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# Establishing Intensively Cultured Hybrid Poplar Plantations for Fuel and Fiber

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# SUMMARY

Intensive culture is the application of agronomic principles and practices for the attainment of forestry objectives. The system is similiar to mechanized farming and is characterized by high energy inputs, high biomass yields, and complete mechanization. Intensive culture includes (a) establishing plantations using thorough site preparation, weed control, and mechanized planting, (b) short rotation, (c) close spacing, (d) fast growing hybrids or genetically improved trees, (e) fertilization, (f) irrigation, and (g) insect and disease management. Some of the factors such as proper site preparation and weed control are essential to successful plantation establishment. Other factors may not be critical by themselves but must be incorporated to attain maximum growth. This paper describes a step-by-step procedure for establishing commercial size intensively cultured plantations of hybrid poplar and summarizes the state-of- knowledge as developed during 10 years of field research at Rhinelander, Wisconsin.

## ENGLISH–METRIC CONVERSIONS

| Multiply | by | to obtain |
|---|---|---|
| inches | 25.4 | millimeters |
| feet | 0.3048 | meters |
| miles | 1.6093 | kilometers |
| pounds/acre | 1.1208 | kilograms/hectare |
| tons/acre | 2.2417 | tonne/hectare |
| gallons | 3.7853 | liters |

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# Establishing Intensively Cultured Hybrid Poplar Plantations for Fuel and Fiber

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Intensive culture of trees has gained much interest the last decade due to projected fiber shortages, competing demands for forest land, and most recently the use of wood for energy. Intensive culture has varied meaning in forestry. Intensive culture as referred to in this report includes (a) establishing plantations using thorough site preparation, weed control and mechanical planting, (b) short rotation, (c) close spacing, (d) fast growing hybrids or genetically improved trees (*Populus* in our case), (e) fertilization and (f) irrigation. Of these, close spacing is not necessarily an essential requirement of intensive culture, and irrigation is not expected to be widely used because of its high cost. The forest management system of intensively cultured hybrid poplar (ICHP) plantations is the application of agronomic principles and practices to attain forestry objectives (fig. 1). The system is similar to mechanized farming and is characterized by high energy inputs, high biomass yields, and complete mechanization. It is designed for application on marginal or unused agricultural land.

Figure 1.—*Four-year-old intensively cultured hybrid poplar plantations of clone NE-299 (NC-5331) at 6 x 6 ft spacing.*

Knowledge on establishing ICHP plantations is in its infancy. Only in the last few years has knowledge progressed to the point where commercial sized plantations can be successfully established. But even now the success of establishing large plantations is not assured for a variety of sites.

Research at Rhinelander, Wisconsin, on ICHP plantations began in 1970. Research on plantation establishment accelerated greatly in 1977 with initiation of 5 years of funding support from the Department of Energy (at that time the Energy Research and Development Administration). This paper describes a step-by-step procedure for establishing commercial size ICHP plantations and summarizes the state-of-knowledge as developed at Rhinelander. Our intent is to provide useful guidelines for practitioners of intensive culture. As such it updates our previous recommendations (Hansen *et al.* 1979). For purpose of this report we refer to the "plantations establishment period" as that period of time from initial site preparation up through the second year of tree growth at which time the tree canopy closes in close-spaced plantations.

These guidelines are based on the current best practices (although in some instances several similar practices are possible with little difference in effectiveness from one another). Alternatives to the recommended practices, supporting data, and discussion are presented in subsequent sections. It is to be expected that the following guidelines will be modified in the future as more information is acquired.

This plantation establishment system was developed and therefore is adapted to the soil and climatic conditions at the Harshaw Forestry Research Farm near Rhinelander, Wisconsin. The prescribed treatments may have to be adjusted for other sites based on judgement as to how much the site differs from that at Rhinelander. Therefore, we will briefly describe the Rhinelander site to serve as a base or starting point.

**Soils:** The land was farmed for about 50 years and potatoes were the major crop. It is level to gently rolling with some potholes that contain water for a few days to weeks in early spring or after extraordinary summer rains. Soils are Padus and Stambaugh series grading from a silt loam to a sandy loam. A plow layer at 10 inches separates the topsoil from a sand to gravelly sand subsoil that extends down more than 10 feet. Almost all the *Populus* roots are above the plow layer even though deeper rooting does not appear to be restricted. A few roots of 3- and 4-year-old trees do reach depths of 3 feet and they may be important in extracting the available soil moisture during late summer. Soil moisture is almost always fully recharged in early spring. The soil in the plow layer is high in potassium and phosporus (500 pounds per acre P and 275 pounds per acre K); has a pH range from 5.4 to 6.3; and averages 3.3 percent in organic matter.

**Climate:** The ground is free of snow for any significant duration from April to mid-November. The growing season for *Populus* is May through September, although there is a 40 percent probability that below freezing temperatures will occur after May 22 and before September 20 (Wisconsin Department of Agriculture 1961). Light frosts frequently occur as late as mid-June and as early as mid-August. Mean monthly temperatures during June, July, and August range from 64 to 68°F; the mean monthly January temperature (the coldest month) is 13°F. Rainfall averages 31 inches per year and monthly averages range from 3.75 to 4.70 inches during the major growing period of June, July, and August.

**Vegetation:** Both bigtooth aspen, *P. grandidentata,* and quaking aspen, *P. tremuloides,* are native to the area; cottonwood, *P. deltoides,* is not—the northernmost limit of its range in Wisconsin ends about 50 miles south of Rhinelander. The major weed competitor on "old field" sites is quack grass *Agropyron repens.* Other important weeds are yellow rocket *Brassica* spp. (winter annual), pigweed *Amaranthus* spp., lambsquarters *Chenopodium album,* white cockle *Lychnus alba,* and marestail *Conyza canadensis* (perennials). These weeds are different from the competitors normally found in forest plantations.

# PLANTATION ESTABLISHMENT PRESCRIPTION

*Populus* species used in ICHP culture are from the Aigeiros or Tacamahaca sections, which are easily propagated by stem cuttings. Species from the Leuce section (aspens) are not used because of the difficulty of rooting stem cuttings.

Hybrid poplars are propagated by means of vegetative cuttings. The plants thus produced are genetically identical to the parent and are collectively called the "clone". The proper clones to plant on a particular field depend on the soil and climate and are best determined by clonal comparison trials done under similar field conditions.

## Site Preparation—Weed Control

Initial site preparation including control of competing weeds is essential for successful establishment of ICHP plantations. Begin site preparation in the fall prior to spring planting. Add lime as necessary to raise soil pH above 5.5. Mow grasses and weeds in August or early September to reduce heavy vegetation and allow grasses time to regrow. Apply a postemergent herbicide such as glyphosate (Roundup) at 1.5 pounds active ingredients (ai) per acre in late September or early October to kill weeds and grasses—especially quack grass. One week later disc the sod and then moldboard plow to the 10 inch depth (fig. 2). In the spring, disc the site and just before planting apply a preemergent herbicide such as linuron or diuron at 1.5 pounds ai per acre to control germinating annual weed and grass seed (fig. 3). These herbicides control weeds for the first 4 to 8 weeks after planting and allow time for the plantation to become established.

With initial good weed control using these practices, we have found no advantage to tree growth from further weed control during the first growing season in fertilized and irrigated plantations. At spacings such as 3.3 x 3.3 feet or narrower, weeds are shaded out by the middle to end of the second year under conditions of good growth, and weed control is no longer needed. At wider spacings, particularly in unirrigated and unfertilized plantations, further weed control will be beneficial.

Figure 2.—*Site preparation includes plowing and discing to control early weed competition and to permit mechanized planting.*

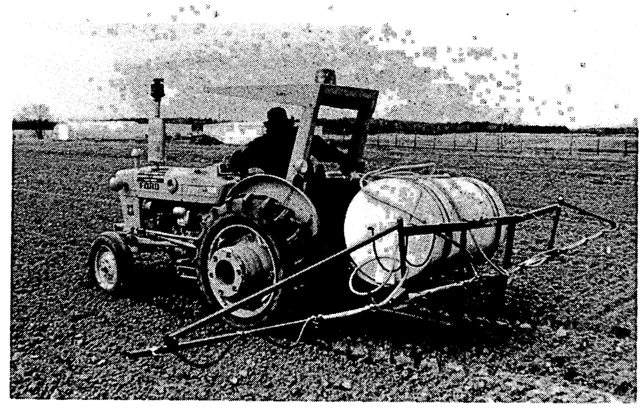

Figure 3.—*Spraying linuron just before planting prevents weed growth for 4 to 6 weeks.*

# Clonal Selection

The results of 5 years of clonal tests at Rhinelander can be used as a guideline for clonal selection (table 1). In general northeast (NE) clones grow better in northern Wisconsin than do Euramericana (DN) clones. However, information is not adequate at this time to recommend particular clones for specific sites with guaranteed success. It is advisable to make local trials to select fast growing clones that root easily, are resistant to insects and disease, and are adapted to the local climate and soils. A group of clones, as compared to a single clone, will reduce the risk of large scale plantation losses.

Clonal trials can consist of a few trees per clone (10 is sufficient) with just one clone per row to avoid mixing clones. It is not necessary to replicate plantings for clonal selection. It is far more beneficial to test additional clones or to test them over the range of planting sites than to improve selection by more precise between-clone comparisons. Clonal selection trials should be maintained for as long as a planting program exists, because these trees are oldest and may show impending problems before they develop in the plantations.

# Cutting Production

Planting material most frequently used is dormant unrooted hardwood cuttings obtained from 1-year-old stump sprouts. The production, collection, and handling of cuttings in covered next.

## CUTTING ORCHARD MANAGEMENT

Cuttings to establish ICHP plantations are produced in cutting orchards or stool beds. A 3.3 x 3.3 foot spacing seems to be satisfactory from the standpoint of high cutting production and good natural weed control from shading. A cutting orchard with 3.3 x 3.3 foot spacing producing an average of 30 cuttings per stump would provide sufficient cuttings to plant an area 120 times larger using a planting spacing of 6.6 x 6.6 feet. An important factor in the establishment of ICHP plantations is to use vigorous, disease- and insect-free, planting stock. Ideally, cutting orchards should not be established directly adjacent to natural or planted stands of poplars where pests may build up and eventually invade the cutting orchard. Cultural measures for cutting orchards such as site preparation, weed control, fertilization, and irrigation are the same as for production plantations and are discussed in the sections that deal with those topics.

## HARVESTING

Trees in the cutting orchard should be allowed to grow for 2 years to develop a strong root system and then harvest the stump sprouts or whips annually. Cut 1-year-old whips 4 to 6 inches above the ground between December and March. We have cut these whips successfully using hand pruning shears, a gasoline powered brush-clearing saw, and a tractor mounted sickle bar, but they can be cut by any method (fig. 4).

