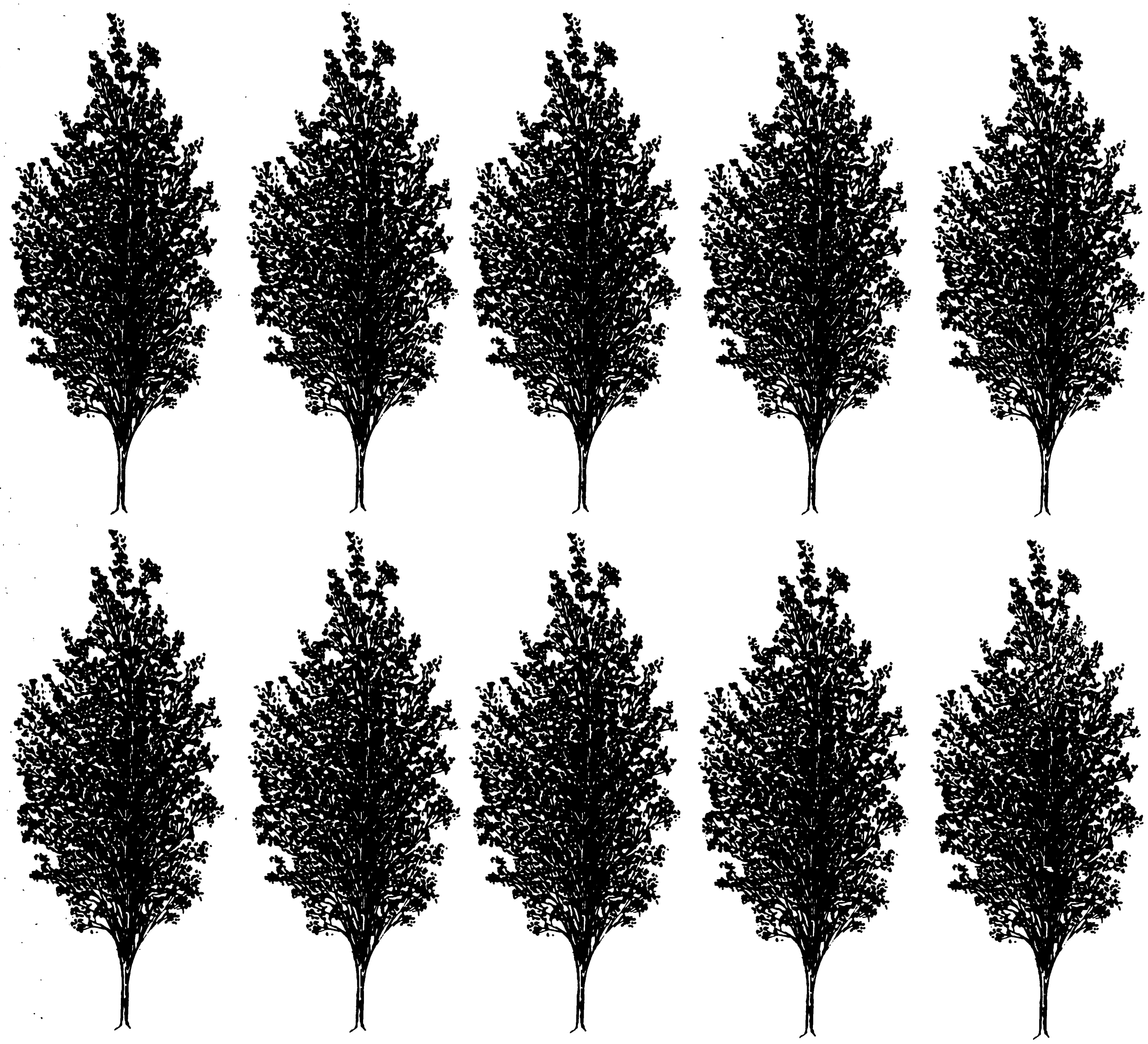

Hansen, Edward A.; Ostry, Michael E.; Johnson, Wendell, D.; Tolsted, David N.; Netzer, Daniel A.; Berguson, William E.; Hall, Richard B. 1994. **Field performance of *Populus* in short-rotation intensive culture plantations in the north-central U.S.** Res. Pap. NC-320. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 13 p.

Describes a network of short-rotation *Populus* research and demonstration plantations that has been established across a 5-State region in the north-central U.S. to identify suitable hybrid poplar clones for large-scale biomass plantations in the region. Reports 6-year results.

KEY WORDS: SRIC, energy plantations, genetic trials, hybrid poplar, disease resistance.

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1992 Folwell Avenue
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Manuscript approved for publication August 18, 1994
1994

Field Performance Of *Populus* In Short-Rotation Intensive Culture Plantations In The North-Central U.S.

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A network of research and demonstration short-rotation *Populus* plantations has been established across a five-State region in the north-central U.S. (fig. 1)[a]. A major objective of this research is to identify suitable hybrid poplar clones for large-scale biomass plantations in the region. Biomass yield in adjacent "yield tests" of commercially available clones averages about 2 dry tons/acre/year across the region about half-way through the projected 10-year rotation (fig. 1). Currently, biomass yield of the best clones on the better sites ranges from 3 to 4 dry tons/acre/year (Hansen 1992). In comparison, the best new clones being tested in adjacent small-plot trials at those same sites yield up to 6 dry tons/acre/year. Although these small-plot yield data are undoubtedly biased high, they indicate potential biomass increases as new clones are introduced into commercial plantings. Therefore, we need to breed, test, and identify new clones with superior growth and disease resistance.

