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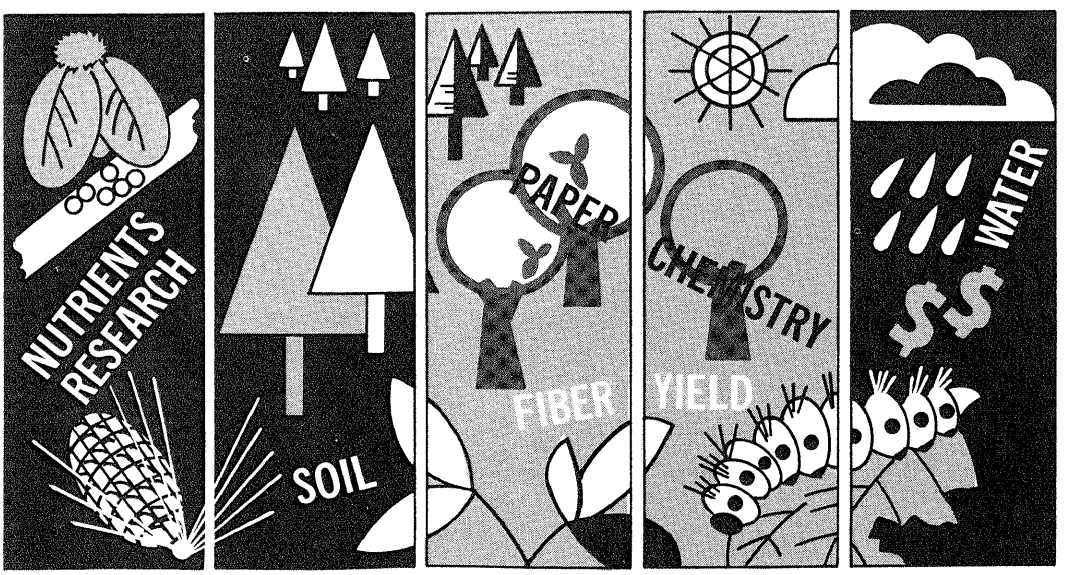
INTENSIVE PLANTATION CULTURE



FIVE YEARS RESEARCH

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE • U.S. DEPARTMENT OF AGRICULTURE

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HISTORY AND ORGANIZATION OF THE MAXIMUM WOOD YIELD PROGRAM

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"Intensive culture" can be defined for this conference as the application of several cultural practices to the establishment and management of plantations with the objective of increasing the quantity and quality of wood produced. The Multiproject Program for maximum yield and intensive culture of planted stands includes research studies in genetics, silviculture, soils, plant nutrient and water needs, utilization, and economics, all directed toward the common goal.

Before the detailed reports of 5 years' progress in specific research areas are presented, it would appear worthwhile to present an overview of the structure, history, and rationale of the organization that provides the framework for the specific studies.

Moreover, we need to discuss terms. The terms "intensive culture" and "maximum yield" have been interpreted in many ways. For purposes of this conference and series of papers, "intensive culture" means the application of several--as opposed to one or two--cultural practices to the establishment and management of plantations with the objective of increasing the quantity and quality of wood produced. "Maximum yield" means the amount of fiber produced when *all* environmental and genetic factors affecting tree growth are optimized.

The program under review is officially termed: "Multiproject Program II: Maximum Yield and Intensive Culture of Planted Stands"--including species selection, cultural methods technology, harvesting techniques, utilization, and economics.

The research mission of the program is "to develop the most biologically efficient and economically feasible method of producing maximum commercial wood per acre by means of a systems approach involving the unified effort of several disciplines."

Obviously, the program is somewhat dissimilar from most other Forest Service research operations in that it encompasses several "specialties"--not just one. That is, it is not a research effort in, for example, silviculture, *or* pathology, *or* economics, *or* genetics, but a team of research people trained in different elements of the broad field of forestry cooperating to accomplish a specific research objective.

The justification for a research program to explore the possibility of maximizing wood yields is emphasized in Forest Resource Report 29, *The Outlook for Timber in the United States* (USDA Forest Service 1973): "...with rising relative prices of 1.5 percent per year above the 1970 trend level of lumber and somewhat smaller price increases for plywood, woodpulp, and other items, projected total timber demands by the year 2000 approximate 19 billion cubic feet. This latter projection includes increases in demand of 5 percent for saw logs between 1970 and 2000, 58 percent for veneer logs, and 130 percent for roundwood pulpwood."

Added to the problem of increasing demands is the probability of reduced acreage on which to grow the wood to meet the demand. There were 8.4 million acres less commercial timberland in 1970 than in 1962. In the Lake States alone, commercial forest land was reduced by 690,000 acres during the same period.

Moreover, much existing forest land is not highly productive. In the North, only 5.5 percent of the forest land is growing at 120 cubic feet per acre per year, and over a third of the acreage is producing only 20 to 50 cubic feet per acre per year.

Costs of owning land are also increasing. Taxes on forest land have risen several hundred percent in the past 10 years. On much of the commercial forest land, the projected value of stumpage is less than the capitalized costs of holding the land for the typical 40-or-more-year rotation (Hilliker 1969).

The alternative of procuring wood in Canada or more distant locations is becoming less viable because transportation costs, too, have risen exponentially. Pulpmill managers are finding that distances pulpwood can be economically hauled are greatly decreasing.

Given these trends and constraints, it is apparent that what is needed is a system of wood production on land near the mills, with large increases in wood production per acre being the objective.

Are increases in wood production of perhaps several hundred percent per acre possible, and if so, how are they to be obtained? Although agricultural productivity per acre has been greatly increased over the past several decades, we have no similar increase in yields of wood products. There are, however, strong indications that large increases in wood yields are possible (Gordon 1975), but as Larson and Gordon (1969) pointed out, "to realize the full potential of photosynthetic productivity, research programs must create new forest conditions rather than just imitate old ones." Questions to be resolved to attain this potential have to do with (1) type and quality of wood produced, whether it be logs or a "maximum-dry weight yield per unit land area," (2) length of rotation, (3) cultural practices and environment, and (4) species (or species variants). Clearly, to fully explore these questions requires a multidisciplinary approach. Thus, silviculturists, physiologists, geneticists, harvesting engineers, wood technologists, and others must work together toward the common goal of maximizing production.

The Multiproject Program headquartered at Rhinelander was organized in 1971 to provide a team of scientists working on the common goal of maximizing wood production per acre, not merely increasing it.

Using some established genetic, physiological, and cultural information and improved plant material, plots have been established each year using poplar selections and hybrids, green ash, larch species and hybrids, jack pine, paper birch, European alder, and silver maple (figs. 1 and 2). The studies are designed to provide preliminary information on optimum spacings, rotations, and cultural methods for maximizing yields. To provide information on growth and yield, such factors as leaf-area-index, ratios of stem wood to total weight, percentages of bark and other plant components to total weight, are recorded and analyzed (fig. 3).

Our early studies did indeed verify the fact that selected hybrid trees grown under nearly optimized conditions of nutrients, water, and plant spacings would produce much more wood than traditional forest management systems. Plots of one *Populus* hybrid produced the equivalent of about 5 tons (dry weight) of wood, exclusive of leaves and bark, per acre per year, calculated from plots 3, 4, and 5 years after planting (fig. 4). The University of Wisconsin, Department

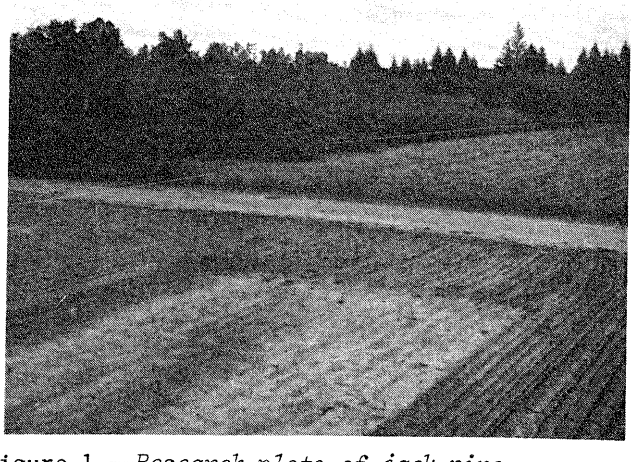

Figure 1.--*Research plots of jack pine, tamarack, and hybrid poplar growing under intensive culture.*

Figure 2.--*Five-year-old intensively cultured tamarack at 1 by 1 foot spacing.*

Figure 3.--*Heavy production of large leaves exposed to full sunlight of* Populus *hybrid* (P. trichocarpa *x* P. betulifolia).

of Forestry, is modeling data from the plots to project yields and thus more precisely estimate optimum rotations and plant spacings (Dawson *et al.* 1976, Ek and Dawson 1975).

Figure 4.--*Five-year-old* Populus *'Tristis' #1 in a 9 inch by 9 inch spaced irrigated and fertilized plot.*

Other studies at Ames, Iowa, and Rhinelander, Wisconsin, indicate that 14 of 30 genetically improved *Populus* hybrids are worthy of further testing. Research at Rhinelander also involves studies in intensive site preparation, plant propagation, nutrient, and water needs for maximum yields.

There is clearly a need in the North Central Region for proper management of the sites totally cleared as a result of the whole-tree chipping system. This type of harvesting leaves the site much "cleaner" than the conventional clearcut, offering excellent opportunities for converting to genetically improved trees. New species combinations, such as hardwood-conifer mixtures for maximum site utilization, need to be explored. Optimum plantation density needs to be determined. Much of this research will be conducted in cooperation with the Forest Engineering Project at Houghton, Michigan.

It has long been recognized that all wood within a given tree species is not anatomically identical. Such factors as specific gravity, fiber length, vessel-fiber ratio, extractives, color, and cell wall thickness may vary greatly within a species and dramatically affect the end product, whether it be paper, particleboard, plywood,

or lumber. Hence, a Station wood technologist is cooperating with the Forest Products Department of the School of Forestry, University of Minnesota, on pulping studies of the "new" intensively grown trees. The Forest Products Laboratory at Madison is cooperating in research involving the use of the plant material in particleboard.

Intensively managed plantations will certainly require special mechanized planting and harvesting techniques. The Engineering Systems Work Unit at Houghton, Michigan, is researching in this area.

Growing dense stands of trees of the same species under near optimized conditions, in some cases irrigated, requires attention to possible disease and insect problems if yields are to be maximized. The Diseases of Forests and Christmas Tree Plantations project at St. Paul and the Plant Pathology Department of the University of Wisconsin have set up several studies to consider disease problems. The Work Unit "Insects Affecting Forest Ecosystems" is cooperating with Michigan State University in studying the impact of insect damage on growth and yield of intensively cultured plantations.

Perhaps the most frequent question regarding maximum yield or intensive culture research is, "Is it economical?" The University of Minnesota, Department of Forest Resources, cooperating with the North Central Station's "Economics of Forest Land Management" Work Unit, has explored and is continuing to study economic feasibility of intensive culture systems in relation to other alternatives.

Close liaison has been maintained with forest managers since the inception of the program. The problem analyses and study plans have been reviewed by managers and cooperating researchers as the program has progressed. Also, an attempt has been made to keep abreast of basic research results constantly being generated worldwide.

The following reports present in detail the research in progress and provide a base for joint planning by managers and researchers for the period ahead.

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YIELDS OF INTENSIVELY GROWN POPULUS: ACTUAL AND PROJECTED

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Yields of Populus 'Tristis #1' *based on 4 years of growth under intensive culture at square spacings of 0.75, 1, and 2 feet are reported. Stem and branch wood yields of up to 45,132 pounds per acre were recorded. Tree growth and competition data from these plots were then used to calibrate a stand growth simulation model to enable projections of these and three wider spacings to 10 to 25 years. Over the range of spacings examined (0.75 to 12.7 feet), the mean annual growth of projections peaked at 8 to 15 years with stem and branch wood dry weights in the range of 13,881 to 16,584 pounds per acre per year, five to six times that possible from reported natural aspen stands. Projected tree sizes and growth patterns are discussed in relation to rotation age and related management alternatives. Continuing growth and yield studies are also outlined.*

Intensive cultural practices are receiving increased attention as means for increasing wood production. This report describes early results and projections of the development of fertilized and irrigated *Populus 'Tristis #1'* (*Populus balsamifera* L. x *P. tristis* Frisch.) at different spacings.[1/]

Initial field plantings concentrated on close spacings because several investigators have indicated substantial tonnages of wood may be produced early in the life of dense stands (Smith and DeBell 1973, Saucier *et al.* 1972, Ek and Brodie 1975). *P. 'Tristis #1'* was chosen for the trials described here because of its rapid early growth and the availability of cuttings. Future selections of hybrids may grow faster than *P. 'Tristis #1'*, but it was felt that experience gained with cultural practices, particularly spacing, fertilization and irrigation, would be useful in studies with other varieties and species.