Table 1.—*Clonal ranking based on index of volume $D^2H$ (where D is the breast height diameter and H is tree height) of unirrigated and unfertilized 5-year-old trees at Harshaw Forestry Research Farm near Rhinelander, Wisconsin. Any two $D^2H$ not next to a common line are significantly different. Ranking for some of the same clones based on irrigated and fertilized 4-year-old height from plots on a sandy nursery site at Rhinelander are also shown.*

| Clone: Original number | Clone: North Central number | Parentage[2] | Height | $D^2H$ | Survival | Nursery[1] ranking |
|---|---|---|---|---|---|---|
| | | | *Feet* | | *Percent* | |
| NE-386 | 5263 | *P.* 'Candicans' x (*P.* x *berolinensis*) | 23.7 | 46.1 | 81 | 2 |
| NE-387 | 5262 | *P.* 'Candicans' x (*P.* x *berolinensis*) | 23.5 | 34.1 | 88 | 3 |
| NE-252 | 5334 | *P. deltoides* var. *angulata* x *P. trichocarpa* | 22.6 | 34.1 | 75 | |
| NE-372 | 5266 | *P. deltoides* var. *angulara* x *P. trichocarpa* | 22.2 | 28.7 | 62 | 8 |
| NE-298 | 5332 | *P. nigra* var. *betulifolia* x *P. trichocarpa* | 21.0 | 27.1 | 91 | 4 |
| NE-375 | 5264 | *P. deltoides* var. *angulata* x *P. nigra* var. *plantierensis* | 21.0 | 24.2 | 78 | |
| NE-1 | 5272 | (*P. nigra* x *P. laurifolia*) 'Strathglass' | 21.9 | 23.4 | 94 | |
| — | 5339 | (*P. alba* x *P. grandidenta*) 'Crandon' | 18.9 | 18.7 | 66 | |
| DN-28 | 5325 | *P.* x *euramericana* 'Ostia' | 18.1 | 16.1 | 25 | |
| — | 5377 | *P.* x *euramericana* 'Wisconsin #5' | 20.2 | 15.2 | 100 | 6 |
| DN-34 | 5326 | *P.* x *euramericana* 'Eugenei' | 18.4 | 11.1 | 66 | 5 |
| DN-30 | 5323 | *P.* x *euramericana* 'Canada Blanc' | 17.4 | 9.9 | 94 | |
| — | 5351 | *Populus* spp. | 15.9 | 8.7 | 94 | |
| — | 5260 | (*P. tristis* x *P. balsamifera*) 'Tristis #1' | 15.3 | 8.2 | 88 | 1 |
| — | 5258 | *Populus* spp. | 16.3 | 6.8 | 97 | 7 |
| — | 9922 | *Populus* spp. | | (3) | | |
| I-476 | 4879 | *P.* x *euramericana* | | (3) | | |
| — | 9921 | *Populus* spp. | | (3) | | |
| NE-299 | 5331 | *P. nigra* var. *betulifolia* x *P. trichocarpa* | | (3) | | |
| NE-388 | 11505 | *P. maximowiczii* x *P. trichocarpa* | | (3) | | |
| P1343437 | 4877 | *P. alba* | | (4) | | |
| I-214 | 4878 | *P.* x *euramericana* | | (4) | | |
| — | 5261 | (*P. deltoides* var. *occidentalis* x *P. balsamifera*) 'Northwest' | | (4) | | |
| NE-374 | 5365 | *P. deltoides* var. *angulata* x *P. trichocarpa* | | (4) | | |
| NE-366 | 5267 | *P. deltoides* x *P. nigra* var. *caudina* | | (4) | | |
| NE-216 | 5268 | *P. deltoides* x *P. trichocarpa* | | (4) | | |
| NE-19 | 5271 | *P. nigra* var. *charkowiensis* x *P. nigra* var. *caudina* | | (4) | | |
| FNS-4452 | 5273 | *P. deltoides* 'Walker' | | (4) | | |
| D-37 | 5318 | *P. deltoides* 'D-37' | | | | |
| D-45 | 5319 | *P. deltoides* | | (4) | | |
| JAC-6 | 5320 | *P. deltoides* x *P. balsamifera* | | (4) | | |
| DN-31 | 5321 | *P.* x *euramericana* 'Negrito de Granada' | | (4) | | |
| I-78-B | 5322 | *P.* x *euramericana* 'Jacometti' | | (4) | | |
| DN-26 | 5324 | *P.* x *euramericana* 'B-56' | | (4) | | |
| I-45/51 | 5328 | *P.* x *euramericana* 'I-45/51' | | (4) | | |
| NE-348 | 5335 | *P. deltoides* x *P. trichocarpa* | | (4) | | |
| — | 7168 | *P. balsamifera* | | (4) | | |
| NE-310 | 9927 | *P. nigra* var. *charkowiensis* x *P. nigra* var. *caudina* | | (4) | | |
| NEA-238 | 9980 | *P. deltoides* x *P. nigra* 'Volga' | | (4) | | |

[1]Data from Meldahl, 1979 tables 12-20.
[2]Names according to Dr. Dickman, Department of Forestry, Michigan State University, East Lansing, MI 48824.
[3]Clones not ranked because they were not included in the comparative tests. Based on growth in large plantations and other 2-year-old clonal trials, clone 9922 would probably rank at or near the top clones, I-476, 9921, and NE-299 would rank in the top seven, and NE-388 would not be suitable due to recurrent severe frost damage.
[4]Unsuitable clones due to frost damage and/or disease.

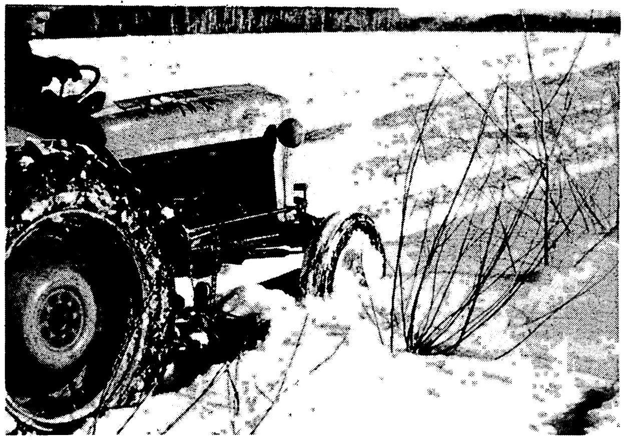

Figure 4.—*Cutting whips with a tractor mounted sickle bar.*

Remove and discard all branches and the lower 2 inches of the whips. Use a table saw, band saw, or radial-arm saw to cut the whip into 8-inch long cuttings up to a minimum diameter of about 0.2 inch. Discard the remaining tip.

## GRADING

For best early survival and growth select only those cuttings that meet the following minimum standards:

1. A cutting diameter greater than 3/8 inch. Generally, the larger the diameter, the better the field performance.
2. No evidence of mechanical damage such as stripped bark, split or crushed ends, or broken or missing buds near the top of the cutting.
3. No signs of insect or disease infestation such as galls, lesions, eggs, borers, or fruiting bodies.
4. Green inner bark and no desiccated or shrivelled outer bark.

## PACKAGING AND STORAGE

Because large-scale harvesting and processing of dormant hardwood cuttings is best done in the winter, the cuttings must be stored for several months before they can be planted.

### Packaging

Store cuttings in polyethylene bags. To facilitate inventory, place approximately the same number of cuttings in each bag—taking care to have buds pointing in the same direction—and tie the bag with a wired label tag for clonal identification. Then place several of these bags in a larger polyethylene bag and seal as before. Double wrapping the cuttings is important to prevent desiccation.

### Temperature

Store cuttings at 25° to 30°F to prevent premature sprouting and rooting. However, for periods up to a maximum of about 3 months, newly harvested cuttings can be stored at temperatures as warm as 37°F.

## PREPLANT TREATMENT

Treating cuttings before field planting as described below improves survival and early growth, especially if hot, dry weather conditions are expected during the first few weeks after planting. These treatments prepare the cutting so that it is ready to begin root and shoot growth soon after planting. However, these treatments must be done carefully, because if carried too far they may result in reduced vigor or survival.

### Raising Storage Temperature

Cuttings that have been stored at below freezing temperatures should be allowed to "warm" slightly at temperatures of about 37°F for 1 to 2 weeks before soaking.

### Soaking

Soak dormant hardwood cuttings in tap water as follows:

1. Place the bundles, with buds pointing up, in containers of water maintained at about 60°F. The temperature may be as low as 40°F but this will prolong the soaking period. Do not remove the cuttings from the plastic bags, just puncture the bottom and top of the bag to admit water.
2. Immerse the cuttings to the same depth as they will be planted, i.e., about 3/4 of their length.
3. Do not expose the cuttings to light for extended periods of time to avoid premature bud break.
4. Soak cuttings for 7 to 10 days until small swellings or bumps appear on the bark surface (fig. 5). These are the developing roots. Leaf buds should be dormant or only slightly developed as indicated by a slight greening. This is an ideal stage for planting. Cuttings should not be allowed to develop roots and expand leaves.
5. If cuttings cannot be planted within a day or two after the above stage is reached, return them to cold storage (32°F) and pack the cutting bundles in crushed ice to prevent further root and shoot development. This method will maintain the cuttings in good condition for at least 2 weeks.

## TRANSPORTING

As with any planting material it is important to avoid damaging the cuttings from exposure to ex-

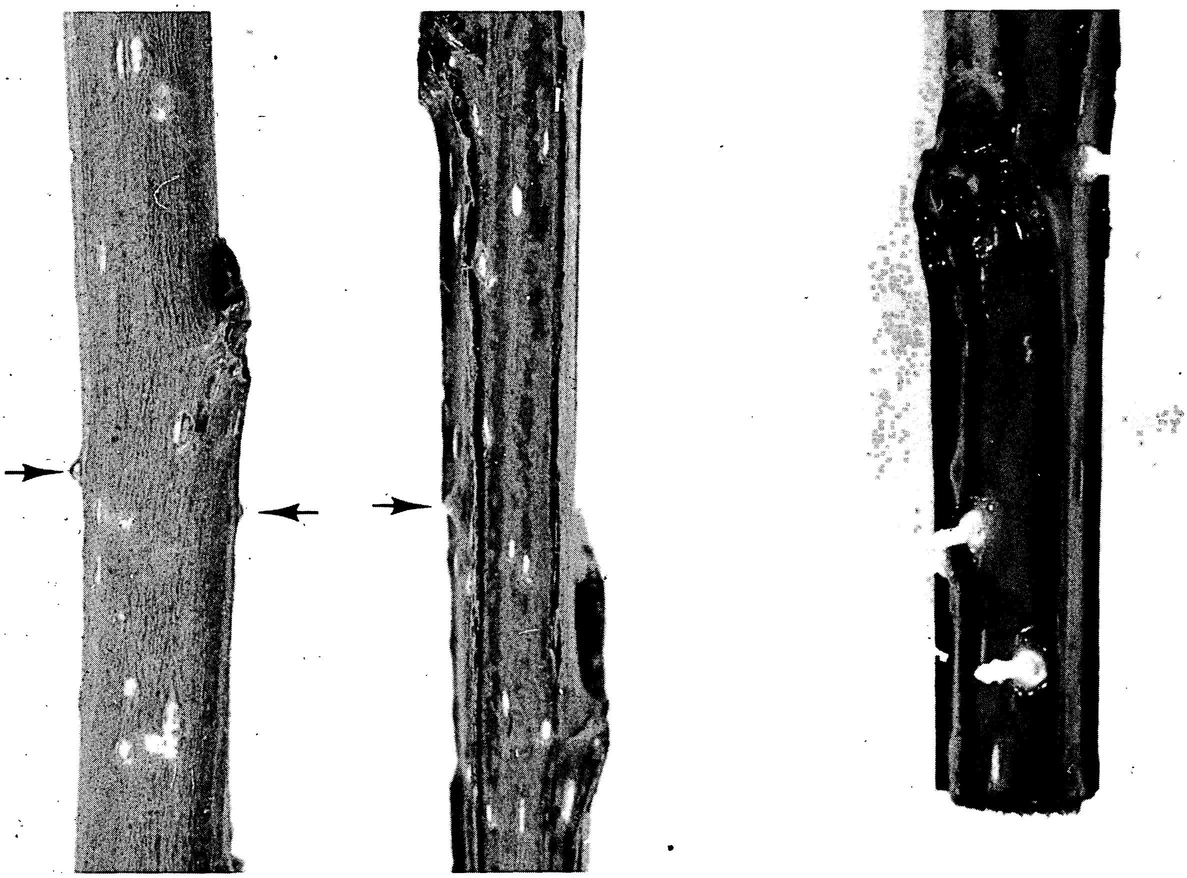

Figure 5.—*Cuttings soaked to (left) proper stage, (right) excessive root development.*