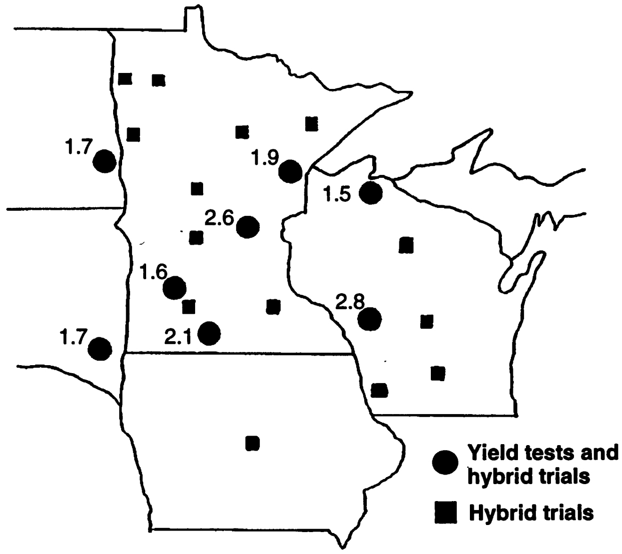

Figure 1.—*Network of short-rotation* Populus *plantations across five north-central States. Numbers are mean biomass yields at 6 years (tons/acre/year).*

Since 1986, 61 clonal trials have been established (41 remaining) with 40 to 80 clones each (table 1 and fig. 1). We tested more than 140 *Populus* selections in the program (Appendix). Results augment earlier trials conducted in the region (Ostry and McNabb 1985, 1986). In this paper we report results of the 5- and 6-year-old

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[a]*These tests are cooperatively supported by the North Central Forest Experiment Station (U.S. Department of Agriculture), the University of Minnesota, the Oak Ridge National Laboratory (U.S. Department of Energy), Energy Performance Systems Inc., and the Electric Power Research Institute (EPRI).*

Table 1.—*Hybrid poplar trials by site and year*

Site	Planting year 1986	1987	1988	1989	1990	1991	1992	Total
Minnesota								
Aitkin	F	F	F	—	—	—	—	3
Alexandria	—	—	—	—	—	—	X*	1
Audubon	—	X	F	X	—	—	—	3
Belgrade	—	—	—	—	X*	—	—	1
Blackduck	—	—	—	—	—	X	—	1
Cloquet°	—	F	X	—	—	—	—	2
Crookston	—	—	—	—	—	—	X	1
Fairmont°	X*	F	X	—	—	—	X*	4
Gary	—	X	X	—	—	—	—	2
Grand Rapids	—	—	F	X	—	—	X	3
Granite Falls°	—	X	X	—	F	—	—	3
Hinckley°	—	F	F	—	—	—	—	2
Howard Lake°	R	R	R	—	—	—	—	3
Lamberton	—	—	X	—	—	—	—	1
Middle River	—	—	—	—	X*	—	—	1
Milaca°	—	X	F	X	—	—	—	3
NRRI	—	X*	X*	X*	—	—	—	3
Wisconsin								
Arlington	—	—	—	—	—	X	—	1
Ashland°	—	X	X	—	—	—	—	2
Hancock	—	—	—	—	—	X	—	1
LaCrosse	—	—	—	—	—	—	Xs	1
Lancaster	—	—	—	—	—	X	—	1
Mondovi°	—	X	X	—	Xs	—	—	3
Rice Lake	—	R	R	—	—	—	—	2
Rhinelander°	—	X	X	—	X	—	—	3
North Dakota								
Fargo°	—	X	F	F	—	—	—	3
South Dakota								
Sioux Falls°	—	X	X	—	X	Xr	—	3
Iowa								
Amana	—	—	—	—	—	—	F	1
Ames	—	F	—	—	X	—	—	2
Michigan								
East Lansing	—	X*	—	—	—	—	—	1
Total	3	18	18	5	7	4	6	61

X = existing site w/current data
X* = existing site wo/current data
F = failed site
R = site removed by owner
Xr = site replanted (combination of clones)
Xs = survival count only
° = sites with disease data reported in paper

clonal trials. We also list new clones added in recent trials, identify the clones that rank in the top 20 of all clones planted that year, and list all clones that have been deleted from the program because of poor performance.

MATERIAL AND METHODS

The plant material we are testing is predominantly hybrid poplar that originated from an old breeding program in the Northeast United States (NE clones) and from a commercial short-rotation fiber program in Ontario, Canada. Four commercially available clones widely planted in the region are also included: Imperial Carolina (also called Eugenei or DN34), Raverdeau (DN182), Robusta (DN17), and Siouxland. These three commercially available 'DN' clones plus a number of the recently introduced 'DN' clones from Canada were bred in Europe and then introduced into North America. Newer clones from tree breeders[b] were also added to this testing program, including *P. deltoides*[1,5], hybrid aspens (*P. tremuloides* x *P. tremula*)[2], *P. trichocarpa*[3], and introduced hybrid clones of variable genetic background[4,5]. (Numbers refer to breeders below.)

The plantations were established on actively farmed land. In most cases the land was in row crops, small grain, or hay the year before plantation establishment. Sites were thoroughly tilled before planting. Hybrid poplars were planted mostly as dormant unrooted cuttings 25 cm long. Only *P. deltoides*, hybrid aspen, and some hard-to-root hybrid poplars were planted as rooted stock. Trees were spaced at 2.4 x 2.4 m. Weeds were controlled by cultivation and herbicides for the first 3 years (Hansen *et al.* 1993). Some clones grew slowly or were severely impacted by disease, which allowed weed reinvasion. In those areas, spot weed control was continued after 3 years.

Each clone was planted in a single 16-tree plot within a given trial. For simplicity, we shall refer to all plant material as "clones," even though some plants were seedlings. (Refer to Appendix for parentage of numbered or named clones mentioned throughout the text.) Individual clonal plots were not replicated within a given trial, but were replicated across sites and through time at some sites. Therefore, the planting design allowed selection of superior broadly adapted clones, but allowed only limited statistical testing of within-location differences.

Tree survival (all 16 trees) and tree growth (center 4 trees, or alternates for missing trees) were measured each year after growth stopped. Tree heights were measured the first 2 years. D.b.h. was measured thereafter. Disease incidence was recorded in late summer. In later years, including 1992—the year of the data reported in this paper—d.b.h. was measured only on clones that had acceptable growth and reasonable resistance to Septoria canker. Clones with good tree form and growth and little or no stem breakage from Septoria canker were designated as "selected" (fig. 2). Clones with slow growth, winter dieback, severe canker and stem breakage, poor survival, or poor tree form were not evaluated further. The frequency at which a clone met the selection criteria across the region was judged a more valid basis for ranking clones than was the more objective d.b.h. measurements. Without the above criteria, clones with stem breakage from disease or with poor tree form usually originating from winter dieback often ranked quite high due to large lower stem diameters accompanied by good survival.