Logistic, space, and time restrictions precluded a large number of spacing trials. Consequently, growth and competition data from the first 4 years of the trials on a limited set of field plots were used to calibrate FOREST, and individual tree based stand simulation model (Ek and Monserud 1974). In brief, the FOREST model simulates the periodic growth of individual trees as a function of their own size or condition and the competition they encounter. The approach allows the expression of individual tree response to a wide range of competition (spacings) and other cultural practices. This model was then used to develop projected yields to later ages.

CONDUCT OF THE STUDY

Cultural Practices

Hardwood cuttings 8 inches long were planted in early June 1970 on a prepared site in the Hugo Sauer Nursery near Rhinelander, Wisconsin. The cuttings were set at a depth of 6.5 inches in a 1 inch diameter hole. The soil is a sandy loam with 2 to 3 percent organic matter. The study plots were fertilized at planting and

[1/] *The research was supported by the College of Agricultural and Life Sciences, University of Wisconsin-Madison, and the USDA Forest Service.*

periodically as determined by tissue tests to maintain the levels below:

pH	6.7-7.0
phosphorous	190-200 pounds per acre
potassium	300-500 pounds per acre
calicum	11.0 millequivalents (replaceable per 100 grams of soil)
boron	2.5-3.0 pounds per acre
magnesium	3.0 millequivalents (replaceable per 100 grams of soil) minimum
manganese	20-40 pounds per acre
zinc	2-4 pounds per acre

Ammoniumnitrate was added to the soil as needed about every 3 weeks to maintain a 3.2 percent level of nitrogen in new leaf tissue. Soil moisture was maintained by irrigating at above 70 percent field capacity and weeds were controlled by the use of the pre-emergence herbicide Linuron.

Outplantings were made at three square spacings: 0.75-, 1, and 2 in plots of size 16.5, 17, and 18 feet on a side, respectively. These spacings correspond to stems per acre figures of 77,440, 43,560, and 10,890. These plantings were replicated three times (replicates I-III). Only a few seedlings died during the first year and these were replaced by similar stock.

Within each plot, a subplot was established for tree growth observations. Subplots contained 10, 30, and 50 trees for the 0.75-, 1-, and 2-foot spacings. Subplot stems were measured annually for total heights (H) and diameters (D) at the base of the root collar (0.083 feet). Only the plots from replicate III, however, were used for calibrating the FOREST model because replicates I and II were largely destroyed over the study period by harvesting for stem yield analyses and removing cuttings needed for additional plantings.

Model Calibration

The calibration of the FOREST model was described in detail by Ek and Dawson (1976); however, major aspects of this effort are noted briefly below. The most important components of the forest model are expressions for (1) potential height and diameter growth; (2) the relations between competition, realized growth, and potential growth; and (3) the relation between competitive status and the probability of survival.

Potential height growth was based on the height growth patterns of the tallest study plot stems and extrapolated to later ages by considering height growth patterns of older *Populus* trials noted in the literature. Potential diameter growth of a tree of height H was taken as the difference between its assumed open-grown diameter and the open-grown diameter of a stem of height $(H + \Delta H)$ where ΔH is height growth. Open-grown diameters were developed as a function of tree height from limited data on open-grown *Populus* stems in the Hugo Sauer Nursery.

Using subplot tree height, diameter, and location data, a competition index was developed for each subplot stem for each growth period. This index was a function of the area of overlap of assumed open-grown crowns and relative subject vs. competitor tree sizes. Open-grown crown diameters were expressed as a function of tree height using the same open-grown stems used for potential diameter growth noted earlier. The competition indices and related subplot growth data were then analyzed by nonlinear regression. This step produced equations for multipliers expressing the degree of realization of potential height and diameter growth.

Survival-competition relations were developed by sorting the growth data into competition classes. The class midpoint competition index was then used as the independent variable to estimate the proportion (probability) of trees surviving through the growth period (1 year). Tree mortality was simulated by comparing the projected probability of survival with a randomly generated (uniform 0-1) threshold value. When the threshold value exceeded the probability of survival, the stem was noted as dead.

Stem Yield

Some trees were harvested from each plot each year as the basis for developing tree yield. Most of this harvesting was from replications I and II. Height and diameter were measured and the trees were physically separated into stem wood, branch wood, bark, tips (terminal buds), and leaves, and then ovendried and weighed. These data were then used as dependent variables to derive tree yield expressions of the form: component weight=f(D,H). Details of measurement procedures and the

actual weight equations developed are given in Ek and Dawson (1976).

Analysis and Projections

Yields for the first 4 years of the study were developed by applying the above weight equations to the subplot trees in replicate III.

Projections using the FOREST model were made from the initial conditions at the end of the first growing season. Projections were first made to age 4 for the 0.75-, 1-, and 2-foot spacings assuming (as was the case) no competition from beyond the plot boundaries. Then projections were made to more advanced ages for 0.75-, 1-, 2-, 4-, 8- and 12.7-foot spacings assuming a forest edge.2/ As with the actual data, yields for the projections were developed by applying tree weight equations to the projected heights and diameters of surviving stems.

RESULTS AND DISCUSSION

Stand development and yields for the actual 0.75-, 1-, and 2-foot spacing plots of replicate III are given in table 1. Table 2 gives yields for the projections and indicates the age of maximum mean annual increment (MAI).

Projection Accuracy and Reliability

Graphic comparisons of actual vs. projected average heights and diameter growth and survival patterns for the first 4 years of study for replicate III are given by Ek and Dawson (1976). Although detailed for inclusion here, in general these comparisons showed close agreement of actual and simulated results. As validation of the general approach, Monserud (1975) also found close agreement between actual stand development and 20- to 25-year projections for the FOREST model as adpated to the nine-species northern hardwood forest type in Wisconsin. As shown by Ek and Dawson in graphic form, table 2 further illustrates desired relative behavior in terms of curve shapes, inflection points, and asymptotic tendencies. The forms of the tree weight models used limit the chance of large errors in extrapolating yield projections to stems beyond the 1- to 4-year age range.

Although differences between actual and projected values do exist, it is important to note that these stand conditions posed an extreme test in terms of the wide range of competition and the large relative changes in tree size considered. Further

2/ *The plot image was replicated and shifted for competition calculations to form an eight-plot border zone around the main plot. See Monserud and Ek (1975) for a description of this methodology and implications.*

Table 1.--*Actual yields of* Populus 'Tristis *#1' study plots*

Age (years) 1/	Average stem diameter	Average total height 2/	Live trees per acre	Dry weight per acre: Stem wood 3/	Dry weight per acre: Stem wood + branch wood
	Inches	*Feet*	*Number*	*Pounds*	*Pounds*
1	0.2	1	77,440	251	327
2	.7	6	74,279	7,069	8,484
3	.9	10	66,178	23,557	27,132
4	1.0	12	61,238	35,213	40,390
		1 BY 1 FOOT SPACING			
1	0.2	1	43,560	111	147
2	.7	6	43,560	4,578	5,686
3	1.0	11	40,299	19,726	22,782
4	1.3	14	38,491	38,300	45,131
		2 BY 2 FOOT SPACING			
1	0.2	1	10,890	23	32
2	.9	6	10,890	1,768	2,326
3	1.6	13	10,487	11,193	13,770
4	2.0	17	10,083	22,636	27,567

0.75 BY 0.75 FOOT SPACING

1/ Values given for ages 2 and 3 based on observations just prior to harvest of sample stems for tree yield determination. The magnitudes of the cuts are omitted as they were all small (less than 5.1 percent of the trees).

2/ At 0.083 feet.

3/ Above 0.083 feet.

Table 2.--*Projected yields of* Populus 'Tristis #1' *plantings at various spacings*

Age (years)	0.75 BY 0.75 FOOT SPACING				1 BY 1 FOOT SPACING				2 BY 2 FOOT SPACING			
	Average stem diameter[1]	Average total height	Live trees per acre	Dry weight per acre: Stem wood[2]	Stem wood + branch wood[2]	Average stem diameter[1]	Average total height	Live trees per acre	Dry weight per acre: Stem wood[2]	Stem wood + branch wood	Average stem diameter[1]	Average total height	Live trees per acre	Dry weight per acre: Stem wood[2]	Stem wood + branch wood
	Inches	*Feet*	*Number*	*Pounds*	*Pounds*	*Inches*	*Feet*	*Number*	*Pounds*	*Pounds*	*Inches*	*Feet*	*Number*	*Pounds*	*Pounds*
			4 BY 4 FOOT SPACING			8 BY 8 FOOT SPACING					12.7 BY 12.7 FOOT SPACING				
1	0.2	1	2,722	6	8	0.2	1	680	1	2	0.2	1	271	1	1
2	.8	6	2,705	326	407	.8	6	676	81	102	.8	6	269	33	41
3	2.1	11	2,672	3,313	4,795	2.1	11	668	828	1,199	2.1	11	266	330	478
4	3.2	17	2,655	12,828	18,283	3.9	16	663	3,981	6,462	3.9	16	264	1,588	2,578
5	4.0	24	2,638	29,729	39,896	6.1	23	659	13,057	22,775	6.3	23	263	5,481	9,983
6	4.4	29	2,621	45,409	59,898	7.4	31	655	26,673	43,514	8.8	29	261	12,743	25,155
8	5.3	35	2,554	78,724	102,893	9.4	46	642	65,402	97,839	13.1	45	258	43,183	82,801
10	6.1	39	2,436	108,972	143,053	10.5	53	630	94,590	138,856	15.1	57	253	74,573	131,300
15	7.9	48	2,083	[3]185,268	[3]248,755	12.7	64	605	[3]163,515	[3]238,470	18.2	75	243	[3]141,858	[3]234,104
20	9.5	54	1,613	222,960	305,157	14.0	70	550	190,117	278,903	19.3	80	228	156,195	256,532
25						15.2	75	508	219,128	323,447	20.0	84	223	169,138	277,161

1/ At 0.083 feet.
2/ Above 0.083 feet.
3/ Age of maximum mean annual increment.

studies on larger plots outlined later will document the accuracy of these projections and likely lead to refinements in projection methodology. For now, however, the projections given here are expected to be a valuable planning aid.

Yield Analysis

Table 1 and 2 values suggest early culmination of current annual increment (CAI). As with natural aspen stands (Ek and Brodie 1975), however, rapid growth continues past the first decade. Although the age of maximum CAI appears to depend on spacing, maximum MAI for stem wood and stem wood plus branch wood fell in the 8- to 15-year range for all spacings. Further, the dry weight yields were similar at maximum MAI except for the extreme spacings. The fact that yield curves are nearly linear in the 8- to 15-year range also suggests great flexibility in rotation ages between 8 and 15 years with little sacrifice in dry weight yields.

The 4-foot spacing appears most promising for fiber production. The MAI of 16,584 pounds per acre for stem and branch wood is approximately six times that possible from natural aspen stands as described by Ek and Brodie (1975).

These yields are promising for fiber production. However, it is also possible that the large trees developed (see table 2) may lead to consideration of thinning and other product alternatives.

FUTURE RESEARCH PLANS

Current plans are to document projection accuracy and refine the FOREST model according to observations on larger plots of *Populus 'Tristis'* over longer time periods. In particular, observations at advanced ages will aid refinement of tree component weight and product functions.

Study plots of numerous other rapid growing *Populus* selections as well as *Larix* hybrids, *Pinus banksiana, Alnus,* and *Betula papyrifera* have also been established. Such plots will be used early to calibrate the FOREST model. Projections and comparisons will then be made to evaluate and screen promising plant materials. Because these genotypes and/or species may respond differently to spacing, extensive use is being

made of a variation of the Nelder plot design (Nelder 1962). The actual layout varies trees spacing in two directions across the plot (fig. 1).