cessive heat or drying. Although soaked cuttings can withstand several hours of drying, it is best to keep them moist, shaded and as cool as possible. Transport the cuttings to the field in the soaking containers, leaving the cuttings in the plastic bag immersed in water. If the cuttings must be in transport overnight or if outside temperatures are high, pack the bundles in crushed ice or in styrofoam coolers.

# Planting

At the planting site, exercise the same care in keeping cuttings moist, shaded, and cool.

1. If planting by machine, load the cuttings into a box and then place it on the planting tray of the machine. A semimechanical transplanter model CT-5 is satisfactory for planting on well-tilled sites. The planting units can be "ganged" on a tool bar so that several rows are planted at one time (fig. 6). Each unit can plant about 1,200 cuttings per hour with an experienced operator.
2. Make certain that the cuttings are planted with the buds pointing up. Otherwise, survival and growth will be poor.
3. Plant cuttings vertically to a depth that will leave one to two buds aboveground (fig. 7). For 8-inch cuttings this will require a hole or slit about 6 inches deep.
4. When planting by hand, carry the cuttings in pails with a small amount of water. An efficient tool

Figure 6.—*A four-row mechanical transplanter can plant unrooted hardwood cuttings at a rate of 5,000/ hour at a 3.3 x 3.3 ft spacing.*

Figure 7.—*One or two buds on the planted cuttings should be above ground. This shoot is 4 weeks old.*

for hand planting cuttings is a dibble made from an iron bar approximately 3/4 inch in diameter with a horizontal projection welded to the bar at a point that will make a hole of the desired depth when the bar is pressed into the ground. Press cuttings into the hole so that firm contact is made between the base of the cutting and soil at the bottom of the hole. Then firm soil around cutting to eliminate air pockets.

5. If the planting operation must be delayed for more than a day, keep the cuttings cool and moist. Pack the cuttings in crushed ice to maintain them in a viable condition and prevent deterioration.
6. Plant unrooted hardwood cuttings anytime from after soil frost has left in early April until mid-June. Cuttings planted in the middle of this period (mid-May) have slightly better survival and height growth than those planted either earlier or later.

# Fertilization

Fertilize annually with 100 pounds N per acre per year. This is equivalent to 300 pounds per acre per year ammonium nitrate. Fertilize annually about July 1 if the nitrogen will be applied all at once. Fertilize in small increments from mid-June to early August

Figure 8.—*Ideally, soil moisture tension should be maintained at less than -0.5 bar by irrigation. Shown here is a self propelled water gun that delivers 500 gals/min and irrigates a strip 300 feet wide by 1/4-mile long.*

if the fertilizer can be applied in several applications. If weed control is excellent and the soils have high organic matter content, it may not be necessary to fertilize the first year or two. If weed competition is severe or soils are coarse textured, it is essential to fertilize with nitrogen for at least several years. Phosphorus and potassium fertilization were not required during the first several years at Harshaw Farm because of the high levels of P and K in the soil. However, they may be necessary on other soils.

# Irrigation

Maintain soil moisture as close to field capacity as possible (-0.05 to -0.2 bar) at the time of planting. Thereafter maintain soil moisture tension at a higher level (less than 0.5 bar as measured at the 6 to 12 inch depth with tensiometers) (fig. 8). If irrigation is not feasible, soil moisture stress can be reduced during the plantation establishment period (until the tree canopies close and completely occupy the site) by providing thorough weed control. Without irrigation, either heavy weed cover or complete canopy closure will usually produce severe soil moisture deficits during the summer.

# Spacing-Rotation

The ideal spacing depends upon management objectives such as tree size and fiber markets but is probably somewhere between 3.3 x 3.3 feet and 10 x 10 feet for rotations of 8 to 15 years, respectively. Spacing affects both cost of plantation establishment and the required duration of weed control. Cost of planting material is exponentially related to tree spacing, e.g., plant material costs of a 3.3 x 3.3 foot spacing would be 9 times that of a 10 x 10 foot spacing. Weed control will be necessary for only the first year in dense plantations but may be required for several years in widely spaced plantations.

Stand density can influence prevalence and severity of diseases within a plantation (Schipper 1976). Reduced air movement through dense stands increases duration of leaf wetness resulting from dew, rain, or irrigation; making a more favorable environment for disease development and pathogen spread (McNabb *et al.* 1980).

Selection of spacing commits the manager to a set of practices, many of which cannot be changed in midrotation without adversely affecting the overall economic outcome. Specifically, spacing will affect rotation length, final size of the crop trees, biomass distribution among tree components, nutrient removal, type of harvesting machinery, harvesting costs, and wood recovery from the biomass. Although these are not part of plantation establishment per se, they need to be considered and are therefore discussed in the next section.

# A PERSPECTIVE

It is apparent from the foregoing that many variables interact in a complex manner to affect the outcome of plantation establishment. Some factors such as proper site preparation and weed control are essential to successful plantation establishment. Others, such as selecting good quality planting material, clonal resistance to insects and diseases, grading cuttings for size, proper storage, pretreatment preparation of cuttings, planting at the best time, fertilization, etc. by themselves may not be critical determinants of plantation establishment. But it is important to note that the effects of these and other variables are cumulative. Plantations may be established successfully without having all variables at optimum levels. If too many variables are neglected, at best a mediocre plantation will result and at worst the plantation will fail. To attain the present-day maximum growth potential in ICHP plantations, all variables must be incorporated.

It is the managers task to determine the degree to which he should (or can afford to) apply these various practices. In the next section we present some relations and management alternatives and discuss their implications as a possible aid to the many decisions that have to be made.

# ALTERNATIVE PRACTICES AND DISCUSSION

## Clonal Selection

Studies have shown significant clone x site interactions (Randall and Mohn 1969, Demeritt 1979) indicating that clonal trials may need to be done on different sites. We have found a few important differences in ranking of eight clones grown on two different sites. Clone NC-5260 ranked much lower and clone NE-372 (NC-5266) much higher on an unirrigated-unfertilized site with silt loam soil as compared to an irrigated-fertilized nursery site with sand soil (table 1). The low ranking of NE-372 in the nursery may have resulted from declining vigor because the entire clone died the following year. However, we attribute the difference in ranking of NC-5260 to clone x site interaction. Site and environmental factors can influence host resistance to many diseases and insect pests. Tables 2 and 3 list the clones tested and their relative susceptibility to the most serious diseases and to the cottonwood leaf beetle, *Chrysomela scripta,* in the north central region and can be used as a guide in selecting clones for use.

In our clonal trials we have found little information gain from replication. Clonal ranking based on only one replicate is nearly the same as that from two replicates. Therefore, for forest managers whose objective is to select a group of fast-growing clones, information could be increased from the same amount of land and labor by testing additional clones or testing clones on different sites rather than by replicating.

Clonal trials should last many years because the clonal ranking changes as disease or unusual frosts slow the growth of some previously fast growing clones (Schreiner 1972, Hansen, unpublished data). Wilkinson (1974) concluded that evaluations made closer to the anticipated rotation provided a better basis for clonal selection. We conclude the same from our screening trials. Clonal ranking changes from year to year because some previously high ranked clones succumb to disease with consequent loss in growth and a decrease in ranking position.

Trees are susceptible to diseases and insects throughout their life, however, the importance of various pests changes with tree age. Generally, foliage diseases of poplars are more important in young plantations where entire crowns of trees may be affected as compared to older trees that have only their

Table 2.—*Severity of* Septoria *and* Marssonina *by clone and location 1976-1981 (compare with table 1 for clonal rankings at Rhinelander)*

| Clone | Location/Disease Severity[1] Rosemount, MN | | | Rhinelander, WI | | | Ames, IA | | |
|---|---|---|---|---|---|---|---|---|---|
| | SLS | MLS | SC[2] | SLS | MLS | SC | SLS | MLS | SC |
| NE-386[5] | H | A | H | L | L | A | H | A | L |
| NE-387[5] | H | A | M | A | L | A | H | L | M |
| NE-252 | H | A | H | L | A | L | H | A | M |
| NE-372 | H | L | H | A | M | A | H | L | M |
| NE-298 | H | H | M | A | M | A | L | H | A |
| NE-375 | H | L | H | A | L | A | H | L | M |
| NE-1[5] | H | L | H | L | L | A | H | A | H |
| NC-5339 | A | L | A[3] | L | L | A[3] | L | A | A |
| DN-28 | L | M | L | A | H | A | L | L | L |
| NC-5377 | L | M | A | A | H | A | L | M | A |
| DN-34 | L | M | A | L | M | A | L | M | A |
| DN-30 | L | M | A | A | H | A | L | M | A |
| NC-5351 | H | H | M | A | H | A | | Not planted | |
| NC-5260 | L | A | L | L | L | A | A | H | A |
| NC-5258 | L | L | A | A | M | A | A | H | A |
| I-476 | A | M | A | A | M | A | | | |
| NE-299[5] | H | A | H | A | M | A | L | M | A |
| P1343437 | A | L | A | | Planting failure | | | Planting failure | |
| I-214 | L | L | L | A | L | A | L | L | A |
| NC-5261 | M | L | L[4] | A | L | A[4] | L | L | A[4] |
| NE-374[5] | H | A | H | | Planting failure | | | Not planted | |
| NE-366 | L | L | L | L | L | A | M | L | L |
| NE-216 | H | A | H | | Planting failure | | | Not planted | |
| NE-19 | L | A | A | A | L | A | L | L | A |
| 44-52 | H | L | A | A | H | A | M | H | A |
| D-37 | L | A | A | | Planting failure | | L | L | A |
| D-45 | M | L | A | | Planting failure | | M | A | A |
| DN-31 | L | M | A | A | M | A | L | M | A |
| 1-78-B | L | M | A | A | M | A | L | M | A |
| DN-26 | L | H | A | A | H | A | | Planting failure | |
| 1-45/51 | L | M | A | A | M | A | L | H | A |
| NE-349 | H | M | H | L | L | A | H | L | L |
| NC-7168 | L | A | A | L | A | A | | Not planted | |
| NE-205 | H | M | H | A | M | A | M | M | H |

[1]H = Heavy (premature defoliation throughout crown, many stem cankers)
M = Medium (premature defoliation in lower and mid crown, few stem cankers, many branch cankers)
L = Light (no defoliation, few branch cankers)
A = Trace or absent.
[2]SLS = *Septoria* leaf spot
MLS = *Marssonina* leaf spot
SC = *Septoria* canker.
[3]Susceptible to *Cytospora* canker.
[4]Susceptible to *Melampsora* leaf rust.
[5]Susceptible to *Septoria* canker in Michigan.

lower crowns affected. Canker diseases are important throughout the rotation, and root rot, stem, and decay fungi will probably be of increasing importance in plantations of older trees and especially in coppiced stands. Defoliators feed on all-size trees, but borers prefer stems and branches of particular sizes. Disease weakened trees are most susceptible to borers. Sucking insects build up on young trees and affect growth mostly in the first 1-3 years after planting.