Plantations on drier sites (western sites—see figure 3) had fewer clones that met the selection criteria, and plantations on wetter sites (eastern sites and sites near Lake Superior) had more clones that met those criteria. Consequently test plantations were divided into "good" (eastern) and "harsh" (western) sites. Of the 14 plantations established in 1987-1988, 6 plantations were in the "harsh" category and 8 plantations were in the "good" category. Individual clones were

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[b]*Tree breeders providing plant material:*

1) *Carl Mohn, University of Minnesota, School of Forestry, 1530 N. Cleveland Ave., St. Paul, MN 55108.*
2) *Gary Wyckoff, University of Minnesota, North Central Forest Experiment Station, 1861 East Highway 169, Grand Rapids, MN 55744.*
3) *Don Riemenschneider, USDA Forest Service, North Central Forest Experiment Station, Forestry Sciences Laboratory, P.O. Box 898, Rhinelander, WI 54501.*
4) *Richard Cunningham, USDA Agricultural Research Service, P.O. Box 459, Mandan, ND 58554.*
5) *Bernie McMahon, Iowa State University, Department of Forestry, 251 Bessey Hall, Ames, IA 50011.*

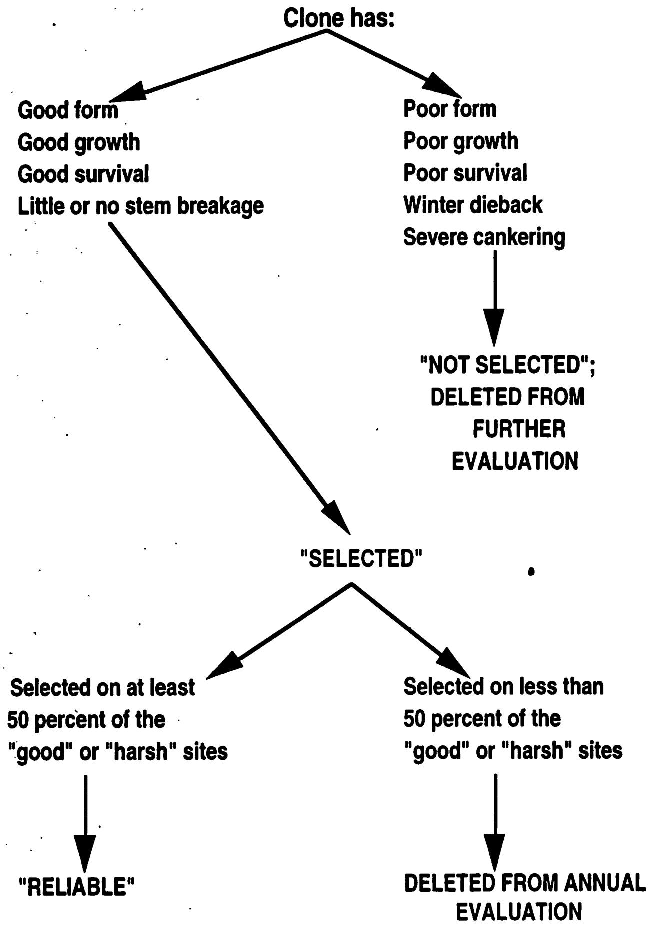

Figure 2.—*Flowchart for selecting* Populus *clones.*

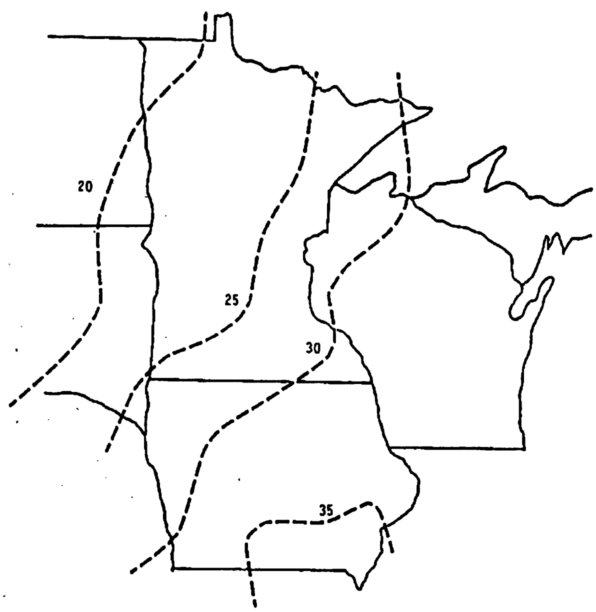

Figure 3.—*Regional precipitation gradient (inches).*

planted in either all or half of the trials within each category. Therefore, a particular clone had either three or six chances to be selected within the "harsh" site category and four or eight chances to be selected within the "good" site category. The percent of sites on which a clone was "selected" determined its clonal reliability. For example, if a clone was selected on six out of six planted sites, it had 100 percent reliability. Clones that did not have a stability score of at least 50 percent for either the "harsh" or "good" sites were deleted from further annual assessments.

Clones were assessed each year for the incidence and severity of the foliar diseases caused by *Melampsora* spp., and *Marssonina brunnea*, along with the foliar and stem diseases caused by *Septoria musiva*. In 1991 and 1992, the following rating classes, based on severity and extent, were used for rating foliage diseases: 0=none; 1=slight, few infected leaves; 2=moderate, infection throughout crown; 3=moderate, premature defoliation in lower crown; 4=severe, defoliation throughout crown. The following classes were used for rating stem disease: 0=none; 1=branch canker(s) only; 2=stem canker(s); and 3=stem dieback and breakage associated with cankers. In addition, the occurrence of winter dieback was also recorded.

RESULTS

Disease severity has increased over time at all sites. Branch and stem cankers caused by *S. musiva* developed on some highly susceptible clones by the second or third year after planting. Septoria canker has been the most damaging disease at all sites, resulting in stem breakage and tree death.