Figure 1.--*Sample of a variable spacing plot (four contiguous replicates) for promising* Populus *varieties. Photo taken in Hugo Sauer Nursery.*

Significant in this modeling approach is that spacing need not be uniform within plots. The FOREST model is calibrated with growing-competition rather than growth-spacing data. A range of spacings within a plot varies competition and through model calibration facilitates extrapolation of the model in subsequent projections of yields for alternative spacings. As expected, this approach is very efficient in terms of the planting stock and space required. It also incorporates and projects the effects of mortality on growth and yield.

As a supplement to simulation analyses, optimal spacing strategies may also be determined by mathematical programming. Such an approach would involve use of growth algorithms from the FOREST model in a formal optimization framework. The problem would be choosing tree coordinates on a plot so as to maximize aggregate tree growth for a period. An outline of this approach is given in Adams and Ek (1975).

In summary, as information on species, species variants, fertilization, irrigation, spacing, etc., expands, the overall modeling approach will increasingly become a focal point of the project. In this framework, the FOREST model will be the principal tool for projecting the implications of changes in cultural practices on wood production in terms of both quality and quantity.

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SOME PHYSIOLOGICAL APPLICATIONS FOR INTENSIVE CULTURE

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Every silvicultural practice employed by the forest manager is based on physiological principles. By understanding how trees grow as they do and how they respond to each silvicultural practice, the physiologist can suggest ways to increase wood yield and to improve wood quality through the deliberate manipulation of the tree's growth. To do this requires information that can only be obtained by physiological research. The results of several studies are summarized showing (a) the relation between leaf production and plant biomass production, (b) the chemical composition of wood, (c) the chemical composition of leaves, and (d) the formation of tension wood in Populus *clones grown under intensive culture. A number of desirable growth traits and tree attributes have been compiled to construct an ideotype, a hypothetical tree.*

Every silvicultural practice employed by the forest manager is based on physiological principles. Stand density management, for example, is the most powerful means available to the silviculturist for directly controlling competition and for regulating growth and yield. Site amelioration also directly affects growth and yield by improving site quality, hence crown and root development. Other silvicultural practices result in more indirect growth responses. For example, the control of crown size and shape by pruning results in a redistribution of growth on the stem, consequently an alteration in stem form and taper. Each of these silvicultural practices is effective because the trees are either stimulated to greater growth or encouraged to grow in a more desirable way. By understanding how trees grow as they do and how they respond to each silvicultural practice, the physiologist can suggest ways to increase wood yield and improve wood quality through the deliberate manipulation of selected stages of the tree's growth (Larson 1969, 1972).

It is well known that silvicultural practices achieve their effects by improving either root or crown development or the relation between them. However, because of the close inter-relation between the two systems and because root growth is so difficult to study, most research has concentrated on the crown. The leaves are the effective organs in terms of growth and the tree crown consists of an orderly assemblage of leaves. Studies have shown that the effectiveness of leaves varies with the relative age of the branch from which they arise and its position in the crown. Leaves are therefore not all alike. These leaf age-leaf position relations are basic to maximizing tree growth and yield, and they can be manipulated by cultural practices. It is the ability to manipulate these relations according to physiological principles that distinguishes intensive culture from conventional forestry. [1/] The premise on which intensive culture is based rests wholly on how efficiently, in terms of time and economic benefits, the silviculturist can manage this array of photosynthesizing leaves to produce the maximum quantity of wood of acceptable quality for a particular end use.

Even under the best of field conditions, young trees never approach their optimum

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1/ *Larson, P. R. 1970. Science and the art of forestry. Belle W. Baruch Lectures, Clemson Univ., Clemson, South Carolina, March 2-6, 1970. (Unpublished.)*

growth potential (Larson 1974). However, physiological research can suggest numerous possibilities for improving the environment and for selecting genotypes that can utilize it more efficiently.[2/3/] By this approach, appropriate cultural practices can be devised for raising productivity well above the level normally attained by conventional forest management.

Physiological manipulation of a tree crop by cultural practices to attain near-maximum wood yield can lead in several directions (Larson 1969, Larson and Gordon 1969). One way would be to increase the total photosynthetic production or the leaf biomass. Under conventional forestry systems the growing site is neither efficiently utilized nor completely covered by photosynthetic organs until rather late in the rotation. By combining intensive culture with close plant spacing and a short rotation, the rapid juvenile growth of selected species can achieve most efficient use of the land. The net result of these cultural practices would be a greatly increased photosynthetic leaf surface, consequently increased dry-weight productivity.

Another way to increase plant productivity and wood yield would be to increase the effective length of the growing season because few temperate zone species utilize it completely or efficiently. Properly directed physiological research can suggest a balanced approach for culturally improving the environment and for selecting responsive genotypes that would significantly extend the growth period and increase productivity per unit land area.

Maximum dry-weight productivity does not necessarily mean maximum wood production nor does it imply that the wood will be distributed within the tree in the most desirable way. However, because of the strong relation between leaf production and wood production in young trees (Larson and Isebrands 1972), intensive cultural practices that maximize growth at close spacings will tend to concentrate growth on the stem. Again, physiological research can suggest many ways in which the high levels of photosynthetic production can be distributed within the tree to increase both the quantity and the quality of the wood produced. Specific examples to be discussed later include tension wood formation and the chemical composition of the fiber cell wall.

Research efforts of the Pioneering Unit of the North Central Station are devoted almost exclusively to the physiology of wood formation. Nevertheless, some of the research results can be applied either directly or indirectly to certain facets of intensive culture. The following research summaries fall broadly within the lines of investigation just discussed.

LEAF PRODUCTION IN *POPULUS* GROWN UNDER INTENSIVE CULTURE

By increasing the photosynthetic productivity or total leaf surface within certain limits, the dry-weight productivity of a forest crop can be increased. The most effective way to increase photosynthetic leaf surface under short-rotation, intensive-culture conditions is to plant at close spacings and thereby increase the total number of leaves produced on the area (Gordon and Bentley 1970). One method of quantifying the potential photosynthetic surface is leaf area index (LAI), which is the ratio of total leaf surface area to land area, i.e., the number of square meters of leaf area per square meter of land area. LAI can be increased by cultural manipulations designed to increase not only the number of leaves but also the size of the leaves in the tree canopy (Zavitkovski *et al.* 1974).[4/]

Trees grown on short-rotation, intensive-culture test plots by the Maximum Yield Project at Rhinelander, Wisconsin, represent examples of how dry-weight productivity can be increased by increasing LAI. Rooted cuttings of *Populus* 'Tristis' were planted at 0.2, 0.3, and 0.6 meter spacings in 4.88 meter square plots. The plots were cultivated, irrigated, and fertilized to provide near optimum growing conditions (Crist and

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2/ Dickson, R. E. 1973. Growth and yield measurements. USDA For. Serv. In-service Workshop on Intensive Culture, Rhinelander, Wisconsin, Sept. 18-19, 1973. (Unpublished.)

3/ Larson, P. R. 1973. Physiological parameters of intensive culture: theoretical and applied. USDA For. Serv. In-service Workshop on Intensive Culture, Rhinelander, Wisconsin, Sept. 18-19, 1973. (Unpublished.)

4/ Isebrands, J. G. 1973. Biomass and primary productivity. USDA For. Serv. In-service Workshop on Intensive Culture, Rhinelander, Wisconsin, Sept. 18-19, 1973. (Unpublished.)

Dawson 1975). After 3 years, the above-ground, dry-weight yields (without leaves) were 12.46, 11.08, and 5.95 metric tons per hectare per year (table 1) for the 0.2, 0.3, and 0.6 meter spacings, respectively (Dawson *et al.* 1976). These yields are much higher than reported for either natural or planted stands of *Populus* in the area.

meter spacings, respectively (table 1). Leaf surface area continued to increase in the 4th year; the upper-surface leaf area per tree averaged 24,557, 33,614, and 65,308 square centimeters for the 0.2, 0.3, and 0.6 meter spacings, respectively. Leaf area per tree was closely related to the dry-weight production of individual trees after 4 years

Table 1.--*Above ground dry-weight yields, leaf number, and leaf area per tree for* Populus *'Tristis' grown in intensive culture plots*

Spacing	Trees per hectare	Age 3: Dry-weight yield 1/ per hecatre per year	Age 3: Leaves 2/	Age 3: Leaf area/tree 2/	Age 4: Leaf area/tree 3/
Meters	*Number*	*Metric tons*	*Number*	*Square centimeter*	*Square centimeter*
0.2 x 0.2	191,358	12.46	680	21,065	24,357
.3 x .3	107,639	11.08	832	21,959	33,614
.6 x .6	26,910	5.92	956	26,225	65,308

1/ Total above ground dry weight (without leaves). Data have been extrapolated from 4.88 square meter plots to a hectare basis (Dawson *et al.* 1975).
2/ Average 4 trees; total tree sample.
3/ Average 4 trees; 25 percent sample.

We attribute the higher productivity of plots in the present study to an increase in photosynthetic capacity resulting from an increase in LAI, a function of intensive management practices. For example, the total number of leaves and their sizes were increased by cultivation, irrigation, and fertilization. These intensive cultural practices also contributed to maintaining a high LAI throughout the growing season by prolonging retention of leaves in the lower canopy despite the close spacings. Furthermore, substantial leaf area development takes place early in the growing season in *Populus*. Therefore, the increase in photosynthetic surface occurred during that part of the growing season most critical for rapid height growth and leaf development. The largest portion of the leaf area produced in this early surge of growth was in the uppermost canopy layers where light interception was at a maximum, a necessary requirement for high productivity (Zavitkovski *et al.* 1974).

The above factors all contributed significantly to a high leaf area per tree. At the end of 3 years the total number of leaves per tree averaged 680, 832, and 956 and the total upper-surface leaf area per tree averaged 21,065, 21,959, and 26,225 square centimeters for the 0.2, 0.3, and 0.6

(fig. 1). The relation is linear because, unlike natural stands, trees growing under short-rotation, intensive-culture conditions are of the same age and have a narrow range of heights and diameters.

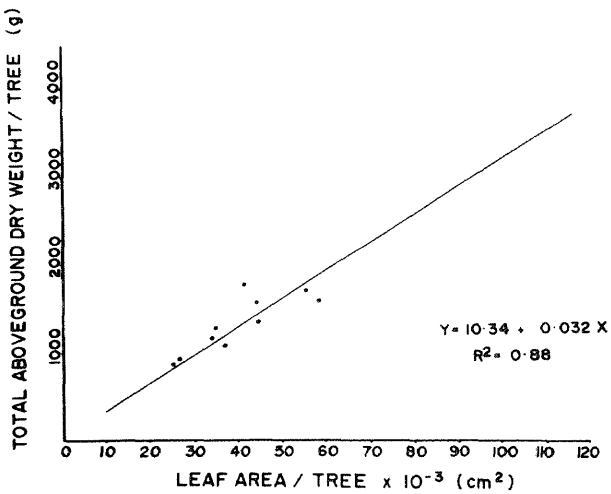

Figure 1.--*The relation between upper-surface leaf area/tree and dry-weight production in 12 4-year-old* Populus *'Tristis' trees grown under intensive culture.*

LAI was estimated by double sampling with regression (see Zavitkovski *et al.* 1974 for detailed methodology). The high leaf area per tree shown above therefore contributed to high LAI estimates for the plots. The LAI values obtained for the plots were much higher than those obtained from natural stands of *Populus* (Zavitkovski *et al.* 1974). For example, after 4 years the LAI for the plots with a 0.6 meter spacing was 17.57. This value may approach the theoretical limits for *P.* 'Tristis' in northern Wisconsin for several reasons. First, no mortality was assumed in making the calculations, and some mortality would normally be anticipated. An adjustment for mortality would lower the LAI estimates. Second, the observations were made on small plots, therefore, downward adjustments in LAI may be required, because small plots allow greater light penetration than larger plots. Consequently, leaves would be larger and leaf retention greater in the small plots, thus biasing the LAI estimates upward. Nevertheless, even after adjusting for these biases, a LAI of 12 to 15 should be expected for the 0.6 meter spacing and a LAI of 20 or more for the closer spacings. These preliminary estimates of LAI are similar to those obtained from several stands of *P.* 'Tristis' constructed by computer simulation (Promnitz and Rose 1974).