## Site Preparation

Site preparation is done to control weeds and prepare the soil for planting. A replicated study of five site preparation methods selected to cover the spec-

Table 3.—*Comparison and ranking of cottonwood leaf beetle injury between Iowa and Minnesota* Populus *study plots. Iowa data from Caldbeck, McNabb, and Hart (1978). Minnesota data from Wilson (1979).*

| | Ames, IA clones[1] | Rosemount, MN clones[2] |
|---|---|---|
| Least Injured | 4877 | 5271 |
| | 5339 | 5261 |
| | 5271 | *P. balsamifera** |
| | 5272 | 5267 |
| | 5270 | 4877 |
| | 5328 | 5339 |
| | 5261 | 5273 |
| | 5331 | 5253* |
| | 5267 | 5260 |
| | 5318 | 5272 |
| | 5322 | 5268 |
| | 5258 | 5323 |
| | 5260 | 5270 |
| | 4879 | 4879 |
| | 5321 | 5325 |
| | 5332 | 5332 |
| | 5266 | 5331 |
| | 5262 | 5322 |
| | 5326 | 5266 |
| | 5265 | 5319 |
| | 5268 | 5327 |
| | 5324 | 5335 |
| | 5319 | 5264 |
| | 5325 | 5328 |
| | 5323 | 5318 |
| | 4878 | 5258 |
| | 5377 | 5321 |
| | 5327 | 5326 |
| | 5334 | 5265 |
| | 5263 | 5324 |
| | 5335 | 5377 |
| | 5273 | 5334 |
| Most Injured | 5264 | 5351* |
| | | 5263 |
| | | 4878 |
| | | 5262 |

[1]Data recorded as mean percent of leaf area lost from three randomly chosen shoots of three trees per clone.
[2]Data recorded as percentage of two major upper shoots defoliated in 20% categories for all trees.
*Clones only in MN test planting.

trum of possible methods showed some significant differences between the methods (Morris, unpublished data). A herbicide treatment combined with summer fallowing resulted in significantly greater tree height growth than did either a summer fallow without herbicide or a no-till (table 4). Fall plowing (both normal plowing depth and extra deep plowing) were intermediate and not significantly different from the other three treatments. The site preparation that we are using and have recommended in this report ranks second of those tested. The summer fallow with herbicides would probably be more effective in most instances, but it is much more expensive and it requires that one whole growing season be sacrificed to site preparation.

We have found thorough tillage to be an important aspect of site preparation. No-till has consistently ranked near the bottom of the site preparation practices tried in a number of our field trials as it has in more extensive tests by Von Althen (1981). Also, cutworms can be serious in a no-till situation. Nevertheless no-till is being used successfully and is advantageous on wet sites with poor trafficability during spring and fall (Mike Morin, personal communication).[1]

## Weed Control

Control of competing weeds and grasses is essential for successful establishment of ICHP plantations and can be done chemically, mechanically, or by using cover crops. Each of these approaches used singly or in various combinations has successfully controlled weeds (Project staff, unpublished data). However, they all have drawbacks under certain conditions.

Hybrid poplars are extremely sensitive to damage from many of the herbicides commonly used in forestry and agriculture. Dry weather may render preemergent herbicides ineffective for weed control; ex-

[1]*Consultant, RENRES, Manistee, MI 49660.*

Table 4.—*Effect of five site preparation treatments on first year height. Any two heights not next to a common line are not significantly different (p=.05).*

| Site preparation | Tree height | Date treatment applied[1] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 6/23 | 7/13 | 7/20 | 7/20-10/1[2] | 10/6 | 11/6 | 4/15 |
| | *Feet* | | | | | | | |
| Summer fallow w/herbicide | 4.1 | G | G | D,P | D | | | D,H |
| Fall plow | 3.8 | | | | | G | D,P,D | D,H |
| Fall deep-plow | 3.6 | | | | | G | D,P | LD[3] |
| Summer fallow | 3.3 | | | D,P | D | | | D,H |
| No-till | 3.3 | | | | | G | D[4] | |

[1]Treatments were: G-glyphosate broadcast spray at 2.2 kg ai/ac, P = plow, D = disc, LD = light disc, and H = harrow.
[2]Disced at about 2-week intervals.
[3]Light disc to smooth soil surface.
[4]Disced to break up sod to permit planting with the mechanical planter.

cessively wet weather may leach the herbicide with consequent damage to trees. Many herbicides have been screened with only a few successful in controlling weeds without damage to the trees (Netzer and Noste 1978). An added difficulty is that *Populus* is not listed on many of the herbicide labels.

Poplars are shallow rooted. Consequently deep cultivation can depress growth or distort root distribution and lead to future windthrow problems. For the first 6 weeks of tree growth we have had good weed control from shallow (2 inch deep) cultivation with a rotary hoe (fig. 9), and for the first growing season we have had good weed control from shallow cultivation with a rolling cultivator (fig. 10). Cultivation is required about every 10 days, which may make it more expensive than chemical weed control, and wet weather sometimes makes cultivation impossible. However, it is usually an effective option if herbicides are not practical.

Cover crops such as clover can successfully prevent weed growth and in addition supply some nitrogen. Clover also appears to limit attack of the tarnished plant bug *Lygus lineolaris* (Sapio *et al.* 1982). However, cover crops (like weeds) compete with the trees for available nutrients and moisture. Fertilization with nitrogen is equally important the first year whether weeds or a nitrogen fixing cover crop is present (Hansen, unpublished data). Cover crops may be more successful in irrigated than non-irrigated plantations because they will compete with trees for moisture where it is limiting.

We have tested many weed control practices and have found no particular advantages between herbicides, cultivation, or cover crops as measured by their effect on first year tree height (table 5). Although a number of significant differences occurred between treatments, much of this variation was due to the weather and the sites. Nevertheless, the following results have been consistent over the years; treatments containing linuron were consistently best; furrow-cultivation was consistently poorest (the shallow planted cuttings desiccated before rooting during the dry spring); and glyphosate applied after the cuttings were planted was poor (due to extreme sensitivity of *Populus*.

Irrigated and fertilized plantations that have good weed control for the first 4 to 8 weeks do not appear to benefit from further weed control during the remainder of the first growing season. In one study with a 3.3 x 3.3 foot spacing, the weeds between rows (primarily quack grass, lambsquarters, and mustard) were shield-sprayed with glyphosate in alternate strips on July 29 during the first growing season. The sprayed strips did not show any superior tree height growth as compared to unsprayed control strips either at the end of the first or the second season (Netzer, unpublished data).

In another study, a number of midsummer weed control treatments were tried in a large plantation with a spacing of 3.3 x 3.3 feet again with little effect on tree height growth (Hansen, unpublished data). Weed control treatments were: 1) weekly hand hoeing from July 6 to August 10 and again on August 26 to keep the plot essentially weed-free, 2) a single application of glyphosate on July 23 with a "rope-wick" applicator, 3) a single application of linuron on August 6 by overspraying the trees and weeds, and 4) a control where nothing was done after the initial establishment in the spring. Based on four

Figure 9.—*A rotary hoe controls weeds both between and within rows but can be used only during the first 6 weeks when the trees are less than 1 foot high.*

Figure 10.—*A rolling cultivator will control weeds during the first growing season if the field is cultivated about once every 10 days.*

Table 5.—*Effect of eight weed control treatments on first year tree height. Any two tree heights not next to a common line are significantly different (p=.05).*

| Weed control treatment | Tree height | Broadcast-spray linuron | Plant cuttings | Cultivate | Shield-spray glyphosate | Seed legume[1] |
|---|---|---|---|---|---|---|
| | | Date treatment applied | | | | |
| | *Ft* | | | | | |
| Herbicide-legume | 3.9 | 5/6 | 5/9 | | | 8/28 |
| Herbicide-cultivation | 3.9 | 5/6 | | 7/10-8/25(5x)[2] | | |
| Herbicide | 3.4 | 5/6 | | | 7/22 | |
| Cultivation | 3.3 | | | 5/20-8/25(11x) | | |
| Legume | 3.2 | | | | | 5/6 |
| Herbicide | 2.7 | | | | 6/11, 7/17 | |
| Furrow cultivation | 2.6 | | | 6/3-8/25(10x) | | |
| Furrow cultivation legume | 2.4 | | | 6/3-8/25(10x) | | 8/28 |

[1]The legume was white dutch clover.
[2](5x) signifies 5 cultivations.

replications, only hoeing was slightly (not statistically significant) better than the control. Moreover, hoeing is not a feasible option for large plantations anyway. Both herbicide treatments were poorer than the control (again not significantly so).

Weed control after the first year may also be unnecessary at close spacings but may be beneficial to wider spaced plantations. This was suggested by our tests in 2-year-old plantations of several clones established at spacings from 2 x 2 to 7 x 7 feet. At age 2, the dense undergrowth consisted mostly of quackgrass and its summer biomass reached about 3,700 pounds per acre in the 7 x 7 foot plantings and about one-half of that in the densest 2 x 2 foot planting. Fall and spring spraying of parts of each plantation with glyphosate at 2 pounds ai per acre effectively controlled quackgrass. However, a dense cover of mostly dicotyledonous weeds developed in sprayed areas of the 7 x 7 foot plantings during the third year. In control areas quackgrass still predominated. The total weed biomass of the control areas was about 20 percent greater than that of the sprayed areas but the difference was nonsignificant.

Effects of weed control from spraying glyphosate at the end of the second year showed no significant gain in the third through fifth year current annual woody biomass increment for most clone-spacing combinations (table 6). However, the *Populus* x *euramericana* (NC-5377 and DN-34) clones produced significantly greater biomass on the wider spaced (6.9 x 6.6 foot) sprayed plots.