Septoria canker has been less severe at the northernmost sites near Fargo, Cloquet, and Ashland (fig. 4). Clones highly resistant to Septoria canker on good sites were, for the most part, more severely diseased on harsh sites (table 2). It was also evident that Septoria leaf spot was much more severe on harsh sites than on good sites. Exceptions to these patterns were clones NM2, NC5260, NE49, NE351, DN1, DN5, DN128, DN131, DN160, and DN173, where Septoria canker was more severe on good sites than on harsh sites. In addition, some clones exhibited

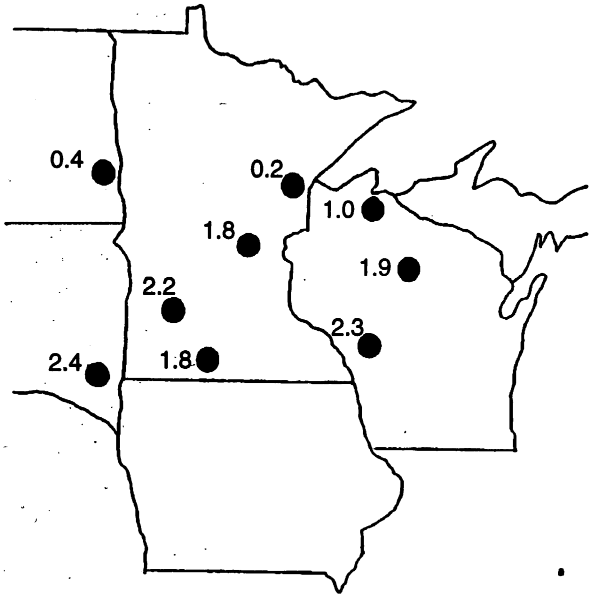

Figure 4.—*Mean severity of Septoria canker on susceptible clones.*

nearly the same level of disease severity on all sites. All diseases, except leaf rust, have been most severe on harsh sites.

Of the 91 clones planted in the 1987 and 1988 trials, 52 have been dropped from the program because they did not exhibit reasonable growth or disease resistance on even half of the "good" sites. The remaining 39 clones are ranked in order of declining reliability in table 3. Some clones that ranked high in resistance to Septoria canker in table 2 did not rank high in reliability because of slow growth. More clones were judged reliable on good than on harsh sites, but the same clones that performed best on harsh sites were among those most reliable on good sites. Nearly half of the 39 clones were 100 percent reliable on good sites. As site conditions (in this case primarily water availability) became less favorable, the number of reliable clones greatly decreased. Of the 39 clones, 25 clones on harsh sites did not meet the 50 percent reliability criterion in contrast to only 1 clone on good sites not meeting that criterion as determined by their frequency of being selected from all planted sites. The lack of clones adaptable to harsh sites but not to good sites (except for DN128) does not provide evidence that clones in this set are site specific, at least in regards to apparent drought tolerance.

There was a strong parentage effect on disease incidence and severity across all sites. Hybrids of pure *P. nigra* or with a parent from the section Tacamahaca (primarily 'NE' clones with *P. trichocarpa* or *P. maximowiczii* parentage) were among the most susceptible clones to Septoria canker (table 4), resulting in their removal from the program (table 5). Hybrids of *P. deltoides* x *P. nigra* (the *P.* x *euramericana* clones), *P. deltoides*, and *P. alba* parentage have been the most resistant to *S. musiva*. There was also an obvious effect of the clonal source. Most of the deleted clones were from the "NE"[c] set of clones (which includes eight DN clones), but only a few "DN" clones from other breeding programs were deleted (table 5).

Marssonina brunnea has been found most frequently on the *P.* x *euramericana* clones, but has not had a serious impact on any of them. Leaf rust, caused by *Melampsora* spp., develops earlier at northern sites, where the alternate host *Larix laricina* is present. Leaf rust has caused premature defoliation of the clone 'Northwest' at all sites each year.

The top eight clones in table 3 (above line) are judged suitable at this time for larger scale plantings. Clones DN17 and DN34 are commercially available and have been widely planted in the region for decades. Two other commercially available clones (DN182 and Sioux, 'Siouxland'), widely planted in the region, did not rank high on "harsh" sites in our tests, although they are suitable for the better sites in the region. Five other clones (DN2, DN5, DN70, NM6, and NE222) identified as reliable performers on "harsh" sites were released in 1993 to private nurseries and I45-51 was released in 1994. There was a strong parentage influence on clonal performance; *P. deltoides* x *P. nigra* (DN) is the parentage of nearly all "selected" clones in table 3, (compare with parentage list in Appendix). Exceptions were the two NM clones (*P. nigra* x *P. maximowiczii*) and clone 45-1, which is a pure *P. deltoides*.

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[c]*The "NE" clones originated from a very narrow genetic base of botanical garden specimens. Sometimes only one individual represented a parent species.*