The explanation for the high LAI's and the associated high dry-weight yields undoubtedly lies with the intensive management practices. However, it should be re-emphasized that preliminary observations on small plots may not necessarily hold for larger acreages. Further research is therefore needed to quantify the effect of LAI on dry-weight production in *Populus* grown under intensive cultural practices.

CHEMICAL COMPOSITION OF WOOD GROWN UNDER INTENSIVE CULTURE

Photosynthates produced by the leaves can be distributed to other growing regions of the tree in various proportions; for example, in the allocation of photosynthate to wood development. The thickness of the fiber wall and the fiber/vessel ratio vary considerably among different *Populus* clones and hybrids. These variations are associated with changes in wood specific gravity and in the proportions of lignin, hemicellulose, and cellulose in the cell walls. Each of these factors significantly influences the yield and quality of the pulp produced. We have investigated some of this variability in wood characteristics among *Populus* hybrid clones grown under intensive culture (Dickson *et al.* 1974). The objective of the study summarized below was to examine the range of variability of several wood quality factors and to identify those clones that may have potential value in a selection program.

The wood samples were obtained from *Populus* clonal trials of the Maximum Yield Project at Rhinelander, Wisconsin. The 18 clones examined were initially selected by tree breeders in different parts of the world for fast growth, disease or insect resistance, or some other selection criterion. The clones therefore represented a wide genetic base, and when they were grown under optimum, but comparable, cultural conditions in the nursery, they exhibited a wide range of variation. In all cases, the third annual growth ring from 3-year-old shoots was sampled.

The range of properties examined varied widely among the 18 clones (table 2). For example, the width of the third annual growth ring varied considerably as did the specific gravity of its wood, although the latter was not directly related to rate of growth. Glucose, which is a measure of cellulose yield, and the remaining wood sugars, which provide a crude estimate of hemicellulose content, also varied widely. The average clonal values for the different wood characteristics, as well as their ranges, indicate that 3-year-old *Populus* wood falls within the limits of acceptability for pulp production.

Table 2.--*Wood properties and growth characteristics of 18* Populus *hybrid clones* (In percent)

Item	Average	Range
Sugars		
Glucose	63.6	60.5 - 69.2 1/
Galactose	3.0	2.5 - 3.6
Mannose	5.5	3.7 - 7.6
Xylose	26.5	22.9 - 29.1
Arabinose	1.4	0.7 - 1.7
Total	100.0	
Lignin	21.3	18.1 - 25.0
Extractives	3.3	2.2 - 4.6
Specific gravity	0.334	0.272 - 0.368
Growth rate (1973 ring wdt.(mm))	6.9	2.4 - 11.4

1/ The sugar percentages were based on total carbohydrates, while the lignin and extractive percentages were based on ovendry weight of extractive-free wood.

We selected three clones as potential candidates for intensive culture on the basis of desirable wood properties determined in this study (table 3). Other growth and yield characteristics would, of course, enter into final clonal selections.

Table 3.--*Wood properties and growth characteristics of three* Populus *clones with potential for intensive culture*

Item	*P. nigra* hybrid (5331)	Crandon (5339)	Unknown 1/ (5351)
Growth			
Height (*meter*)	5.5	5.5	5.0
Diameter (*centimeter*)	5.8	4.6	9.6
1973 Ring width (*millimeter*)	9.0	7.7	6.6
Specific gravity	0.363	0.349	0.339
Lignin (*percent*)	20.4	18.9	18.1
Extractives (*percent*)	2.2	2.8	2.9
Sugars (*percent*)			
Glucose	60.9	65.5	64.5
Xylose	28.8	26.1	26.3

1/ *Populus* sp. Parentage unknown, but contains some *P. balsamifera*.

One important question regarding intensive culture is how growth rate affects wood characteristics. Growth rate alone appeared to exert little influence on the wood chemical characteristics of the *Populus* hybrids. Furthermore, no consistent differences in wood chemical constituents were revealed between rapid-grown cottonwood trees from plantations and slower-grown trees from natural stands (Dickson *et al.* In press). The yield differences that were present resulted either from inherent age patterns or from individual tree variation, but not from rate of growth.

TENSION WOOD IN *POPULUS* GROWN UNDER INTENSIVE CULTURE

The acceptability of the short-rotation, intensive-culture approach from the standpoint of wood utilization will depend not only upon the quantity of wood fiber produced, but also its quality. *Populus* species tend to produce large volumes of tension wood (Isebrands and Bensend 1972). The proportion and distribution of gelatinous fibers comprising the tension wood affects the uniformity and strength of the resultant pulp.

In a study of *Populus* 'Tristis' grown under intensive-culture conditions, Isebrands and Parham (1974a) found that 2- and 3-year-old stems contained a high proportion of gelatinous fibers; percentages ranged from 13.8 to 38.7 in 2-year-old stems and from 14.0 to 37.5 in 3-year-old stems depending on the sampling position in the stem. After kraft pulping, gelatinous fibers were more bulky than normal wood fibers, and thus lower in collapsibility. Furthermore, the gelatinous fibers were characterized by slip planes and minute compression failures that lower the strength of the individual fibers and detract from uniformity of the pulps produced (Isebrands and Parham 1974a, b). Because of the detrimental effect of large quantities of gelatinous fibers, rotation ages of 2 to 3 years for *Populus* 'Tristis' may be too short from a utilization standpoint.

The above results also have physiological implications. The high proportion of gelatinous fibers produced by *Populus* trees grown under intensive culture indicate that large quantities of photosynthate were being diverted into the production of wood with undesirable properties, namely tension wood, rather than normal wood. The trees were therefore inefficient in terms of wood production from a physiological standpoint. Also of physiological importance, tension wood formation in stems of *Populus* grown under intensive culture appeared to be strongly related to rapid growth rate rather than to lean or other tree abnormalities. This observation confirms earlier work on trees from rapidly grown cottonwood plantations (Isebrands and Bensend 1972), and suggests that rapid growth rate may produce a balance

of hormone and photosynthate within the tree to favor the formation of gelatinous fibers.

CHEMICAL COMPOSITION OF LEAVES GROWN UNDER INTENSIVE CULTURE

Research on the utilization of foliage has been given little consideration within the United States (Keays and Barton 1975). With present methods of whole tree utilization, leaves, or leaves plus bark, constitute a costly chip contaminant. However, there are several potential uses of foliage that might make its separation and utilization profitable. One of these might be a protein concentrate for either human or livestock consumption, depending on its recovery grade and purity (Stahmann 1968, Pirie 1971). Another use might be as a livestock feed in the form of "muka" (Keays and Barton 1975). Muka, as prepared in the USSR, is an animal feed and vitamin supplement made of finely ground foliage, bark, and small branches. Depending on the amount of branch and bark material in the mix, muka can be a satisfactory substitute for an equal weight of alfalfa or clover meal. If the protein or nitrogen content of the foliage is low, urea can be added during the processing. The use of tree foliage as a partial replacement for conventional animal feeds appears to offer an immediate gain from research and the greatest potential for the utilization of what is at present a waste product.

As part of the information necessary for utilization of foliage from trees grown under intensive cultural conditions, the major chemical constituents were examined in leaves from essentially the same *Populus* hybrid clones that were examined for wood chemical characteristics.[5/] In addition, leaves from 2-year-old trembling and bigtooth aspen sprouts and from 3-year-old nursery-grown green ash and silver maple saplings were examined for comparison.

Although all of the trees except bigtooth and trembling aspen were grown in the same area of the nursery and received the same amounts of fertilizer and water, there were considerable differences in the various chemical fractions (table 4). For example, total nitrogen (N) of the *Populus* leaves ranged from 2.1 to 3.9 percent on a dry-weight basis. Leaves from the unfertilized trembling aspen sprouts and the green ash and silver maple saplings contained lower average amounts of total N and protein than the *Populus* clones.

The extracted protein and soluble amino acid fractions provide estimates of the food value of leaves, particularly if used for human consumption or for high quality livestock-feed supplements. However, much of the protein is not extracted by the methods used to isolate these fractions. A better indication of the potential for muka production is therefore crude protein, which is calculated by multiplying total nitrogen percent by 6.25. The average crude protein value for the *Populus* leaves was 19.5 percent of the total dry weight. This value compares favorably with that found in alfalfa, one of the major forage crops produced in the United States (Kohler and Bickoff 1971).

The carbohydrate fractions of forage also provide important nutritional benefits, particularly to ruminants. Total nonstructural carbohydrate (TNC) is a common measure for estimating carbohydrate food value of forage; it consists of the total soluble sugars plus starch. TNC averaged about 2 percent of the total leaf weight in both the *Populus* hybrids and the other fast-growing trees.

Leaves from four clones with potential for muka production (table 5) contained high levels of total N, protein, and TNC. It is evident from these data that *Populus* leaves have a high potential as an animal-feed supplement.

SUGGESTED APPLICATIONS OF PHYSIOLOGICAL RESEARCH

The foregoing study summaries suggest several ways for improving certain growth and yield characteristics of *Populus* when grown under short-rotation, intensive-culture conditions. The characteristics studied are not necessarily those of most interest to the silviculturist. Many growth and yield traits must be considered when selecting the species or clones for a given set of end-use requirements. However, the greater the data base available to either the silviculturist or the geneticist, the better he can make his initial selections and improve on subsequent ones destined for future rotations. The tree physiologist can contribute

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5/ Dickson, R. E., and P. R. Larson. Unpublished data on file at the Institute of Forest Genetics, North Central Forest Experiment Station, Rhinelander, Wisconsin.

Table 4.--*Major chemical fractions from leaves of* Populus *hybrid clones and from other trees with potential for intensive culture plantations*

(In percent, dry weight) [1/]

Chemical fraction	Nursery grown *Populus* hybrids [2/]		Other fast-growing trees [3/]	
	Average	Range	Average	Range
Total N	3.1	2.1 - 3.9	2.4	2.0 - 2.8
Crude protein (N x 6.25)	19.5	13.4 -24.1	15.3	12.6 -17.4
Extracted protein	3.2	1.0 - 5.9	2.2	1.4 - 3.3
Soluble amino acids	0.16	0.09 -0.24	0.15	0.05 -0.21
Reducing sugar	8.7	3.6 -12.4	8.8	6.0 -10.9
Total soluble sugar	16.4	9.6 -21.4	16.1	10.6 -22.4
Total nonstructural carbohydrates (TNC)	21.8	16.0 -26.5	21.2	19.0 -23.8
Starch (TNC-total sugar)	5.4	2.9 - 7.1	6.3	1.4 -25.8

1/ The data do not total 100 percent because not all chemical fractions are included.

2/ Recently matured leaves from 21 *Populus* hybrids growing in the Maximum Fiber Yield Project clonal nursery at Rhinelander, Wisconsin.

3/ Three-year-old nursery-grown green ash and silver maple saplings, and 2-year-old trembling and bigtooth aspen sprouts from natural stands.

Table 5.--*Leaf chemical fractions of four* Populus *hybrid clones with potential for "muka" production*

(In percent, dry weight)

Chemical fractions	*P. candicans x P. berolinensis* (5263)	*P. betulifolia x P. trichocarpa P. nigra* (5331)	*P. euramericana* (cv. Wisconsin 5) (5377)	Unknown [1/] (5351)
Total N	3.9	3.8	3.5	3.4
Crude protein (N x 6.25)	24.1	23.6	21.8	21.5
Extracted protein	3.5	4.6	5.9	4.1
Soluble amino acids	0.13	0.24	0.21	0.17
Reducing sugars	11.1	6.6	6.8	8.7
Total soluble sugar	19.6	20.2	16.4	13.4
Total nonstructural carbohydrates (TNC)	24.0	23.1	22.0	17.4
Starch (TNC-total sugar)	4.4	2.9	5.5	4.0

1/ *Populus* sp. Parentage unknown, but it contains some *P. balsamifera*.

to this data base, explain and interpret sources of variation in selected growth and yield traits, and recommend traits that show promise for future improvement. By means of an integrated research program involving the efforts of silviculturists, physiologists, and tree breeders, the characteristics and requirements for an ideal tree might be proposed and the best approaches for achieving them prescribed.