Table 6.—*Effect of weed control from fall or spring application of glyphosate at age 2 on current annual biomass increment of hybrid poplar at ages 3, 4, and 5. Control plots had no weed control.*
(In t/ac/yr)

| Clone | Spacing | Age (years) 3 Control | 3 Fall | 3 Spring | 4 Control | 4 Fall | 4 Spring | 5 Control | 5 Fall | 5 Spring |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Feet* | | | | | | | | | |
| NE-299 | 2.3x2.3 | 5.9 | 6.2 | 4.9 | 7.3 | 6.7 | 6.6 | 5.0 | 4.7 | 4.8 |
| | 3.6x3.6 | 4.4 | 5.0 | 4.9 | 7.1 | 6.1 | 6.8 | | lost | |
| | 6.9x6.6 | 2.7 | 2.7 | 4.1 | 6.8 | 6.2 | 6.6 | 6.4 | 6.6 | lost |
| NC-5260 | 3.6x3.6 | 2.7 | 2.6 | 4.1 | 6.2 | 6.2 | 6.2 | 3.6 | 3.8 | 4.2 |
| | 6.9x6.6 | 0.6 | 1.0 | 1.3 | 3.3 | 5.9 | 6.8 | 5.3 | 5.6 | 6.1 |
| NC-5337 | 3.6x3.6 | 3.7 | 2.4 | 2.5 | 4.7 | 3.5 | 3.8 | 2.7 | 2.8 | 3.1 |
| | 6.9x6.6 | 0.5 | 0.7 | 0.6 | 1.5 | 2.2 | 2.4 | 1.6 | 2.3 | 3.0 |
| DN-34 | 6.9x6.6 | 0.2 | 0.5 | 0.7 | 0.8 | 1.8 | 2.2 | 1.1 | 2.1 | 2.5 |
| Overall Mean | | 2.6 | 2.6 | 2.9 | 4.7 | 4.9 | 5.2 | 3.7 | 3.8 | 4.0 |
| | S.D. | 2.1 | 2.0 | 1.8 | 2.6 | 2.0 | 2.1 | 2.0 | 1.6 | 1.3 |

We conclude that little can be done with further weed control to improve upon tree growth in 3.3 x 3.3 foot or closer spaced irrigated and fertilized plantations if they have been established with initially good weed control. However, further weed control may be beneficial for wider spacings and, we believe, it is highly beneficial for non-irrigated and nonfertilized plantations.

## Insects and Disease

Diseases and insect pests that may be of minor importance in natural poplar stands can cause plantation failure or reductions in quantity and quality of fiber yields of ICHP plantations. Large, densely planted, monoclonal stands of even-aged trees exotic to a region are vulnerable to attack by insects, mites, fungi, viruses, and bacteria throughout all stages of an intensive culture program. Pest management considerations made prior to or during nursery or plantation establishment and integrated with other management activities can help avoid or minimize future problems.

To determine what diseases and insects were potentially damaging to hybrid poplars in the north central region of the United States and what clones exhibited resistance to them, a series of small plots, each containing 36 clones of poplar species and hybrids, were established in 1976 and 1977 (Ostry 1979). Since these plantings were established, several potentially serious diseases and insects have developed in them and many additional pests of possible periodic importance have also been detected. Foliage diseases caused by *Melampsora medusae, Marssonina brunnea,* and *Septoria musiva* result in premature defoliation that reduces growth (figs. 11, 12) (Schipper *et al.* 1978, Palmer *et al.* 1980b, and Palmer *et al.* 1980a). Trees that are repeatedly infected become stressed and weakened and are then subject to attack by stem diseases caused by *Cytospora, Dothichiza,* and *Phomopsis. Septoria,* in addition to causing a leaf disease, also causes a serious branch and stem canker that can jeopardize the success of a plantation (fig. 13). These weakened trees attract insect pests.

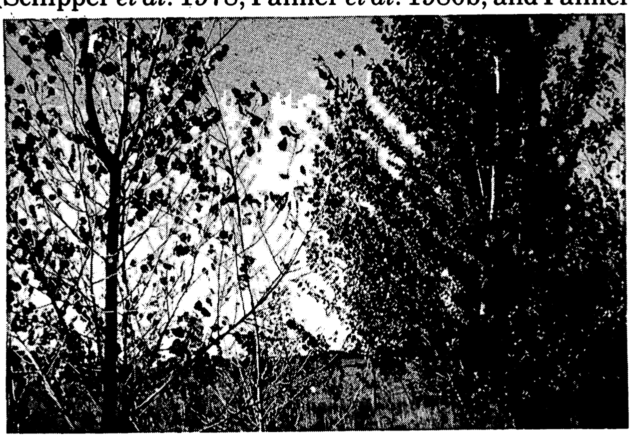

Figure 11.—*Premature defoliation of susceptible trees (left) caused by* Septoria musiva *contrasted to resistant tree.*

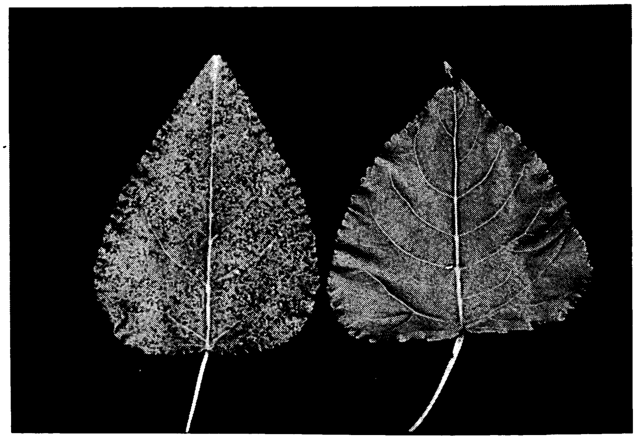

Figure 12.—*Infected and healthy leaves of trees in fig. 11.*

Figure 13.—*Dieback of tree infected with* Septoria *canker.*

Three major conclusions can be drawn from results of the screening plots:

1. Different poplar diseases and insects may be of more importance in one area than another. For example, *Melampsora* rust is far more severe in Rhinelander, where larch, its alternate host, is present, than in Iowa where rust spores arrive later in the season and trees therefore are not infected until late in the season (Widin and Schipper 1981). This illustrates the importance of locally screening clones for disease and insect resistance before they are widely planted.
2. Disease organisms often take several years before they become a serious problem. For instance, *Marssonina* was not prevalent in plantings at Rosemount, Minnesota in 1975. However, since then it has become epidemic on susceptible clones. *Septoria* leaf spot was low and *Septoria* canker absent on trees at Rhinelander until 1981. It is expected that this disease will increase in importance there, as it has elsewhere in the Lake States. Also, the poplar- and willow-borer, *Cryptorhynchus lapathi,* only recently has become important in Wisconsin and Michigan. Clones NE-252, NE-372, NE-375, NE-374, DN-30, DN-34, and NC-5377 so far have been identified as susceptible to this weevil. It is certain more clones will become affected as more plantations are set out and trees get older.
3. Some pests, although usually of little significance, can under the right environmental conditions, be of periodic importance (Ostry 1980a, 1980b). Consideration must be given to these when various cultural practices are carried out to ensure that conditions are not changed to favor pest development. For instance, weed control appears to favor buildup of the tarnished plant bug. Certain cultural practices including cover cropping with white dutch clover reduce the insect (Sapio *et al.* 1982). Clones most suceptible so far are NE-298, NE-386, NE-387, and NC-9921. Similarly, environmental stresses such as drought and winter injury can predispose trees to pests not ordinarily a problem.

# Deer Browsing

A concern in establishing ICHP plantations is deer browsing of newly planted trees. A 7-acre plantation established in an area with a large deer population was sampled for deer damage during the first 2 years. During the first winter deer browsed 55 percent of the 200 trees in the sample plot, removing an average of 4 inches from the terminals of the browsed trees. Trees of all heights were browsed although browsing was less frequent on trees more than 5.5 feet tall. During the second growing season browsed trees grew as much in height as the unbrowsed trees. By the end of the second growing season tree height averaged 10.5 feet, which is above the browsing height of deer, and browsed trees appeared to be of equal vigor and form to unbrowsed trees. Although in this case 4 inches of tree height was lost because of deer browsing, it does not appear that browsing will be a barrier to successful establishment of well-managed irrigated plantations. On less intensively managed and slower growing plantations, browsing in successive years may cause problems with tree growth and form but such data are not available at this time.

# Planting Material

Although we recommend and use dormant hardwood cuttings, other types of planting material exist. One-year-old rooted stock is frequently sold by commercial nurseries and in one case has been used for large field plantings by a private corporation (Mike Morin, personal communications). Hardwood cuttings may also be rooted and planted as containerized stock. The advantages of containerized stock are (1) even very small diameter cuttings survive and grow well, (2) the planting season may be extended, and (3) survival may be improved on harsh sites. *Populus* can also be propagated by rooting greenwood tip cuttings in various containers and media or in a dilute nutrient solution (Phipps *et al.* 1977, 1980). Rooted greenwood cuttings can be produced in a short time and may provide additional planting stock if hardwood cutting supplies are inadequate. Also, certain clones or hybrids of *Populus alba* are more easily rooted from greenwood cuttings.

# Cutting Production

## CLONAL ORCHARD MANAGEMENT

Trees for cutting production have commonly been planted at spacings from 1 to 4 feet within rows and from 10 to 12 feet between rows. Stool beds established in this manner have the advantage of easy access to individual rows and make mix ups between clones less likely than in closer spaced orchards. Sanitation practices are necessary to reduce inoculum from infected stock and are more easily, and thoroughly accomplished in wider-spaced stool beds. Cultural practices such as roguing, and disposal of infected residues together with soil cultivation to bury infected fallen leaf debris can reduce disease severity. Disadvantages are that a larger area is required to produce cuttings compared to block plantings at closer spacings such as 3.3 x 3.3 feet. Also the wide spacing requires continual weed control. Close spacing increases incidence of disease such as *Septoria* canker.

## HARVESTING

### Harvesting Methods

Harvesting methods vary depending on the number of cuttings to be harvested and the availability of labor. Hand pruners and power brush saws are often used in harvesting operations. Tractor mounted sickle bars can be used to "mow" whips especially if whips from a single stump are tied together prior to harvest. Mechanical harvesting systems are being developed that will cut whips, tie them in bundles and load them on to wagons for transport to the processing area (fig. 14).

### Time of Harvesting

When to harvest dormant hardwood cuttings depends on their stage of physiological readiness to develop roots and shoots (vigor) and a convenient harvesting time. Like most deciduous broadleaved species of the temperate zone, *Populus* hybrids require a period of exposure to subfreezing temperatures to reach the proper condition for normal root and shoot development. Date when proper condition is reached depends on climate.

In a greenhouse study on root and shoot development of cuttings taken monthly from November through March, we found development proceeded more rapidly as cuttings were collected later in the dormant period (Phipps and Netzer 1981). Beyond December, however, effects were less pronounced. In a second study, cuttings of several clones were collected monthly from September to December and stored at several temperatures ranging from 4°F to 36°F and then planted in the field. Early results indicate that overall survival and height growth were best for cuttings collected in December (Phipps and Fege, unpublished data). However, cuttings collected in October and November performed almost as well except for those stored at the lowest temperature–suggesting that the tissue of these cuttings was not yet sufficiently hardened to tolerate such a low storage temperature. Cuttings collected in September did not survive or grow well and this early date should not be considered for harvesting.