Table 2.—Septoria leaf spot and canker on harsh and good sites

Poplar clone	Septoria leaf spot[a] Harsh site mean	Number of plots	Good site mean	Number of plots	Poplar clone	Septoria canker[b] Harsh site mean	Number of plots	Good site mean	Number of plots
45-1	0.5	6	0.6	8	NC5339	0.0	1	0.0	2
DN93	0.7	3	*	0	NE6	0.0	1	2.0	4
DN22	1.0	4	1.4	9	NE49	0.0	1	1.6	8
DN128	1.0	2	0.7	9	NM2	0.0	2	0.8	5
I476	1.0	2	1.3	4	45-1	0.0	6	0.0	8
NC5339	1.0	1	0.0	2	NC5260	0.3	6	1.1	9
NE6	1.0	1	2.3	4	DN74	0.5	2	0.6	5
NE299	1.0	1	1.8	6	NM6	0.7	3	0.4	5
NE386	1.0	1	2.0	4	DN1	1.0	2	2.0	5
DN181	1.3	4	0.8	5	DN5	1.0	2	2.2	5
DN2	1.3	6	1.1	9	DN128	1.0	2	1.6	9
DN17	1.3	6	1.2	9	DN177	1.0	2	1.4	5
NC5260	1.3	6	1.1	9	I476	1.0	2	0.8	4
NM6	1.3	3	1.0	5	DN2	1.2	6	1.3	9
DN34	1.5	5	0.9	9	DN17	1.2	6	1.2	9
DN74	1.5	2	1.2	5	DN34	1.2	5	0.2	9
DN177	1.5	2	1.4	5	I45/51	1.2	5	0.7	9
NE389	1.5	2	0.0	1	DN93	1.3	3	*	0
NM2	1.5	2	0.8	5	NE264	1.4	5	0.4	5
DN21	1.6	5	1.1	9	DN106	1.5	2	2.0	6
DN131	1.6	5	1.8	5	DN160	1.5	2	2.8	5
DN182	1.6	5	1.2	9	DN170	1.5	2	0.0	4
NE17	1.6	5	1.0	8	DN173	1.5	2	2.3	4
NE35	1.6	5	1.6	8	DN179	1.5	2	1.6	5
NE264	1.6	5	1.4	5	NE222	1.5	6	1.0	9
DN70	1.7	3	0.8	5	NE389	1.5	2	0.0	1
NE295	1.7	3	1.6	8	NW	1.5	2	0.5	4
DN55	1.8	5	1.1	9	DN18	1.6	5	1.8	9
I45/51	1.8	5	0.9	9	NE33	1.6	5	1.5	6
SIOUX	1.8	5	1.3	9	DN181	1.8	4	1.0	5
DN5	2.0	2	2.4	5	DN16	1.8	5	1.1	9
DN106	2.0	2	1.5	6	DN55	1.8	5	1.3	9
DN114	2.0	1	1.2	5	DN182	1.8	5	1.4	9
DN173	2.0	2	1.5	4	DN9	2.0	5	1.8	8
JACKII4	2.0	6	1.7	9	DN70	2.0	3	0.4	5
NE16	2.0	1	1.5	8	DN131	2.0	5	3.0	5
NE22	2.0	1	1.6	5	DN174	2.0	2	1.6	5
NE49	2.0	1	1.5	8	NE35	2.0	5	1.5	8
NE54	2.0	2	2.1	8	NE351	2.0	1	2.6	5
NE56	2.0	1	2.4	7	WIS5	2.0	1	0.0	5
NE265	2.0	2	1.3	7	JACKII4	2.2	6	2.1	9
NE283	2.0	1	2.4	5	DN21	2.2	5	1.0	9
NE293	2.0	1	1.0	1	DN38	2.3	3	1.2	5
WIS5	2.0	1	1.2	5	SIOUX	2.4	5	1.4	9
NE222	2.2	6	1.6	9	NE28	2.5	2	1.3	6
NE19	2.2	5	1.2	9	NE257	2.5	2	2.0	4
DN9	2.4	5	1.3	8	NE265	2.5	2	1.7	7
NE20	2.4	5	1.2	9	NE308	2.5	4	2.3	9

(table 2 continued on next page)

(table 2 continued)

Poplar clone	Septoria leaf spot[a] Harsh site mean	Number of plots	Good site mean	Number of plots
NE21	2.4	5	1.1	8
DN1	2.5	2	1.4	5
DN170	2.5	2	1.5	4
DN174	2.5	2	1.4	5
DN179	2.5	2	1.8	5
NE28	2.5	2	2.3	6
NE51	2.5	2	1.6	7
NE224	2.5	2	2.5	4
DN16	2.6	5	1.7	9
DN38	2.7	3	1.2	5
DTAC16	3.0	1	3.0	4
DTAC26	3.0	1	3.3	4
NE27	3.0	1	1.8	6
NE41	3.0	1	1.1	7
NE48	3.0	1	1.4	7
NE202	3.0	1	1.7	7
NE242	3.0	4	2.2	9
NE259	3.0	1	1.7	6
NE300	3.0	2	1.3	4
NE351	3.0	1	2.8	5
NE366	3.0	1	2.4	5
DN18	3.2	5	1.8	9
NE33	3.2	5	2.0	6
DTAC7	3.3	3	2.5	2
NE44	3.3	3	2.0	5
NE257	3.5	2	1.8	4
NE308	3.5	4	1.9	9
NE252	3.8	4	2.3	8
DN160	4.0	2	2.4	5
NE256	4.0	1	1.0	1
NE258	4.0	3	2.6	5
NW	4.0	2	3.5	4
DN28	*	0	2.2	5
HY5	*	0	*	0
HY11	*	0	*	0
NE10	*	0	1.7	6
NE37	*	0	1.5	6
NE42	*	0	1.7	6
NE47	*	0	2.0	6
NE50	*	0	2.0	1
NE52	*	0	1.0	1
NE225	*	0	2.0	1
NE237	*	0	1.0	1
NE285	*	0	2.0	1
NE387	*	0	1.7	7
Mean	2.2		1.6	

Poplar clone	Septoria canker[b] Harsh site mean	Number of plots	Good site mean	Number of plots
NE21	2.6	5	2.1	8
NE 258	2.7	3	2.8	5
NE242	2.8	4	1.8	9
NE252	2.8	4	1.9	8
NE17	2.8	5	2.3	8
DN22	3.0	4	1.2	9
DN114	3.0	1	1.6	5
DTAC7	3.0	3	2.5	2
DTAC16	3.0	1	2.8	4
DTAC26	3.0	1	2.3	4
NE16	3.0	1	1.6	8
NE19	3.0	5	2.4	9
NE20	3.0	5	2.1	9
NE22	3.0	1	1.4	5
NE27	3.0	1	2.5	6
NE41	3.0	1	2.0	7
NE44	3.0	3	1.2	5
NE48	3.0	1	1.6	7
NE51	3.0	2	2.4	7
NE54	3.0	2	2.1	8
NE56	3.0	1	2.0	7
NE202	3.0	1	1.9	7
NE224	3.0	2	3.0	4
NE256	3.0	1	3.0	1
NE259	3.0	1	1.5	6
NE283	3.0	1	1.2	5
NE293	3.0	1	3.0	1
NE295	3.0	3	1.6	8
NE299	3.0	1	1.8	6
NE300	3.0	2	1.3	4
NE366	3.0	1	2.4	5
NE386	3.0	1	3.0	4
DN28	*	0	2.2	5
HY5	*	0	*	0
HY11	*	0	*	0
NE10	*	0	1.5	6
NE37	*	0	1.7	6
NE42	*	0	1.8	6
NE47	*	0	2.0	6
NE50	*	0	3.0	1
NE52	*	0	3.0	1
NE225	*	0	2.0	1
NE237	*	0	0.0	1
NE285	*	0	3.0	1
NE387	*	0	1.6	7
Mean	2.0		1.6	