The ideal tree for intensive culture would produce the maximum quantity of usable wood in the shortest possible time. The ideal tree can be easily visualized by constructing an "ideotype" (Donald 1968), a biological model that incorporates a number of desirable growth traits and tree attributes into a hypothetical tree. An ideotype, proposed for cottonwood, based on selected physiological and morphological attributes is shown below. A tree ideotype with a slightly different set of attributes was prepared by Dickmann (1975). Although the ideal, or perfect, tree is perhaps unattainable, the ideotype can provide a theoretical goal for the researcher and a practical one for the silviculturist.

COTTONWOOD IDEOTYPE

Shoot Growth

Rapid juvenile growth to fully and quickly occupy site at close spacings.
Rapid growth early in season to take advantage of growing season and site.
Slower shoot growth later in season to minimize vessel formation.
Relatively short internodes to maintain stem stability and divert more photosynthate to cambial growth.
Cambium should remain active until late in season for maximum wood formation.
Weak competitor so that all stems survive at desired spacing and for uniformity at harvest.

Leaves

Medium to large size to maximize photosynthesis per unit leaf area.
Well distributed on stem with petioles erect if leaves are small, pendant if large, to maximize light interception.
High photosynthetic efficiency.
Long leaf retention under low light and stress until late in season to maximize fiber formation; i.e., light tolerant with low compensation point.

Branches

Short and sparse to tolerate high stand density and to maximize dry matter distribution to stem.
Ideally, no branches, but some may be required to fill lower canopy and to maintain stem stability.

Stem

Small pith.
Straight, thick stem to concentrate wood, minimize pith and bark volumes and tension wood formation.

Bark

Thin bark.
Low stone cell, high fiber content if pulped.
Good bark slippage if removed before pulping.

Roots

Good balance between root and shoot.
Good nutrient and water uptake.
Good coppicing ability, but sparse coppice per shoot.
Ability to withstand repeat harvesting.

From Larson 3/

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CONTROLLED-ENVIRONMENT SELECTION OF POPULUS CLONES[1]

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Short-term, controlled-environment growth was used to select fast growing Populus *clones. The selection technique was a ranking process using leaf weight, stem weight, and total height as indicators of growth potential. Twenty-five clones were tested, and 14 clones were recommended for field trials.*

In north-central United States, *Populus* clones are being examined for intensive silviculture because of their rapid growth, ease of propagation, and high utility for a variety of wood fiber products (Schreiner 1970, Cram 1960, Larson and Gordon 1969, Dawson and Hutchinson 1973). Because more *Populus* species and variants are available than can be reasonably field-tested, researchers must decide what material should be used in breeding programs and field trials. A technique for rapidly selecting superior clones, a key element in intensive silviculture, must be devised.

A study was designed to select clones for use in field and laboratory studies by Iowa State University and the North Central Forest Experiment Station, USDA Forest Service. Several clones, previously identified as having rapid juvenile growth, were compared under three differenent environmental conditions. Different environments were used because the performance of a clone under several test environments may be a better guide to performance in the field than the performance of the clone under any one test environment.

METHODS

The 25 *Populus* clones used in this study were chosen from those gathered by the Maximum Yield Project of the North Central Forest Experiment Station for possible use in field trials (table 1). No particular mix of parentage or origin was chosen; for some clones (e.g., 5258), no reliable information on lineage was available. Rather, I wanted to compare clones as they would normally become available for field use; that is, from a wide variety of sources, often with little detailed genetic information. (Clones 2 and 19 probably are the same; this was discovered after all analysis of the data was completed.)

In all three environments, apical cuttings rooted under mist were grown in 2-gallon plastic pots containing a 3:1 Jiffy-Mix:Perlite artificial substrate.

1/ *Journal Paper No. J-8382 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Project Nos. 2129 and 2033.*

Table 1.--Populus *clones included in this study*

Clone numbers		Name and parentage
Iowa State University	North Central Forest Experiment Station	
1	4877	*Populus alba* L.
2	4878 (5327)	*Populus* x *euramericana* Guinier *deltoides* x *nigra*
3	4879	*Populus* x *euramericana* Guinier
4	5258	*Populus sp.*
5	5262	*Populus candicans* Ait. x *Populus berolinensis* Dipp.
6	5263	*Populus candicans* Ait. x *Populus berolinensis* Dipp.
7	5264	*Populus deltoides* Marsh. x *Populus plantierensis* Schneid.
8	5265	*Populus deltoides* Marsh. x *Populus trichocarpa* Torr. et Gray
9	5266	*Populus deltoides* Marsh. x *Populus trichocarpa* Torr. et Gray
10	5267	*Populus deltoides* Marsh. x *Populus caudina*
11	5271	*Populus charkoviensis* Schroed. x *Populus deltoides* Marsh.
12	5272	*Populus nigra* L. x *Populus laurifolia* Ledeb.
13	5321	*Populus* x *euramericana* Guinier
14	5322	*Populus* x *euramericana* Guinier
15	5323	*Populus* x *euramericana* Guinier
16	5324	*Populus* x *euramericana* Guinier
17	5325	*Populus* x *euramericana* Guinier
18	5326	*Populus* x *euramericana* Guinier
19	5327 (4878)	*Populus* x *euramericana* Guinier
20	5328	*Populus* x *euramericana* Guinier
21	5331	*Populus betulafolia* Dipp. x *Populus trichocarpa* Torr. et Gray
22	5332	*Populus betulafolia* Dipp. x *Populus trichocarpa* Torr. et Gray
23	5334	*Populus deltoides* Marsh. x *Populus trichocarpa* Torr. et Gray
24	5260	*Populus tristis* Fish. x *Populus balsamifera* L.
25	5377	*Populus* x *euramericana* Guinier, "Wisconsin No. 5"

Pot moisture was maintained near field capacity by frequent watering, and nutrient level was kept high by weekly fertilization with a commercial water-soluble fertilizer (20-20-20) with an added micronutrient mixture. Pots were thoroughly flushed with water every 2 weeks to prevent salt accumulation.

These conditions are not, of course, known to be optimum for all clones included in the study. They have, however, produced consistently greater growth for *Populus* than any other conditions we have tried, including aeration, complete-nutrient-solution, or hydroponic culture.

The three environments, differing primarily in light quality, light intensity, and temperature, were:

Greenhouse I
- Growth period: 8 weeks (April 12 to June 7).
- Photoperiod: 18 hours (part of which was artificial light).
- Temperature: variable (with the thermostat set at 21°C).

Greenhouse II
- Growth period: 8 weeks (May 17 to July 12).
- Photoperiod: 18 hours (part of

which was artificial light).
Temperature: variable (with the thermostat set at 21°C).

Growth Chambers
Growth period: 6 weeks.
Photoperiod: 18 hours (in Percival, Model PT-80 growth chambers).
Temperature: 25°C day and 15°C night.

The growth-chamber environment was the least variable, with little variation in photoperiod, light intensity, and temperature. Greenhouse II had a much higher temperature and a longer natural light photoperiod than did Greenhouse I. Light intensities were highest in Greenhouse II because of seasonal changes in solar position.

The plants were placed on benches in the greenhouse and in growth chambers at random.

Growth rates were determined from weekly total leaf counts and total height measurements (cm), beginning with initial measurements when the rooted cuttings were removed from the propagation bench. Leaf ovendry weight (g) and stem ovendry weight (g) were determined at the end of the growth period.

RESULTS

Growth

Clones varied greatly in all growth characteristics measured, but showed some consistency when compared across the three test environments. Total height and dry weight of leaves and stems showed large differences among clones and environments (tables 2, 3, and 4).

When all clones were pooled, mean leaf and stem dry weight and total height were all greatest in Greenhouse II (table 5). The greater total solar radiation available in this environment, due to longer natural daylight periods, greater average light intensity during the longer days, and a greater proportion of clear days during the 8-week growth period, all contributed to greater growth in this environment. The growth chamber means were smaller than those of either greenhouse environment,

Table 2.--*Any two means not next to a common line are significantly different (Duncan's new multiple range test for significant differences)*
(In grams)

Greenhouse I		Greenhouse II		Growth Chambers	
Clone	Mean	Clone	Mean	Clone	Mean
3	18.80	4	32.49	24	7.96
4	18.01	23	31.89	4	6.71
5	17.58	18	31.28	18	6.68
9	17.32	25	30.88	5	6.65
23	15.40	9	27.97	25	6.62
8	14.73	3	27.25	3	5.95
15	14.57	17	24.81	9	5.91
18	14.42	15	23.82	1	5.83
21	14.31	7	23.54	6	5.78
16	14.19	5	23.16	17	5.55
17	14.14	20	22.78	21	5.46
12	14.13	8	22.19	23	5.33
22	13.52	6	20.62	15	5.32
7	13.46	1	20.23	7	4.95
25	12.64	12	19.51	12	4.94
6	12.10	2	18.88	22	4.91
24	12.01	16	18.11	8	4.77
19	11.54	14	18.08	13	4.66
14	11.35	19	17.34	2	4.47
2	10.35	22	17.26	16	4.30
13	10.15	21	16.43	19	3.98
20	8.39	24	15.51	20	3.38
10	6.91	10	10.47	14	3.27
11	6.87	13	10.25	11	3.20
1	6.12	11	7.38	10	2.57

Table 3.--*Any two means not next to a common line are significantly different (Duncan's new multiple range test for significant differences)*

(In grams)

Greenhouse I		Greenhouse II		Growth chambers	
Clone	Mean	Clone	Mean	Clone	Mean
9	32.49	23	54.88	9	22.37
8	29.71	9	49.27	23	19.84
23	29.59	8	45.46	8	19.52
4	27.38	7	43.76	4	19.02
3	27.28	4	42.99	25	18.63
7	25.36	15	39.22	6	18.37
15	24.36	18	39.01	18	17.75
5	24.33	17	37.90	17	17.40
17	23.86	25	37.27	5	16.96
18	21.75	3	36.34	1	16.86
16	21.50	14	34.63	7	16.77
14	21.32	5	32.82	15	16.76
21	21.22	20	31.44	12	16.06
12	20.44	1	31.23	21	15.88
20	20.41	2	30.69	24	15.51
19	18.42	19	29.56	3	15.18
22	18.31	12	28.73	20	14.85
2	18.04	6	28.59	16	14.83
13	17.95	16	28.26	13	14.28
25	17.93	21	26.14	2	13.74
24	17.40	24	22.07	22	13.60
6	16.94	22	21.80	19	12.44
10	13.00	10	18.59	14	12.09
1	12.85	13	17.74	10	10.33
11	9.91	11	11.45	11	7.90

Table 4.--*Any two means not next to a common line are significantly different (Duncan's new multiple range test for significant differences)*

(In centimeters)

Greenhouse I		Greenhouse II		Growth chambers	
Clone	Mean	Clone	Mean	Clone	Mean
5	181.2	23	192.8	5	94.8
3	163.4	5	188.8	6	86.9
9	158.2	9	180.0	24	85.5
22	157.6	3	172.1	3	82.1
6	156.4	18	171.6	1	81.9
23	155.9	7	170.6	12	80.7
12	151.0	25	170.4	2	79.7
19	144.0	6	170.2	9	79.0
15	141.8	17	169.5	18	78.9
8	141.4	22	167.7	23	78.6
16	140.8	4	166.6	22	78.1
4	140.4	12	164.9	7	77.0
17	137.9	15	160.6	15	76.5
2	136.8	2	160.0	25	75.6
7	135.4	8	156.4	17	75.2
25	134.2	21	154.2	4	75.1
18	130.5	1	153.8	21	74.9
24	124.4	16	147.9	19	72.8
13	121.8	19	142.6	8	71.9
1	120.9	24	134.7	16	65.5
14	117.5	14	133.4	13	65.4
21	115.2	20	124.6	11	64.3
10	110.3	10	118.7	10	58.6
11	104.8	11	112.6	14	55.6
20	97.9	13	108.8	20	49.9

Table 5.--*Means and ranges for leaf and stem weight and total height for all clones pooled in each environment*

Item	Green-house I	Green-house II	Growth chambers
LEAF WEIGHT (GRAMS)			
Mean	20.68	32.79	15.79
High	32.49	54.88	22.37
Low	5.82	11.45	7.90
Variance	39.92	55.12	15.46
STEM WEIGHT (GRAMS)			
Mean	12.54	21.29	5.18
High	18.80	32.49	7.96
Low	3.04	7.38	2.57
Variance	15.10	23.69	2.72
TOTAL HEIGHT (CENTIMETERS)			
Mean	134.7	155.7	74.3
High	181.2	192.8	94.8
Low	82.5	98.8	49.9
Variance	25.79	219.28	68.24

primarily because of the shorter growth-chamber growth period (6 rather than 8 weeks), but also because of lower growth-chamber light intensities. Because total photoperiod was the same in all three environments, photoperiodic reactions should not have caused differences in growth among environments.