For many nurseries December or January would also be a convenient time of year to harvest and process cuttings. The main disadvantage, however, in many northern areas is the deep snow and extreme cold in which this operation must be performed. February and March may be alternative collection dates, if this activity does not conflict with other operations. However, soil conditions would have

Figure 14.—*A modified corn binder shows promise for mechanically cutting and bundling whips.*

to permit the use of harvesting machinery and the cutting collection would have to be completed before trees break dormancy. Although the results of the studies mentioned above are tentative, it appears that cuttings collected from November through March will perform satisfactorily. Interestingly, the best time to harvest *Populus* cuttings coincides with the best harvesting time to achieve the most vigorous coppice regeneration (stump sprouts) for the next seasons production.

## GRADING

One of the most important criteria for selecting cuttings that will survive and grow well after field planting is diameter, measured usually at the base of the cutting. It has been found for some species at least, that hardwood cuttings taken from basal portions of stem shoots root better than those taken near the tip (Hartmann and Kester 1975). This was confirmed for *Populus alba* (Hansen and Tolsted 1981). For most *Populus* clones cuttings with a diameter range from 3/8 to 1 inch will perform well in the field. Cuttings larger than 1 inch may be used if they can be accommodated by the planting machine or will be hand planted.

The effect of cutting diameter on early survival and growth were studied at Rhinelander, Wisconsin, and East Lansing, Michigan (Dickmann *et al.* 1980). One-year-old shoots of six different clones were made into cuttings ranging in diameter from less than 1/4 inch to about 3/4 inch and field planted. Results after one growing season showed that survival and growth increased significantly with diameter (fig. 15). Shoots of small cuttings were only 1/3 to 2/3 as tall as those from large cuttings during the first 11 weeks after planting (fig. 16). During this period,

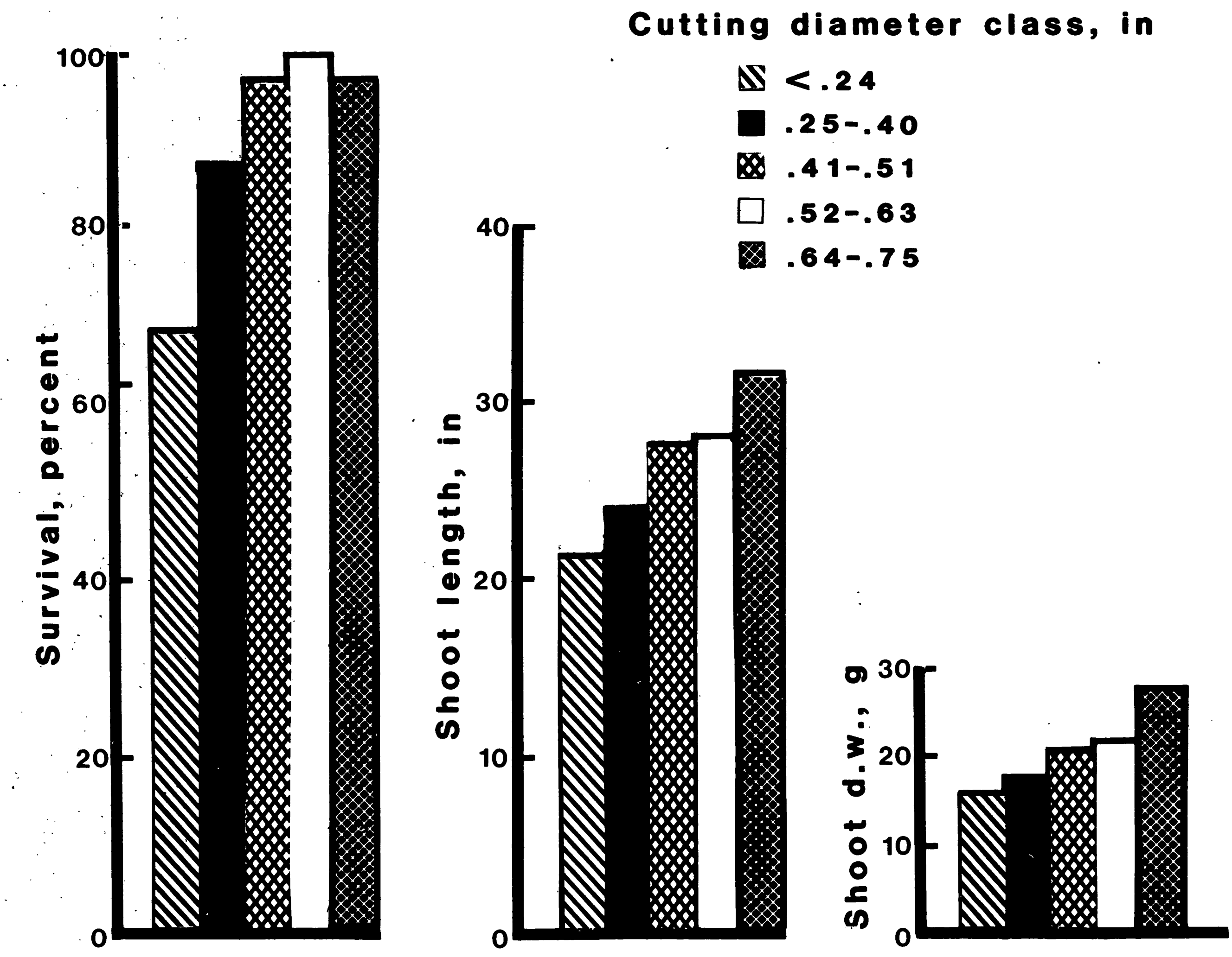


Figure 15.—*Effect of cutting diameter on survival, shoot length, and shoot dry weight (d.w.) of* Populus *cv.* rasumowskyana *x* P. *cv. 'incrassata' (NE-58).*

cuttings are susceptible to environmental stress and weed competition and may fail without irrigation and weed control. The performance of cuttings less than 1/4 inch diameter was very poor and would not be satisfactory for unirrigated field planting. However, small diameter cuttings can be used for clonal stock in nurseries where cultural conditions may be more favorable.

It is imperative to avoid introducing serious pest problems to new areas by carefully examining and culling all diseased nursery stock found. *Marssonina* and *Septoria* and insect eggs and borers can be present on or in hardwood cuttings and spread through an entire plantation if infected or infested stock is planted. A European bacterial canker caused by *Xanthomonas populi,* is not known to be present in our region. Poplar mosaic virus is widely distributed in Europe and has been found in Canada but has not yet been confirmed in the United States (Navratil 1977).

## STORAGE

Our experience has shown that dormant hardwood cuttings of most clones can be stored at 37°F for a maximum of about 3 months. However, at this temperature maintenance of internal bark moisture is critical to avoid losses caused by fungi that attack cuttings in storage. Temperatures at or below freezing are preferable for most storage, and are essential for long term storage. Cuttings of several different clones have been successfully stored for 2 years in chest freezers at temperatures between 10 and 20°F. To prevent desiccation cutting bundles are double bagged in heavy polyethylene. In areas where win-

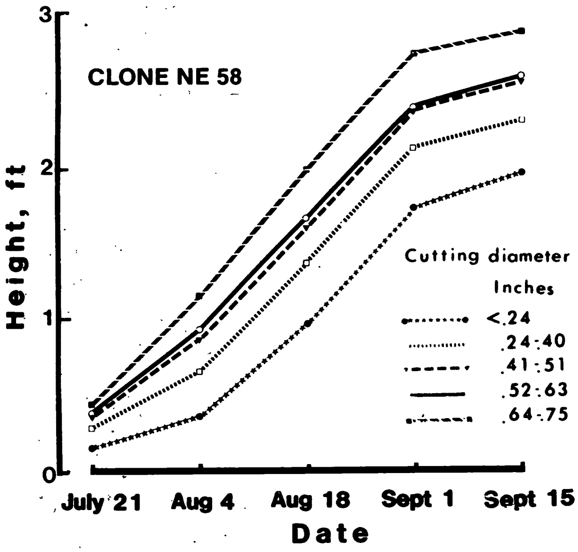


Figure 16.—*Effect of cutting diameter on height growth of clone NE-58 during the first 11 weeks after planting in East Lansing, Michigan.*

ters are sufficiently cold, cuttings may be stored for several months in unheated shelters or buildings without refrigeration. However, late winter temperatures can fluctuate widely and cause the cuttings to break dormancy before they can be planted. Therefore some provision for refrigeration is recommended.

Cuttings stored improperly may be affected by a condition known as blackstem. Microorganisms present on bark surfaces of cuttings cause deterioration of cuttings, killing them directly in storage or weakening them. Weakened cuttings produce unthrifty plants that may be predisposed to other stresses resulting in planting failures.

An alternative to bagging cuttings in polyethylene is to pack them in a moist medium such as sphagnum peat moss in boxes or crates. Early results of a field planting test with cuttings stored by the latter method indicate satisfactory performance. However, special care should be taken that the medium does not dry out. It is also possible that entire stems or whips can be stored without protective covering for a short time before making them into cuttings. In this case, it is essential to maintain humidity in the storage area high enough to prevent desiccation. It is not known if this method could be used for longer periods of storage or at subfreezing temperatures. Further study of storage of entire whips would be necessary before the method could be recommended.

## PREPLANT TREATMENT

### Raising Storage Temperature

Shoots and roots grow slower on cuttings stored at subfreezing temperatures than on cuttings stored at above freezing temperatures (Phipps and Netzer 1981). In some cases, cuttings stored at subfreezing temperatures fail to develop and eventually die. To compensate for the detrimental effects of subfreezing storage raise the storage temperature to 37°-40°F for 1 to 2 weeks before planting (Phipps, unpublished data). Best results are obtained when this treatment is followed by soaking for from 7 to 10 days at 60°F.

### Soaking

Soaking hardwood cuttings in water before planting has been practiced in some parts of Europe and to some extent in the southern United States with cottonwood (*P. deltoides*). McKnight (1970) recommended that cottonwood cuttings be soaked in water until fully saturated (up to 3 days) before field planting. Petersen and Phipps (1976) found that soaking stimulated root emergence and improved field establishment as compared with unsoaked cuttings for three different hybrid *Populus* clones tested.

Field studies have shown a consistent 10 percent increase in height growth due to soaking under conditions of adequate soil moisture (Hansen, unpublished data). Observations of field plantings suggest that the benefit of soaking increases as soil moisture stress increases.

Both water temperature and soaking duration affect subsequent performance of the cutting. Cuttings of two clones were soaked in water at 40°F and 60°F for 2, 4, 6, and 8 days. Cuttings were then grown in a growth room and evaluated in terms of shoot length, number of shoots, and average length of the longest root. Cuttings soaked at 60°F were significantly better then those soaked at 40°F (Phipps, unpublished data). Also, shoots and roots grew longer with increased soaking time, although differences were not significant.

Two questions may frequently confront a field manager:

1. Can cuttings soaked to the proper stage for planting be held in a vigorous condition if planting must be delayed?
2. Will soaked cuttings be severely damaged by short periods of drying that inevitably occur during the planting operation?