[a] *0 = none*
1 = slight, few infected leaves
2 = moderate, infection throughout crown
3 = moderate, premature defoliation in lower crown
4 = severe, defoliation throughout crown
* = *No surviving trees.*

[b] *0 = none*
1 = branch canker(s) only
2 = stem canker(s)
3 = stem dieback and breakage associated with cankers

Table 3.—*Ranking of 5- and 6-year-old clones* (planted 1987, 1988)*

Clone	Harsh sites Reliability	Harsh sites Sites	Good sites Reliability	Good sites Sites
	Percent	*Number*	*Percent*	*Number*
DN5	100	3	100	4
NM6	100	3	100	4
DN70	100	3	100	4
DN2	84	6	100	8
DN34	84	6	100	8
I45-51	84	6	100	8
DN17	66	6	100	8
NE222	66	6	87.5	8 **
DN38	66	3	100	4
DN177	66	3	100	4
DN170	66	3	100	4
I476	66	3	50	4
DN128	66	3	0	4
NE264	50	6	100	5
DN9	33	6	87.5	8
DN74	33	3	100	4
NM2	33	3	100	4
NC5377	33	3	100	4
DN16	33	6	75	8
45-1	33	6	75	8
DN174	33	3	75	4
DN131	33	6	62.5	8
DN173	33	3	50	4
DN179	33	3	50	4
DN55	16	6	100	8
DN182**	16	6	100	8
DN1	0	3	100	4
SIOUX**	16	6	87.5	8
DN181	0	3	75	4
NE35	16	6	62.5	8
NE295	0	6	62.5	8
DN18	16	6	50	8
DN106	0	3	50	4
NE49	0	6	50	8
DN114	0	6	50	8
NE300	0	3	50	4
NC5339	0	3	50	4
DTAC7	0	3	50	4
DTAC26	0	3	50	4

**Clones with >50 percent reliability on at least one of two clusters of sites, where "reliability" = the percent of sites on which a given clone exhibited good growth relative to the other clones and fair resistance to Septoria through age 5 or 6 years.*

***Clones in commercial production at this time (includes all clones above line).*

Table 4.—*Mean incidence of* Septoria musiva *by clonal parentage and site quality on 5- and 6-year-old trees*[1]

Parentage	n	Canker		Leaf spot	
		Good sites	Harsh sites	Good sites	Harsh sites
P. alba	1	0.0	0.0	0.0	1.6
P. deltoides	1	0.0	0.0	0.6	0.5
P. delt. x *nigra*	47	1.4	1.8	1.5	2.0
P. nigra	7	2.0	2.8	1.4	2.3
Tacamahaca	35	2.0	2.3	1.8	2.5
Overall	91	1.7	2.0	1.6	2.2

[1]***Canker***
0 = none
1 = branch(s) only
2 = stem canker(s)
3 = stem dieback or breakage associated with cankers

Leaf spot
0 = none
1 = slight, few infected leaves
2 = moderate, infection throughout crown
3 = moderate, premature defoliation in lower crown
4 = severe, defolication throughout crown

Table 5.—*Clones deleted from program (see Appendix for parentages)*

DN21*	NE242*
DN22	NE252*
DN28	NE256
DN93	NE257
DN160	NE258
NE6	NE259
NE10	NE265*
NE16	NE283
NE17*	NE293
NE19*	NE299*
NE20*	NE308*
NE21*	NE351
NE22*	NE366*
NE27	NE386
NE28*	NE387*
NE33*	NE389*
NE37	JACKII4*
NE41	DTAC16*
NE42*	NC5260*
NE44	NW
NE47	HY5
NE48*	HY11
NE51	
NE54	
NE56*	
NE202*	
NE224	

**Clone that grew well on at least one site, but on less than half of the "good" sites.*

New clonal material has been added to the tests each year. Some of the material planted since 1989 has shown good early performance relative to older material under test. New clones that ranked in the top 20 of all clones planted in a specific year are listed in table 6. Note that most new selections, including all the *P. deltoides*, were planted as rooted stock and therefore had an initial height advantage over unrooted stock.

DISCUSSION

Disease susceptibility among clones was expressed early, usually by the second year, at most of the planting sites. Clones susceptible to Septoria canker differ in the incidence of stem breakage. Some clones have partially callused over the cankers and may survive the projected rotation of 10 years. Tree form and fiber quality, however, have been adversely affected. Trees severely affected by Septoria canker may also be predisposed to other damaging agents, such as decay fungi, wood-boring insects, and wind breakage.

Premature defoliation caused by foliage pathogens can increase the risk of winter dieback and reduction in overall tree vigor and productivity. Foliar pathogens, such as *S. musiva* and *M. brunnea*, overwinter on fallen infected leaf debris, and can rapidly build to epidemic populations given favorable environmental conditions in the

Table 6.—*Newer planting stock in the top 20 ranked clones each planting year (ranked in terms of selection frequency based on early disease resistance and height growth). Not all clones were planted each year. (See Appendix for parentages)*

1989 (3 sites)	1990 (2 sites)	1991 (5 sites)	1992 (2 sites)
NE225**	DN132	DN154	DN117.53
NE237**	DN154	DN164	DN107.14
DIPL*	DN164	IS31*	IS31*
	D101*	NC5339*	NC5339*
	D102*	D111*	DN154
	D103*	D113*	DN164
	D104*	D115*	Tricho
	D105*	D117*	D103*
	D108*	D119*	D104*
	D109*	D121*	D105*
	D110*	D122*	D108*
	D111*	180-1	D111*
	D112*		D112*
	D113*		D114*
	D118*		D116*
	D122*		D118*
	D124*		D122*
	D125*		D124*
	180-1		
	T50-197		

** Rooted stock.*
*** Planted only in 1989.*

spring and early summer (Ostry and McNabb 1990). Thorough cultivation in the early stages of plantation management may minimize inoculum levels within the plantation. However, inoculum originating from outside the planting or from infected debris in older plantings that have not been cultivated, increases the risk of infection and damage to susceptible clones.