Within each environment a high rank for one variable did not necessarily indicate high rank for other variables. Moreover, clonal ranking based on individual variables or sums varied from environment to environment. Clearly, further analysis beyond simple ranking and summing was necessary to indicate clearly which clones, in fact, had the greatest juvenile growth potential and stability across environments. Therefore, growth variables for clones within environments were subjected to analysis of variance, and differences among clones (for each growth variable in each environment) were examined by use of Duncan's new multiple-range test (tables 2, 3, and 4).

Greenhouse II produced the greatest number of significant differences among clones in stem weight as well as the greatest stem weights (table 2). Seven clones produced significantly greater mean stem weight regardless of environment. These seven clones (3, 4, 9, 17, 18, 23, and 25) may be regarded as consistent producers of heavy stems across all environments.

Clones producing the greatest total leaf weight were also consistent for all three environments (table 3). As with stem weight, Greenhouse II produced the greatest number of significant differences. Three clones, 8, 9, and 23, constituted the top group. Two of these (9 and 23) also were in the top group for all environments in stem weight production.

Total height analysis presented a somewhat different picture. Greenhouse I produced the greatest number of significant differences in total height (table 4). But, of the six tallest clones in Greenhouse I, only three (3, 9, and 23) appeared in the group showing consistently greatest stem weight, and only two (9 and 23) appeared in the group showing consistently greatest leaf weight. Thus, high potential for top weight production is not necessarily related to high potential for elongation growth.

Leaf number increased roughly with time; therefore, regressions of leaf number on time were examined to see if rate of leaf production, as indicated by the slope of this regression line, was an indicator of final weight or height or both. If it were, it might be possible to reduce or eliminate destructive measurement. Again, Greenhouse II produced the greatest slopes, reiterating the generally better growing conditions in this environment. There was little consistency, however, between leaf production and final weight and (or) height. For example, clone 23, one of the best performers in terms of stem and leaf weight and height growth, had one of the lowest rates of leaf production.

DISCUSSION

Short-term juvenile production of photosynthate is the trait most desired for the clones to be used in larger field trials. If distribution of the photosynthate does not change during the first few years of growth of these clones, selection can be based entirely on stem weight production. But because distribution of photosynthate may change, total height growth of the clones must also be considered. Therefore, recommendations for clones to be used in field trials must be based on both stem weight and total height. The leaf/stem ratio also is an important criterion for selection, but not as critical as the absolute value of the photosynthate produced. In these data, a trend of more favorable leaf/stem ratio is discernible for the faster growing clones.

Thus, our initial selection of clones for field trials is based on ranking of total height and stem weight for the three environments. The following clones are recommended for field trials: 2, 3, 4, 5, 6, 7, 9, 12, 15, 17, 18, 22, 23, and 25. This type of selection scheme will separate clones that grow well in height and stem weight under all three environments. Further screening must be done for disease and insect resistance and fiber quality before making final selection of clones for use in intensive culture systems.

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RAPID SELECTION TECHNIQUES FOR IDENTIFYING SUPERIOR CLONES[1]

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Techniques for selecting fast-growing Populus *clones use physiological and morphological variables as indicators of field performance. The selection indices can be a valuable tool in preliminary work where large numbers of clones must be considered.*

Although agricultural productivity has been greatly increased over the past several decades, there has been little concomitant increase in our ability to produce greater yields per-acre of wood products. The need for new approaches to the production of wood fiber has been stated (Larson and Gordon 1969b, Gordon and Bentley 1970, White 1973), and the development of comprehensive methods for producing high per-acre yields of wood fiber under intensive cultural conditions has been underway for some time (McAlpine *et al.* 1966).

The current emphasis is to increase wood fiber yield to aid conventional wood-using industries, but there is some interest in woody plants as a source of fuel and protein (Szego and Kemp 1973, Grantham and Ellis 1974, Pirie 1969). Eventually, wood will be regarded as a chemical raw material. When this occurs, current quality criteria such as fiber length and wood strength will be less important, the definition of "superior genotype" will change, and more emphasis will be placed on maximum dry-mass production. Techniques for the rapid selection of superior clones will be a key element in intensive silviculture.

As has been pointed out in the previous paper in this proceedings, one of the most promising candidates for maximum fiber production management in north-central United States is the genus *Populus*. The chances of successful early selection are enhanced by genetic consistency of clonal material, knowledge already accumulated about the culture of poplar, and the well defined cultural conditions and relatively short rotations used in intensive silviculture (Larson and Gordon 1969b). Intensive silviculture improves chances of successful selection because environmental and genetic variation, and time, the principal saboteurs of growth-predicting correlations, are much reduced.

If controlled environment and physiological indicators can be used to select genotypes capable of rapid growth, large field trials could be greatly reduced in size, with savings in time, effort, and money. Currently, our cooperative effort with the North Central Forest Experiment Station is concentrating on the development

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of comprehensive techniques for rapid screening by using controlled-environment growth studies (Wray 1974, Zuuring 1975) detailing procedures from propagation to data analysis and interpretation.

Physiological analysis and field experiments also play an important role in our program to develop selection methods. Physiological criteria could be used by themselves to predict field performance. We think, however, that combining physiological criteria with measurements of growth in controlled environments will predict field performance best (fig. 1).

The major objective of our program is to identify clones with combinations of characteristics that result in maximum dry weight yield in the field. Our approach involves the construction of indices based on controlled-environment growth and simple physiological measurements that will accurately predict field performance under specific cultural regimes. Our approach has been to consider clones that differ markedly in juvenile growth rate and to examine them for differences in the physiological processes and morphological characteristics that we believe determine productivity (Gordon 1975). At the same time, we are studying growth of the same clones in a variety of controlled and field environments and determining what combinations of environment and growth variables best predict field performance (Hennessey and Gordon in press).

PREDICTIVE VARIABLES

If predicting growth is the only objective, variables correlated only with growth rate can be used, but we believe that there are sound reasons for working with morphological characteristics and physiological processes that are causally related to growth and yield. Not only are such variables likely to be good predictors, but increased knowledge will point the way to efficient yield improvement in the future.

Physiological Variables

On the basis of previous knowledge about tree and stand growth, we think that three broad areas of tree physiology are most likely to contain predictive variables:

1. Photosynthesis and respiration--the processes directly determining net carbon fixation (which is dry-weight growth if the small percentage of dry weight due to mineral uptake is disregarded).
2. Nitrogen uptake and metabolism--the processes responsible for the utilization of the nutrient most often limiting tree growth.
3. Hormone metabolism--the basic system of meristem coordination and control.

Each of these physiological areas can be described by many measured variables,

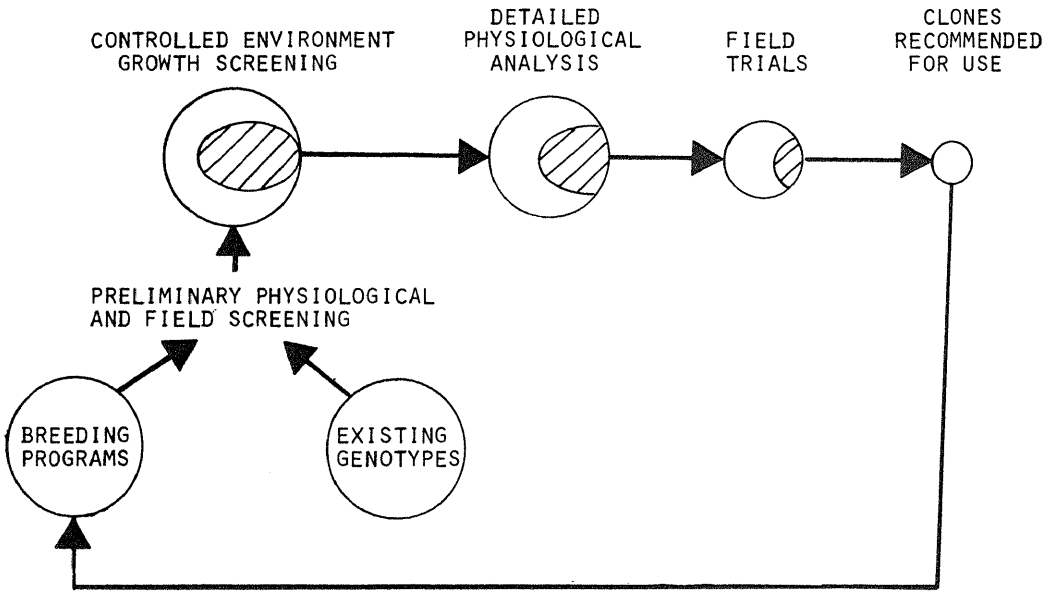

Figure 1.--*Proposed system for use in screening* Populus *clones.*

and measurements can be made at different levels of organization (subcellular, cellular, tissue, organ, tree, or stand) and at different places in the biochemical chain, linking information stored in the genome to form and function (nuclear acids, individual enzymes, systems of enzymes, fluxes of substrates, and products). If thousands of genotypes must be screened rapidly, physiological measurements must be simple, inexpensive, and fast. We have thus concentrated on measurements of gas exchange and specific enzymes at the tissue and organ level while being careful to relate measurements to whole tree and stand measures of growth.

Variables we have measured include:

1. Net photosynthesis, photorespiration, and dark respiration (Domingo and Gordon 1974, Dickmann *et al.* in press) as well as the related measures of leaf physiological state and activity, CO_2 compensation point (Dickmann and Gjerstad 1973), stomatal diffusion resistance, incorporation of ^{14}C-labeled photosynthate into leaf protein (Dickmann *et al.* in press), and glycolate oxidase activity (Gjerstad 1975).
2. Peroxidase activity, both as total activity in crude extracts and as isoenzymes resolved in acrylamide gel electrophoresis (Gordon 1974, Wolter and Gordon 1975, Wray 1974).
3. Nitrate reductase activity (Dykstra 1974, Fasehun 1975).

Morphological and Growth Variables

Morphological and growth variables also were used as indicators of growth potential in our studies. Several growth studies under controlled environment (Wray 1974, Hennessey and Gordon in press, Zuuring 1975, Dykstra 1974, Fasehun 1975) and field environment (Rose and Promnitz 1975) have given us information about growth potential of several *Populus* clones.

Morphological and growth variables that we have measured include:

1. Short-term measurements of growth potential--experiments under uniform growth-chamber environment plus studies during several times of the year under the more variable greenhouse environment.
2. Field trials--clonal densities studies at Ames, Iowa, and Rhinelander, Wisconsin.
3. Crown geometry--leaf orientation and shape as related to optimum crown arrangement for entrapment of solar energy.

RESULTS

Initial growth studies (Wray 1974, Zuuring 1975) examined a large set of *Populus* clones to determine potential growth differences (fig. 2). From this set, a subset of *Populus* x *euramericana* clones was selected that exhibited different growth rates and response to environments (table 1). Clone 5321 was slow growing, while clones 5323, 5326, and 5377 grew consistently faster (table 2). Primary emphasis of further experiments dealing with controlled-environment growth, physiological characteristics, and field performance concentrated on this subset of clones.

Although the subset of clones is small, it seems that controlled-environment growth studies can identify genetic potential for growth under certain field conditions (fig. 3). Better controlled-environment growth conditions will, however, improve the differentiation among clones and increase predictive abilities (Wray 1974, Hennessey and Gordon in press).

Several studies have attempted to relate clonal growth potential to a wide variety of physiological and morphological variables (table 3). These clones were found to differ in photosynthetic properties, leaf nitrate reductase activity, peroxidase activity, leaf angles, and leaf density. Consideration of variables singularly, however, tends to obscure the issue of growth performance. Individual variables measure only a single component in a large system that results in growth. When many physiological measures are combined through multivariate analysis, discrimination among clones often is improved. For example, when eight photosynthetic variables are combined into two canonical variables, clear discrimination between clones 5321 and 5326 can be made (fig. 4).