In a separate part of the study cuttings were soaked for various lengths of time and then exposed to different combinations of cooling by packing in crushed ice for 2 weeks and/or air drying for 8 hours before planting.

Results indicated that cuttings could be maintained for 2 weeks by packing in ice and returning to cold storage, and cuttings could be subjected to air drying for 8 hours without suffering serious growth loss. However, it should be stressed that best results will be obtained when cuttings are planted as quickly as possible after soaking, and packing in ice must be regarded only as an emergency measure.

# Planting

## MACHINERY

The semi-mechanical transplanter model CT-5[2,3] is the most efficient planter we have tested for unrooted hardwood cuttings on well-tilled sites. With a 4-row planter our 6-man field crew planted about 5,000 cuttings per hour or in excess of 30,000 cuttings in 6 hours, at a 3.3 x 3.3 foot spacing. A 2 unit Model 1525 transplanter is advantageous for stony sites or untilled areas. About 500 cuttings per unit per hour can be planted with this transplanter. This planter also allows planting of rooted stock, containerized stock, or long whips. The Model 1525 planter was slightly modified by engineers at the Forestry Sciences Laboratory in Houghton, Michigan. They added an audible system to control within-row spacing, redesigned the packing system, added larger and stronger planting shoes, and added protective shields for the operators.

## DEPTH

Various recommendations have appeared in the literature for best depth of planting hardwood cuttings of different species. Generally, these range from leaving from 2 to 3 buds exposed above ground to planting the cutting flush with the ground level. In most situations leaving 1 or 2 buds above ground or leaving the cutting 1 inch above ground if no buds are present will produce good results with *Populus* hybrid cuttings. Early results of tests designed to determine the effects of cutting length and planting depth showed that 8 inch cuttings produced the least number of main shoots when planted flush with the ground surface in a silt loam soil. However, first-year shoot height was less than that of cuttings planted at shallower depths of either 4 or 6 inches (Phipps, unpublished data). Whether the results would be the same on coarser textured soils remains to be studied.

## TIME

It is generally believed that the best time to plant is shortly after soil frost leaves in the spring. However, 3 years of planting throughout the soil frost-free period showed that cuttings planted in April grew less in height during the growing season than those planted in May (fig. 17) (Hansen, unpublished data). In fact, in northern Wisconsin early June planting dates are generally as good as those in April. Mid-May was consistently the best planting time although the increase in growth was slight. August plantings failed each year due to frost heaving of the weakly rooted cuttings. Fall planting resulted in mixed success from year-to-year due to frost heaving; one year out of three resulted in successful establishment. We speculate that fall planting would be more successful on sandy soils or during winters with deeper snowpacks—our two fall planting failures preceded winters with light snowpacks.

# Fertilization

Hybrid poplars require large amounts of nitrogen (Hansen and Baker 1979). On our silt loam soils if all weeds were kept out of the plantation by hand weeding, growth was not accelerated from fertilization with 100 pounds nitrogen per acre per year during the first 2 years. In contrast, if weeds are present (as is the case in all field plantations), fertilization significantly increases tree growth (table 7) (Hansen, unpublished data). In our studies fertilization with 100 pounds nitrogen per acre per year increased 1- and 2-year tree height as much as 80 percent on weedy plots. In cases where severe weed competition

Table 7.—*Effect of N fertilizer (applied as $NH_4NO_3$) on 1- and 2-year tree heights on "weedy" and "weed-free" plots*

(In feet)

| Fertilizer rate (lbs/ac/yr) | Total seasonal height growth | | | |
|---|---|---|---|---|
| | Weedy plot | | Weed-free plot | |
| | 1-year-old | 2-year-old | 1-year-old | 2-year-old |
| 0 | 3.3 | 4.0 | 3.7 | 9.0 |
| 50 | 3.5 | 4.7 | — | — |
| 100 | 4.7 | 7.7 | — | — |
| 150 | 4.9 | 7.2 | 3.6 | 8.7 |

[2]*Available from Mechanical Transplanter Company, South Central Avenue at US-31, Holland, Michigan 49423.*

[3]*Mention of trade names does not constitute endorsement of the product by the USDA Forest Service.*

develops shortly after planting, fertilization is essential for successful establishment. Fertilizer increases the incidence and attacks by sucking insects but tends to decrease wood borers and some defoliators (Wilson 1976).

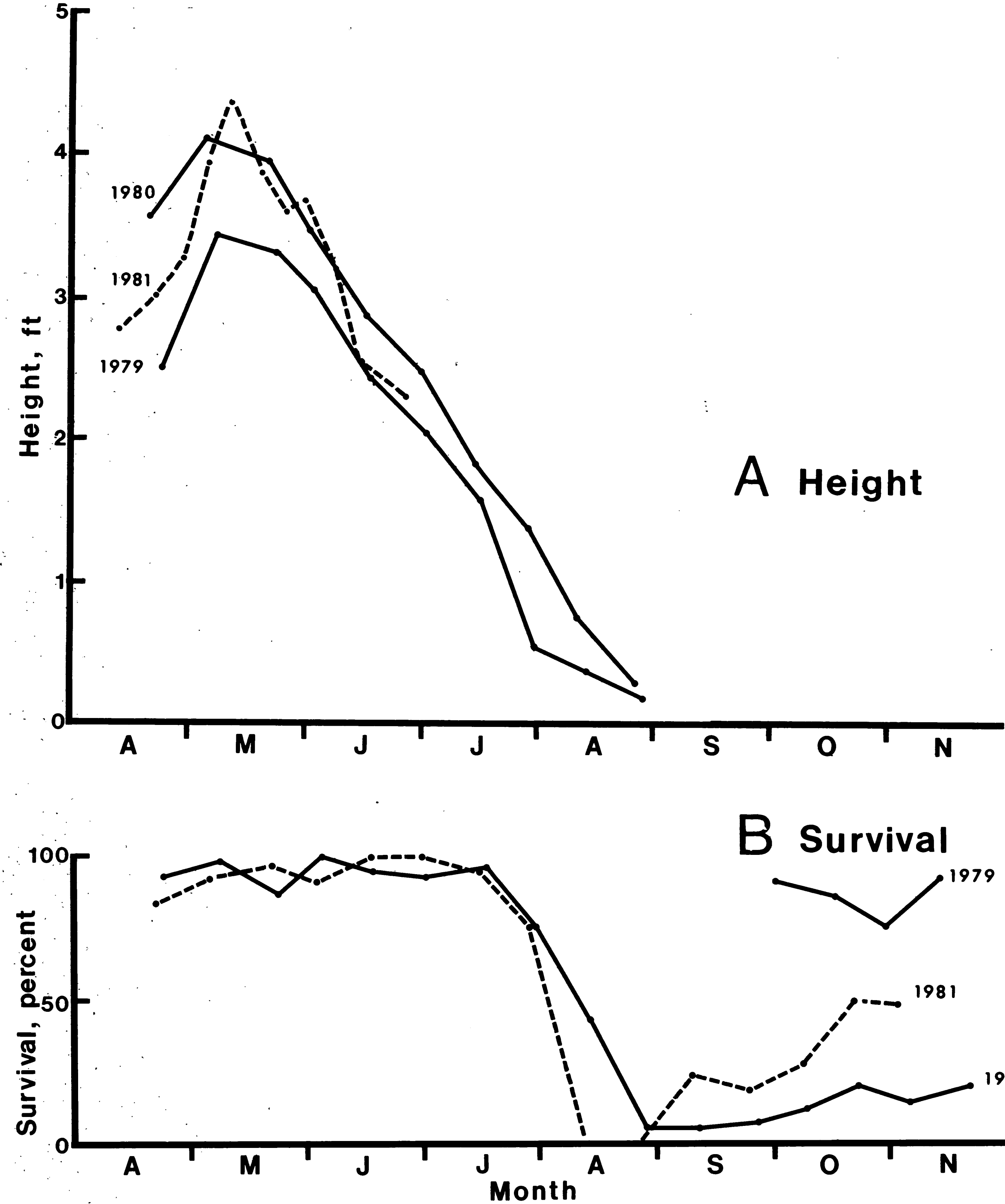


Figure 17.—*(A) Total height and (B) survival of 1- and 2-year-old trees respectively as related to planting date for 3 years of trials with clone NC-9922.*

Seeding an herbaceous legume cover crop such as birdsfoot trefoil in a plantation at or shortly after the time of planting cuttings has the potential for eventually providing nitrogen. However, our studies show no benefit to first or second year tree growth (Hansen, unpublished data). Nitrogen fertilization is required as much the first 2 years with legumes as it is with weeds.

Another future possibility for managing nitrogen on the site is to mix nitrogen-fixing trees such as *Alnus* with the *Populus* (DeBell and Radwan 1979, Hansen and Dawson 1982). However, this concept is still in the developmental stage and not yet ready for commercial plantations.

Soil pH can vary considerably but should be maintained between 5.0 and 7.5 by liming (van den Burg and Schoenfeld 1978, Wolkowski and Schulte 1980).

# Irrigation

At the time of planting, soil moisture tension should be $-0.2$ bar or less. A growthroom study using boxes of soil at different moisture tension levels showed that early shoot growth of unrooted hardwood cuttings increased as soil moisture tensions decreased to at least $-0.05$ bar indicating that new plantations should be kept moist (fig. 18) (Hansen and Phipps, unpublished data). The time required for bud break and shoot growth to begin also decreased as the soil became wetter. However, in some soils the reduced aeration from rain or irrigation may negate the potential benefits of low soil moisture tension.

Soil moisture can usually be maintained at high levels in early spring by good site preparation and weed control practices that prevent soil moisture withdrawal by weeds. If soils do dry out, moisture levels can be restored by irrigation. If irrigation is not possible and if the planting workload is small, planting can be delayed until after a rain. Also the effects of dry soil can be offset to a large extent by soaking the cuttings prior to planting (fig. 18). (Refer to "Preplant Treatment" section for discussion of soaking technique.) The best planting procedure is a combination of both practices—plant soaked cuttings in a moist soil.