Clones that did not make the 'selected list' (table 3) but that grow well on at least one site will continue to be monitored infrequently in the future. Any that remain vigorous and fast-growing for the entire rotation may warrant further testing as a potential site-specific clone. Most clones tend to perform consistently from site to site (Hansen *et al.* 1992). But good performance by a clone on only one or a few sites may reflect a fortuitous set of climatic or cultural circumstances, or it may indicate a site-specific clone. However, identifying site-specific clones requires replicated plantings at the multiple sites of interest, replicated plantings through time (to differentiate climatic vs. soils effects), and rigorous uniform cultural tending spatially and temporally. This field testing period encompassed 2 years of record drought (1988-1989), which varied widely in severity across the region, further complicating the indentification of site-specific clones. Identifying such clones under these naturally variable conditions is beyond the scope of our testing program.

We could identify a group of clones that had reasonable disease resistance and biomass production across the range of sites. Clones that performed well on harsh sites also performed well on good sites; however, clones that performed well on good sites often were affected more severely by disease on harsh sites.

Results presented from these trials are interim, even for the oldest clones being tested. The trees are little more than halfway to their projected 10-year rotation. In addition, pathogen virulence can change, undoing years of field testing results. Thus, there may be significant changes in the future.

Many potentially high-yielding clones we evaluated are too vulnerable to damage by one or more diseases to be planted on a large scale. There is a critical need to develop and test new poplar clones in the north-central and northeastern regions of the United States to identify clones that can resist disease better and grow more rapidly than those currently available.

These hybrid trials will provide information for the next 5 to 10 years about which poplar species and clones are best suited for large-scale biomass plantations. The development of improved selections will be accelerated by the shift to testing poplar clones that have been selected and bred within the region.

RECOMMENDATIONS

The following general recommendations for selecting poplars can help minimize disease problems and increase plantation productivity:

1. Plant clones that have been grown in the region for a long time and have performed well. They are:

DN34	(Imperial Carolina, Eugenei)
DN17	(Robusta)
DN182	(Raverdeau) (not suitable for harsh sites)

2. Plant only limited acreage with clones that have not been field tested extensively. Some clones newly introduced into the region have the potential for greater yields, but have greater risk because of short-term testing. These "newer" clones released for limited planting are:

DN2	NM6
DN5	NE222
DN70	I45-51

3. Select clones based on their performance over a minimum of half of the projected rotation. Do not assume that because a tree grew 8 feet the first year and is healthy that it is the "super tree" for your area. Disease symptoms may not occur until trees are 4 years of age or older.

4. Select clones based on their performance in plantations. Open-grown trees are not a good indication of plantation performance. For example, clones such as Siouxland that grow well in shelterbelts are more disease prone in plantations.

ACKNOWLEDGMENTS

This research is a result of the long hours and conscientious effort of Greg Herman, often under exceedingly difficult conditions, to establish and tend this widespread regional test network. Thanks also go to Kathy Ward, who helped collect and summarize the data, and to Terry Strong, who developed the original measurement plots and data compilation methods.

LITERATURE CITED

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

Hansen, Edward; Heilman, Paul; Strobl, Silvia. 1992. **Clonal testing and selection for field plantations**. In: Mitchell, C.P.; *et al.*, eds. Ecophysiology of short rotation forest crops. London and New York: Elsevier Applied Science: 124-145.

Hansen, Edward A.; Netzer, Daniel A.; Tolsted, David N. 1993. **Guidelines for establishing poplar plantations in the north-central U.S.** Res. Note NC-363. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 6 p.

Ostry, Michael E.; McNabb, Harold S., Jr. 1985. **Susceptibility of *Populus* species and hybrids to disease in the north central United States**. Plant Disease. 69: 755-757.

Ostry, Michael E.; McNabb, Harold S., Jr. 1986. ***Populus* species and hybrid clones resistant to Melampsora, Marssonina, and Septoria.** Res. Pap. NC-272. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 6 p.

Ostry, Michael E.; McNabb, Harold S., Jr. 1990.
Minimizing disease injury to hybrid poplars.
Journal of Environmental Horticulture. 9: 96-98.

APPENDIX
HYBRID POPLAR CLONES UNDER TEST

Listings show only new clones added each year

1987/88 trials (5- and 6-year-old):