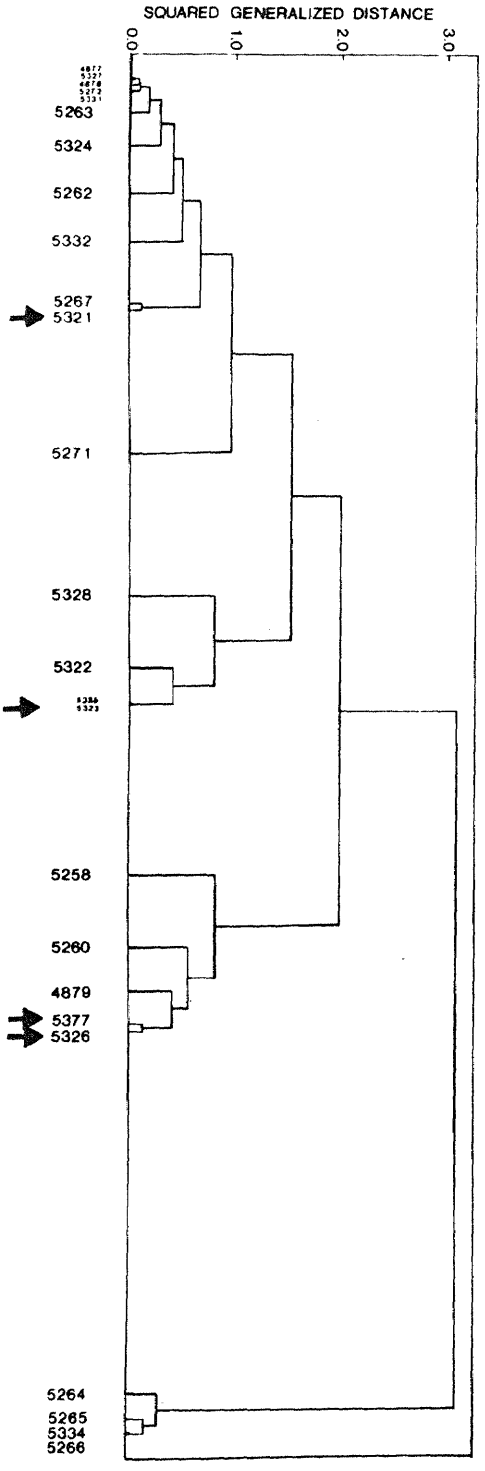

Figure 2.--*Dendrograph displaying the results of a cluster analysis performed on the generalized squared distances between 25 clones based on stem dry weight, leaf dry weight, and height.*

Table 1.--*Parentage of the contrasted clones*

Clone	Sex	Parentage			Clone name
5321	female	Populus x euramericana (Dode) Guinier			Negrito de Grancda
5323	male	do.	do.	do.	Canda Blanc
5326	male	do.	do.	do.	Eugenii
5377	male	do.	do.	do.	Wisconsin No. 5.

Table 2.--*Total stem dry weight of selected* Populus *clones grown under various environmental conditions*
(In grams)

Clone	Age		
	6 weeks	8 weeks	2 years
5321	4.7	10.2	341.6
5323	5.3	19.2	487.3
5326	6.7	22.8	594.1
5377	6.6	21.8	500.9

Alternative sets of variables also can be used under specific conditions for prediction. For example, clone 5321 grows slowly but has a high rate of photosynthesis. This is partly because clone 5321 is somewhat shade tolerant (Fasehun 1975). Plants with high peroxidase activity may have the potential for faster growth because of the relation between peroxidase and lignification (Siegel 1956). Nitrate reductase levels may indicate potential for utilization of nitrogen by the plant.

At this preliminary stage in development of selection techniques, it may be best to rely on simple growth measures because growth is an expression of the combination of all morphological and physiological variables. We believe, however, that combining physiological criteria with measures of growth in controlled environment will give the best predictions of field performance. Growth rate under optimal conditions is not the only property we wish to select for. We are now beginning studies aimed at discovering early selection criteria for disease and insect resistance and response to nitrogen and water. It has been suggested that early selection for wood-quality criteria such as fiber-to-vessel ratio, could be carried out successfully (Larson and Gordon 1969a), particularly if the relation between growth rate and wood formation is better understood.

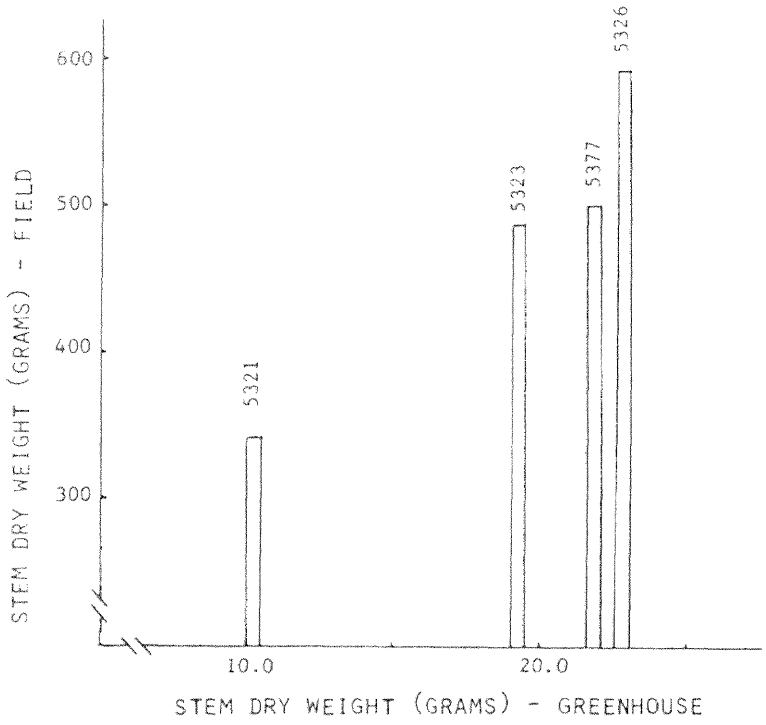

Figure 3.--*Comparison of average dry weight of clones grown in greenhouse versus average dry weight of clones grown in the field for 2 years.*

Table 3.--*Physiological and morphological variables of the contrasted clones*

Clone	Physiological variables				Morphological variables			
	Dark respiration: mg CO_2 $hr^{-1}dm^{-2}$ LPA 10	Photosynthesis: mg CO_2 $hr^{-1}dm^{-2}$ LPA 10	Nitrate reductase: NO_2 hr^{-1} g^{-1} LPA 10	Total peroxidase: units g^{-1}(dry wt) internode	Leaf area/weight: cm^2/g	Leaf angle: LPA 10 Long	Leaf angle: LPA 10 Short	Stem/leaf dry weight ratio
5321	0.97	11.94	3.2	0.88	100.3	83	51	0.33
5323	.82	9.77	10.4	1.10	94.0	112	59	.35
5326	1.31	13.91	4.2	1.03	115.2	92	41	.38
5377	1.33	11.00	5.5	1.06	110.8	95	39	.35

CONCLUSIONS

Early selection techniques for the identification of "superior" clones will form an important component of tree breeding programs and intensive silviculture. Ultimately, selection criteria could be based solely on physiological variables

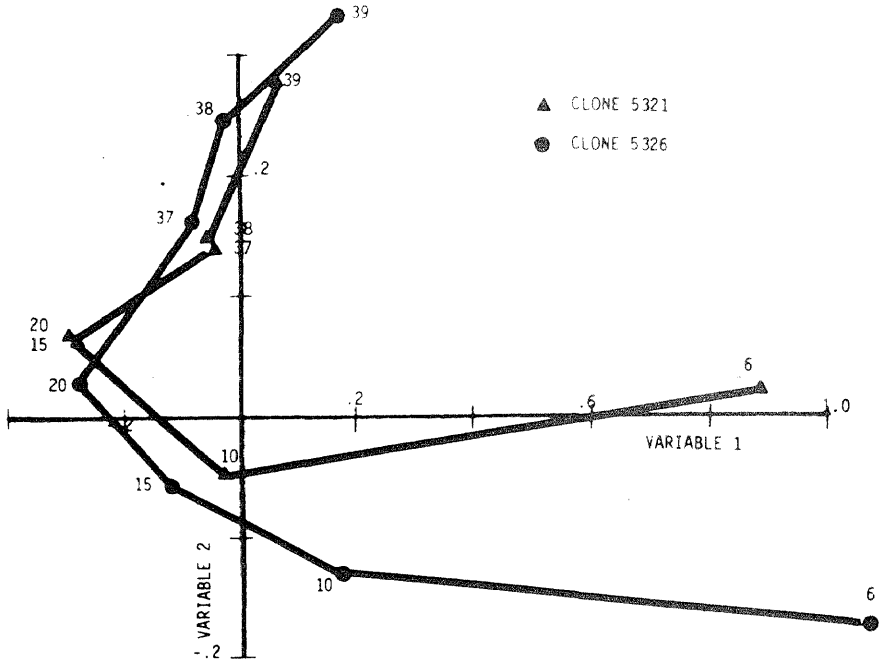

Figure 4.--*Multivariate plot of canonical variables 1 and 2 for leaves of different ages for clones 5321 and 5326. The canonical variables are functions of photosynthesis (21 percent O_2), photosynthesis (2 percent O_2), dark respiration (2 percent O_2), apparent photorespiration (21 percent O_2), apparent photorespiration (2 percent O_2), CO_2 compensation concentration, and diffusion resistance.*

measured at the cellular level. Our success with controlled-environment studies, however, indicates that, for the best prediction of field performance, some combination of physiological criteria with measures of growth will be necessary. Although such screening techniques may be subject to error in classification of growth potential, they can provide, in conjunction with small-scale field observations, a valuable tool in preliminary work in which large numbers of clones must be considered.

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BIOMASS STUDIES IN INTENSIVELY MANAGED FOREST STANDS

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Whole tree utilization and pulping systems require that forest products be measured in weight rather than in volume. Sampling methods, based on destructive tree sampling and allometric relations are outlined for determination of standing biomass and production of genetically improved pulp tree species. Maximization of biomass production will be achieved by optimizing various plant and environmental factors including leaf biomass, spacing, soils moisture, and nutrients. Biological optimum rotation age will be determined for each species grown in plantations at various spacings. Efficiency of solar energy conversion in the intensively managed stands will be estimated from their biomass production and energy content (obtained by calorimetry) of the tissues.

Recent technological advances in whole tree utilization (Young 1968) and pulping of tree parts such as branches, tree tops, and stumps (Chase *et al.* 1971, 1973) are likely to drastically change methods of harvesting and merchandizing pulp species. Weight rather than volume will be used in commercial transactions in the near future and weight tables will have to be prepared for many species used for pulping. The existing information on standing biomass and biomass production of stands is inadequate both from the standpoint of number of species for which the information is available and their geographical location. Little basic biomass data are available for genetically improved forest tree species.

In intensive culture, rapidly growing species would be mechanically planted on suitable land after adequate site preparation, would be fertilized and irrigated, and mechanically harvested when the mean annual biomass growth of the plantation culminates. The most favorable rotation age will have to be determined for various species and hybrids grown at various spacings under a variety of treatments including cultivation, fertilization, and irrigation. The studies proposed here are designed to provide such information for northern Wisconsin.

APPROACHES AND MODELS USED IN BIOMASS STUDIES

Methodology for assessing standing biomass and biomasss production of stands by both destructive and nondestructive sampling has been investigated by forest ecologists since the 1950's (Ovington 1956, 1957; Ovington and Pearsall 1956). A brief review of three frequently used methods follows.

One of the earliest and most expedient methods was the mean tree method in which one or more trees of mean dimensions was harvested and total biomass per unit area obtained by simple expansion based on density. The main assumption of this method is that a tree of mean dimensions is also a tree of mean biomass. This assumption is approximated in even-aged plantations of intolerant species such as pines (Ovington 1956, 1957; Ovington and Pearsall 1956), but biomass estimates of stands of tolerant species and natural stands obtained by this method may be in error by as much as 50 percent (Baskerville 1965b, Crow 1971).