Maintaining high soil moisture is important even after the cuttings begin to grow. In our tests tree volume was greatest at the wettest soil moisture level and was almost double that of unirrigated trees (fig. 19) (Hansen, unpublished data). These results were obtained during the first 2 years of tree growth in a study in which a particular treatment was irrigated whenever the specified soil moisture level

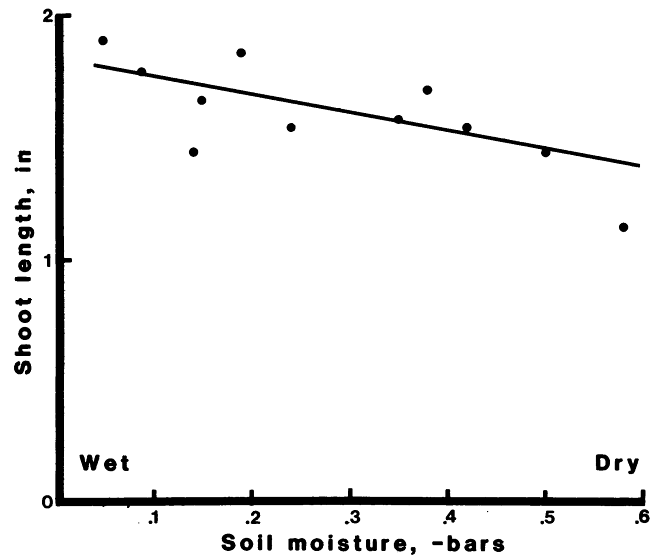


Figure 18.—*Relation of 10-day shoot elongation of clone NC-5260 to the initial soil moisture tension. The cuttings were soaked 10 days prior to planting. Cuttings that were not soaked had not yet begun to grow.*

was reached. From these results we concluded that the management objective should be to maintain high soil moisture levels by irrigation—if possible. In the absence of irrigation, periods of high soil moisture can be extended by good weed control. But eventually the tree canopies close and the trees completely

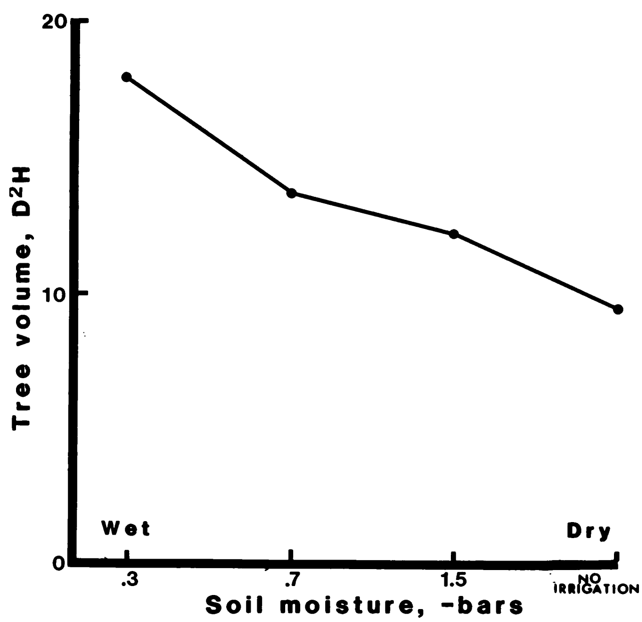


Figure 19.—*Relation of the tree volume index $D^2H$ (where D is the breast height diameter and H is tree height) to maximum soil moisture tension permitted before irrigating. Data are from the 2-year-old clone NC-9922 with three replications.*

occupy the site, and soil moisture may become limiting. Then, little can be done to manage soil moisture. Without irrigation, soil moisture deficits in northern Wisconsin occur regularly in mid- to late summer (Hansen, unpublished data). Trees under water stress are more susceptible to diseases (Haywood and McNabb 1979) and insect pests (Stark 1975) and these can contribute to the decline or death of trees even after moisture is restored.

Data were collected during two summers of near normal precipitation in plantations with few weeds and in which the tree canopies had not yet closed (fig. 19). Under these conditions irrigation was highly beneficial to tree growth. Irrigation will probably have an even greater impact in dryer years, in weedy plantations, and in these plantations in the future now that the canopies have been closed. Another benefit is that morning irrigation can reduce populations of the cottonwood leaf beetle, some aphids, and some mites.

Although irrigation is expensive, sewage or industrial effluent can be used to satisfy the dual objective of tree irrigation and waste disposal (Hansen *et al.* 1980). This could provide additional economic benefits beyond just fiber production and make irrigation a feasible option.

# Spacing

### BIOMASS

Selection of a given spacing—within reasonable limits—will have only minimal, if any, effect of sustained biomass yield as long as the important principle of harvesting when the mean annual biomass increment culminates is observed. Adequate evidence has accumulated over the last decade on the so-called principle of "biomass production independence of spacing" which simply means that the same biomass yield can be obtained in plantations with a wide range of densities (Zavitkovski 1981b).

In the following discussion we will assume that the same quantity of stem-branch biomass can be produced in dense and open ICHP plantations, spaced from about 1 x 1 to 20 x 20 feet. Studies of Ek and Dawson (1976) suggested that the mean annual biomass production of dry weight of stems and branches in northern Wisconsin could reach 6.7 tons per acre per year. Because these quantities were determined in small plots with unplanted plot borders (Zavitkovski 1981a), this value may be an optimistic estimate but perhaps can be reached in large plantations of more productive hybrid poplar clones such as NE-299 (NC-5331) or NC-9922, which appear to be well adapted to the severe climate of the region.

### WEED CONTROL

The duration required for weed control is determined primarily by tree spacing. In dense plantations canopies usually close during the second growing season and thus shade out the weeds so no weed control is required beyond the first year. In non-irrigated and nonfertilized plantations with rows 10 feet apart weed control by cultivation or herbicides may be required for several years. Here weed control is done primarily to reduce soil moisture and nutrient use by weeds. This is the standard practice in the industrial plantations in Ontario scheduled for rotation cycles of about 10 years (Raitanen 1978).

### ESTABLISHMENT COSTS

Plantation establishment costs are composed of (1) various site preparation operations, which are the same for any spacing, and (2) the planting operation, a major cost of which is planting material—cuttings. Planting materials for dense plantations may add substantially to the total cost. For example, at a 3.3 x 3.3 foot spacing, 4,000 cuttings are planted per acre; at a 6.6 x 6.6 foot spacing only 1,000 cuttings are needed. At a price of 15 per cutting, costs per acre for the planting material alone are $600 for the 3.3 x 3.3 foot planting and $150 for the 6.6 by 6.6 foot planting. The cost of the planting operation itself also increases for dense plantations but no experimental data are available at this time. Part of the additional cost to establish dense plantations may be recovered because they require a shorter period of weed control.

### ROTATION

In general, on the same site or under the same cultural treatments, as spacing increases–so does rotation length. Studies with *Populus* 'Tristis #1' indicated that in dense plantings, e.g., 9 x 9 inches, the mean annual biomass increment culminates at an age of about 3 years (Ek and Dawson 1976) but in more open stands, e.g., 8 x 8 feet, the maximum was not reached yet at age 9 (Zavitkovski, unpublished data).

### TREE SIZE

As the spacing and rotation length increase, the size of the final crop trees also increases. For example, the average height and d.b.h. of the 3-year-old trees in the 9 x 9 inch planting were about 11 feet and 1 inch, respectively (Ek and Dawson 1976). The corresponding values for the 9-year-old trees in the 8 x 8 foot planting were 38 feet and 4.5 inches (Zavitkovski, unpublished data).

## BIOMASS DISTRIBUTION

Spacing and age affect biomass distribution between stems and branches, and wood and bark and therefore affect the quality of the material produced. In general, the percentage of stem biomass increases with decreasing spacing and with age (table 8). In dense stands, e.g., 1 x 1 foot, stems accounted for about 75 percent of the total woody biomass in stands from 3- to 5-years-old. In widely spaced stands, e.g., 8 x 8 feet, stem biomass increased from 53 to 57 percent from age 3 to 5 and reached 65 percent in the 9-year-old stand.

Spacing also affects percentage of bark on stems and branches. For both components, percentage of bark decreases with wider spacing and with age (table 8). For example, at age 5, stem bark percentage in plantings spaced from 1 x 1 to 8 x 8 feet ranged from 20 to 14 percent and that of branches from 41 to 30 percent. At age 9 in the 8 x 8 foot planting, stem bark accounted for 12 percent of the total stem biomass and branch bark for 30 percent of the total branch biomass.

## NUTRIENT REMOVALS

Tree spacing affects both tree size and rotation age and consequently nutrient concentration and total quantity of nutrients removed at harvest (Hansen and Baker 1979). In particular removal of N, and to a lesser extent P and K, can be reduced with longer rotations. For example, nitrogen concentration in the above-ground biomass of 9-year-old NC-5260 was only one-third that in 2-year-old trees of the same clone (Hansen, unpublished data). So wider spacings and longer rotations will drain less nutrients.

## HARVESTING COSTS

Harvesting costs of dense plantations will be higher than that of open stands. Mattson (unpublished report dated 1976) calculated that efficiency of existing whole-tree chipping systems (visualized for harvesting of ICHP plantations) increases with wider spacing. The total cost of whole-tree harvesting, expressed in dollars per dry ton harvested, would be about three times higher in dense plantations (2 x 2 feet) than in open plantations (12 x 12 feet). For this calculation, Mattson assumed (from Ek and Dawson 1976) that both plantations will have the same biomass at age 10 but the dense plantation would have 33 times more trees than the open one. Our studies indicate that a different situation may develop in the harvesting of the two stands. The dense planting would be harvested several times (about 3 times) while the open plantation only once to accumulate the same stem-branch biomass. Under this system, the economic disparity may be even greater unless new harvesting-chipping machines being developed will substantially reduce harvesting costs in ICHP plantations.

The foregoing discussion indicates that the decision of "which spacing" should be made after considering a number of factors. No one spacing will be best for all cases. From the economic standpoint, not only plantation establishment but also harvesting will be less expensive in open plantations. The longer rotation cycles may have an additional advantage in reducing both soil compaction and the impact on site fertility.

Table 8.—*Biomass distribution among tree components of ICHP in Wisconsin*[1]

| Spacing (ft) | Age | Woody biomass: Stems | Woody biomass: Branches | Stems: Wood | Stems: Bark | Branches: Wood | Branches: Bark |
|---|---|---|---|---|---|---|---|
| | Years | Percent | | | | | |
| 1 x 1 | 3 | 74 | 26 | 75 | 25 | 56 | 44 |
| | 4 | 76 | 24 | 79 | 21 | 58 | 42 |
| | 5 | 78 | 22 | 80 | 20 | 59 | 41 |
| 2 x 2 | 3 | 63 | 37 | 78 | 22 | 60 | 40 |
| | 4 | 72 | 28 | 81 | 19 | 60 | 40 |
| | 5 | 77 | 23 | 83 | 17 | 61 | 39 |
| 4 x 4 | 3 | 53 | 47 | 79 | 21 | 64 | 36 |
| | 4 | 64 | 36 | 83 | 17 | 65 | 35 |
| | 5 | 69 | 31 | 85 | 15 | 65 | 35 |
| 8 x 8 | 3 | 53 | 47 | 78 | 22 | 67 | 33 |
| | 4 | 56 | 44 | 84 | 16 | 69 | 31 |
| | 5 | 57 | 43 | 86 | 14 | 70 | 30 |
| | 9 | 65 | 35 | 88 | 12 | 70 | 30 |

[1]Based on Meldahl's (1979) PhD Thesis and on measurements and calculations of the authors.

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# PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary landfill dump, or crush and bury them in a level, isolated place.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because regulations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

PROTECT

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FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

Hansen, Edward; Moore, Lincoln; Netzer, Daniel; Ostry, Michael; Phipps, Howard; Zavitkovski, Jaroslav.
Establishing intensively cultured hybrid poplar plantations for fuel and fiber. Gen. Tech. Rep. NC-78. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983, 24p.

This paper describes a step-by-step procedure for establishing commercial size intensively cultured plantations of hybrid poplar and summarizes the state-of-knowledge as developed during 10 years of field research at Rhinelander, Wisconsin.

KEY WORDS: Intensive forestry, biomass plantations, energy plantations, maximum yield.

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