Clone	Parentage
NC-5260	*P. tristis* x *P. balsamifera* (Tristis)
NC-5339	*P. alba* x *P. grandidentata* (Crandon)
NC-5377	*P. deltoides* x *P. nigra* (Wisconsin 5)
NE-6	*P. nigra* x *P. laurifolia*
NE-10	*P. nigra* x *P. trichocarpa*
NE-16	*P. charkowiensis* x *P. deltoides*
NE-17	*P. charkowiensis* x *P. caudina*
NE-19	*P. charkowiensis* x *P. caudina*
NE-20	*P. charkowiensis* x *P. caudina*
NE-21	*P. charkowiensis* x *P. caudina*
NE-22	*P. charkowiensis* x *P. incrassata*
NE-27	*P. charkowiensis* x *P. berolinensis*
NE-28	*P. charkowiensis* x *P. trichocarpa*
NE-33	*P. angulata* x *P. berolinensis*
NE-35	*P. angulata* x *P. plantierensis*
NE-37	*P. sargentii* x *P. berolinensis*
NE-41	*P. maximowiczii* x *P. trichocarpa*
NE-42	*P. maximowiczii* x *P. trichocarpa*
NE-44	*P. maximowiczii* x *P. berolinensis*
NE-47	*P. maximowiczii* x *P. berolinensis*
NE-48	*P. maximowiczii* x *P. berolinensis*
NE-49	*P. maximowiczii* x *P. berolinensis*
NE-51	*P. maximowiczii* x *P. plantierensis*
NE-54	*P. candicans* x *P. berolinensis*
NE-56	*P. rasumowskyana* x *P. caudina*
NE-202	*P. deltoides* x *P. trichocarpa*
NE-222	*P. deltoides* x *P. caudina*
NE-224	*P. deltoides* x *P. caudina*
NE-242	*P. deltoides* x *P. plantierensis*
NE-252	*P. angulata* x *P. trichocarpa*
NE-256	*P. angulata* x *P. trichocarpa*
NE-257	*P. angulata* x *P. trichocarpa*
NE-258 (5334)	*P. angulata* x *P. trichocarpa*
NE-259	*P. angulata* x *P. incrassata*
NE-264	*P. angulata* x *P. volga*
NE-265	*P. angulata* x *P. volga*
NE-283	*P. nigra* x *P. laurifolia*
NE-293	*P. betulifolia* x *P. volga*
NE-295	*P. betulifolia* x *P. volga*
NE-299 (5331)	*P. betulifolia* x *P. trichocarpa*
NE-300	*P. beutifolia* x *P. trichocarpa*
NE-308	*P. charkowiensis* x *P. incrassata*
NE-351	*P. deltoides* x *P. caudina*
NE-366	*P. deltoides* x *P. caudina*
NE-386 (5363)	*P. candicans* x *P. berolinensis*
NE-387 (5262)	*P. candicans* x *P. berolinensis*
NE-389	*P. deltoides* x *P. caudina*
DN-1	*P. deltoides* x *P. nigra*
DN-2	*P. deltoides* x *P. nigra*
DN-5	*P. deltoides* x *P. nigra*
DN-9	*P. deltoides* x *P. nigra*
DN-16	*P. deltoides* x *P. nigra*
DN-17	*P. deltoides* x *P. nigra* (Robusta)
DN-18	*P. deltoides* x *P. nigra*
DN-21	*P. deltoides* x *P. nigra*
DN-22	*P. deltoides* x *P. nigra*
DN-28	*P. deltoides* x *P. nigra*
DN-34 (5326)	*P. deltoides* x *P. nigra* (Eugenei, Imperial Carolina, Norway)
DN-38	*P. deltoides* x *P. nigra*
DN-55	*P. deltoides* x *P. nigra*
DN-70	*P. deltoides* x *P. nigra*
DN-74	*P. deltoides* x *P. nigra*
DN-93	*P. deltoides* x *P. nigra*
DN-106	*P. deltoides* x *P. nigra*
DN-114	*P. deltoides* x *P. nigra*
DN-128	*P. deltoides* x *P. nigra*
DN-131	*P. deltoides* x *P. nigra*
DN-160	*P. deltoides* x *P. nigra*
DN-170	*P. deltoides* x *P. nigra*
DN-173	*P. deltoides* x *P. nigra*
DN-174	*P. deltoides* x *P. nigra*
DN-177	*P. deltoides* x *P. nigra*
DN-179	*P. deltoides* x *P. nigra*
DN-181	*P. deltoides* x *P. nigra*
DN-182	*P. deltoides* x *P. nigra* (Raverdeau)

APPENDIX (cont.)

Clone	Parentage
I-45/51	*P. deltoides* x *P. nigra*
I-476 (4879)	*P. deltoides* x *P. nigra*
45-1	*P. deltoides*
Jackii4	*P. balsamifera* x *P. deltoides*
NW	*P. deltoides* x *P. volga* (Northwest)
Sioux	*P. deltoides* x *P. nigra* (Siouxland)*
DTAC-7	*P. deltoides* x *P. trichocarpa*
DTAC-16	*P. deltoides* x *P. trichocarpa*
DTAC-26	*P. deltoides* x *P. trichocarpa*
HY-5	*P. trichocarpa* x *P. deltoides*
HY-11	*P. trichocarpa* x *P. deltoides*
NM-2	*P. nigra* x *P. maximowiczii*
NM-6	*P. nigra* x *P. maximowiczii*
1989 trials:	
NE50	*P. maximowiczii* x *P. berolinensis*
NE52	*P. maximowiczii* x *P. plantierensis*
NE225	*P. deltoides* x *P. caudina*
NE237	*P. deltoides* x *P. volga*
NE285	*P. nigra* x *P. trichocarpa*
TRIP	*P. tremuloides* x *P. tremula*
DIPL	*P. tremuloides* x *P. tremula*
1990 trials:	
DN132	*P. deltoides* x *P. nigra*
DN154	*P. deltoides* x *P. nigra*
DN164	*P. deltoides* x *P. nigra*
D101	*P. deltoides*
D102	*P. deltoides*
D103	*P. deltoides*
D104	*P. deltoides*
D105	*P. deltoides*
D108	*P. deltoides*
D109	*P. deltoides*
D110	*P. deltoides*
D111	*P. deltoides*
D112	*P. deltoides*
D113	*P. deltoides*
D114	*P. deltoides*
D118	*P. deltoides*
D122	*P. deltoides*
D124	*P. deltoides*
D125	*P. deltoides*
180-1	*P. deltoides*
T50-197	*P. trichocarpa* x *P. deltoides*

Clone	Parentage
1991 trials:	
DN173	*P. deltoides* x *P. nigra*
D115	*P. deltoides*
D117	*P. deltoides*
D119	*P. deltoides*
D121	*P. deltoides*
178-4	*P. deltoides*
193-5	*P. deltoides*
14044	*P.* x Xpetroskyana
14165	*P.* 'Melville'
14174	*P. balsamifera* x *P. simonii* (38P38)
14271	*P. deltoides* x *P. nigra* 'Italica' #78102
14390	*P.* xp., PX71-W131 OP progeny of 'Walker'
13277	*P. trichocarpa*
13279	*P. trichocarpa*
13280	*P. trichocarpa*
13281	*P. trichocarpa*
IS-31	*P. deltoides* x *P. nigra***
FARGO	*P. deltoides* (local source)
19-89	*P. tremuloides* x *P. tremula*
21-89	*P. tremuloides* x *P. tremula*
1992 trials:	
42.7	*P. deltoides*
107.14	*P. deltoides* x *P. nigra*
117.53	*P. deltoides* x *P. nigra*
9252.46	*P. deltoides*
7300501	*P. deltoides*
8000113	*P. deltoides*

**Siouxland is a wildtype selection thought to be a* P. deltoides *x* P. nigra *cross.*

***IS-31 is a wildtype selection by Dr. Richard Hall thought to be a* P. deltoides *x* P. nigra *cross.*

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Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

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