The second method, called unit area, was used by Bray and Dudkiewicz (1963) in biomass studies of *Populus* forests. Projected crown area and total biomass of each sample tree were determined and biomass expressed per unit land area. This approach was found to be the least reliable in a comparative study of three approaches used for biomass estimation (Ovington *et al.* 1967). A modification of this method was used by Zavitkovski and Newton (1968) in biomass studies of *Ceanothus velutinus*, a nitrogen-fixing shrub of the Oregon Cascades. All shrubs were harvested from sample areas of 40.5 square meters (1/100 acre) and fresh weight obtained in the field. A representative subsample was taken for fresh weight/dry weight ratio determinations. This method has also been used by various workers for biomass determination of young tree plantations (Person *et al.* 1971, Heilman *et al.* 1972, Saucier *et al.* 1972, Crist and Dawson 1975).

The most reliable method for biomass estimation is regression analysis, also called dimensional analysis by Whittaker and Woodwell (1968), or allometry by Kira and Shidei (1967). In this method, the dependent variable, i.e., whole tree or tree component dry weight, is expressed as a power function of some easily measurable independent variable, mostly Dbh, Dbh^2, height, or a combination thereof. For statistical purposes and curve fitting, the original form of the allometric equation $Y = aX^b$ is transformed to a logarithmic form: $\ln Y = \ln a + b \ln X$. This transformed form has a statistical advantage because it normalizes the variance of biological data that often follow a lognormal distribution (Baskerville 1972).

Problems arise when the log-transformed units are transformed back to the original arithmetic units, because if lnY is normally distributed, Y distribution is skewed. This problem was recognized first by mathematicians (Finney 1941) and later by ecologists when the use of allometric equation became common in ecology (Madgwick 1970). Correction procedures for the bias have been proposed by Baskerville (1972).

Goodness of fit of the data in regression techniques can be evaluated in various ways. The coefficient of determination, R^2, is used by most workers. A different measure, essentially equivalent to a coefficient of variation, called $\underline{e}$ or $\underline{E}$, is advocated by Whittaker and Woodwell (1968). For regressions in arithmetic units, $\underline{e}$, or estimate of relative error, is obtained by dividing the standard error, $S_{y.x}$, by the mean value of the dependent variable Y. In the allometric regressions, the standard error of estimate is a logarithm added to or substracted from an estimate of lnY; its antilog is a factor by which a given value of Y is multiplied or divided. A value of $\underline{E}$, the estimate of relative error for a logarithmic regression, equal 1.25 thus suggests an expected error range from 1.25Y to Y/1.25.

APPLYING ALLOMETRY IN BIOMASS STUDIES

The first step in estimating biomass production of forest stands is to develop equations relating some easily measurable variables, usually dbh and height, with dry weights of whole trees and tree components (Zavitkovski 1971). Sample trees are selected in target stands avoiding the border trees which are atypical. Sample allocation should be based on dbh or tree basal area distribution so that the whole range of sizes is represented. Sample size (i.e., number of sample trees) will depend on the variability, allowable sampling error, and manpower available. For components whose variability is high, such as dead branches and foliage, a prohibitively large sample would have to be collected to obtain a low sampling error so, a compromise will have to be made in which the sample size will be determined by the most important component, usually the biomass of stems.

Sample trees are cut at the ground line and separated into components of interest (e.g., stem, branches, leaves, etc.), bagged and dried at 70°C to equilibrium. For large trees, fresh weights of individual components are obtained in the field and subsamples of each taken for dry/weight fresh weight ratio determination. Dry weights of individual components are obtained by multiplying fresh weights by the ratio. Allocation of subsamples should be at random and subsample size proportional to weight variation of the component. As a rule, stem sections of the same length, regularly spaced along the stem, are taken for stem wood and stem bark weight determination. One or more branches are taken at random from each whorl or annual height growth increment and all leaves from the sample branches separated and bagged. Fresh weights of each subsample are obtained in the field and dry

weights after drying in the laboratory. Desirable precision of weighing, which is assumed to be without error, is to 0.1 percent of the weight, i.e., for weights of 100 grams to the nearest 0.1 gram.

Modifications of the general method may be required for some specific sampling. Leaves (needles) of evergreen species may be separated into current year's and older classes. Estimates of leaf biomass of deciduous stands may be obtained from litter sampling which, for less effort, yields more accurate data.

Plotting of the data may indicate which independent variables should be used in fitting the allometric model by the method of least squares. Corrected values are calculated as discussed by Baskerville (1972):

$$Y = \exp(\ln Y' + \sigma^2/2)$$

where Y and Y' are the estimated corrected and uncorrected values in arithmetic units, (Y' from the allometric regression), and σ^2 is sample variance of the logarithmic equation. The variance, σ^2_A, for the skewed distribution of Y's in arrthmetic units, is calculated as follows:

$$\sigma^2_A = \exp(2\sigma^2 + 2\ \ln Y') - \exp(\sigma^2 + 2\ln Y').$$

ESTIMATING STAND BIOMASS

Stand biomass is estimated by the method of "every-tree summation" (Baskerville 1965b). Dbh, height, or other variables used in the allometric regression are measured on all trees (excluding border trees) of a plantation and biomasses of all trees, corrected for bias resulting from log-transformation, summed. The standing biomass is then expressed in metric tons per hectare or other units relating weight and area. For large plantations, sample area approach, such as used in forest inventory (Freese 1962), may be used.

Time of biomass estimation is important especially if two successive estimates are used for estimating biomass production. The measurements should be taken during the dormant season avoiding, however, very cold days on which dbh measurements, and consequently biomasses of trees, would be underestimated (Godman and Mattson 1970).

ESTIMATING BIOMASS PRODUCTION

Newbould (1967) presents two basic models for estimating biomass production (P) of a single tree or whole forest stand:

$$P = \Delta B + L + G \quad (1)$$

$$P = B_c + L + G \quad (2)$$

In the first approach, biomass (B) is measured twice at times t_1 and t_2 and the difference (ΔB) is the biomass change during that time (Model 1). In the second approach, instead of measuring the biomass twice, trees are harvested at the end of the growing season and by means of stem analysis and separating the current year's organs (e.g., twigs) for the current growth, B_c is estimated (Model 2). In both Models, the losses by death and shedding (L) and by organisms (G) must be added.

A third approach, applicable to uneven-aged forest stands was used by Zavitkovski and Stevens (1972) in studies on biomass growth of red alder stands in Oregon. Standing biomass of 50 red alder stands containing trees ranging in age from 1 to 65 years and growing on latosolic soil of similar productivity was determined during the leafless period in winter. Relations between an index of volume (dbh^2 x height) and dry weight of individual tree components and whole trees were established by analyzing 119 felled sample trees and biomasses of stands obtained by the method of every tree summation discussed previously (Baskerville 1965b). Von Bertalanffy's growth model was fitted to the above ground dry weight of stands as a function of age by a method described by Ricklefs (1967). Mathematically, the first derivative of this function is equivalent to ΔB of Newbould's (1967) equation 1 shown above, i.e., stand biomass change from t_n to t_{n+1}. Total annual biomass production, P, is then obtained by adding losses, i.e., mortality, litter fall, and consumption by organisms, to ΔB.

ROLE OF CANOPIES IN BIOMASS PRODUCTION

Positive and significant relations were found between leaf area index, LAI, and production of various crop plants (Donald 1961, Williams 1966), but the information on the role of LAI in biomass production of forests is inadequate (Zavitkovski *et al.* 1974). In broadleaved deciduous forests, LAI's ranged

from 3.1 to 14.2 (Tadaki and Shidei 1960, Chalupa 1961, Whittaker and Woodwell 1968, Assmann 1970, Art and Marks 1971) and from 6 to 13 (or 12 to 26 for both sides) in coniferous and other evergreen forests (Tadaki *et al.* 1965, Kira *et al.* 1969, Assmann 1970).

The information on leaf biomass, which is used by production ecologists in a way similar to the way plant physiologists use LAI, is more comprehensive. In deciduous forests, leaf biomasses were estimated indirectly from litter traps (Bray and Gorham 1964, Zavitkovski and Newton 1971), while in coniferous stands direct determinations were usually made (Baskerville 1965a, Fujimori 1971). Leaf biomass of the deciduous forests ranged from about 2 to 6.6 metric tons per hectare whereas coniferous forests had as much as 22 metric tons per hectare primarily because of the longevity of needles in some species.

In a recent review of forest biomass studies, Zavitkovski *et al.* (1974) found a positive relation between the leaf biomass and net annual production of stems and branches for stands of numerous tree species. In general, foliage of the deciduous species was found to be more efficient than that of evergreens in producing stem-branch biomass. On the average, 1 metric ton of foliage produced 1 metric ton of stems-branches in the coniferous and 2.17 metric tons in the deciduous forests. The variability of the data prevented any detailed analysis on the possible reduction of stem-branches production in stands having very high leaf biomasses. However, a detailed study of red alder (Zavitkovski and Stevens 1972) indicated that productivity was reduced when the leaf biomass was higher than 5.6 metric tons per hectare. Stated differently, an optimum leaf biomass for natural red alder stands was about 5.5 metric tons per hectare (Zavitkovski *et al.* 1974).

From the production standpoint, the concept of optimum leaf biomass or LAI is very important for maximizing biomass production. Experimental plantations seem to be suited for such studies because their densities can be better controlled than in natural stands.

ENERGY CONVERSION IN INTENSIVELY MANAGED STANDS

Closely related to leaf biomass and dry matter production is the efficiency of solar energy (light) utilization of a stand. Hellmers and Bonner (1959) suggested that forest communities utilize only 2 to 2½ percent of the visible portion of the incoming solar energy. By contrast, the best managed field crops may utilize 2 to 5 percent and algal cultures 7 to 10 percent (Wassink 1959, Talling 1961, Bonner 1962). Forest biomass studies conducted since the 1960's show that both planted and natural forest communities are more efficient than suggested by Hellmers and Bonner (1959). Natural stands of red alder may utilize up to 4.4 percent of the growing season's light and natural stands of western hemlock about 2.8 percent of a whole year's light. In intensively cultured stands, even greater light utilization may be reached.

Solar energy incorporated into an intensively managed stand is a product of dry matter production and energy content per unit weight obtained by calorimetry. Results are expressed in kilocalories per hectare per year. Efficiency of solar energy conversion is determined from the total energy incorporated into annual biomass production and incoming solar radiation measured by a solarimeter. Results are expressed in percent of growing season's or whole year's solar energy input over the total or visible spectrum (400 to 700 nm).

OPTIMUM ROTATION AGE

With no economic constraints imposed, the optimum rotation age would be reached when the mean annual biomass growth culminates. This occurs several years after the culmination of the net annual growth. For example, in red alder, the optimum rotation age was achieved at 21 years but the peak was flat indicating that between 16 and 27 years production would be within 5 percent of maximum (Zavitkovski *et al.* 1974). From the utilization standpoint, proportion of dead tree biomass may be important for fiber production because in whole-tree harvesting, standing dead trees would be harvested along with the living trees. However, the data for red alder stands indicate that between ages 12 and 35 years standing dead trees account for less than 5 percent of the total biomass.

Economic constraints, especially at current high interest rates, would reduce the optimum biological rotation. For aspen stands in the Lake States, Einspahr and Benson

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Economic constraints, especially at current high interest rates, would reduce the optimum biological rotation. For aspen stands in the Lake States, Einspahr and Benson

(1968) considered an economic rotation between 10 and 20 years possible, and Ek and Brodie (1975) from 20 to 30 years. Ek and Brodie suggested that extremely short rotations (less than 15 years) would be undesirable because volume and value growth rates are sustained into the third decade. For intensively culuted *Populus* 'Tristis #1', grown for 5 years at six spacings ranging from 0.75 to 12 feet, Ek and Dawson (in press) projected optimum biological rotations from 8 to 15 years, indicating that optimum economic rotations would be less than 10 years. Such short rotations have also been projected for intensively cultured sycamore in southern United States (Steinbeck *et al.* 1972).

PRELIMINARY STUDIES ON POPULUS TRISTIS CANOPIES

Studies on leaf biomass production were begun in 3-year-old experimental plantations of *Populus tristis* established at four spacings--1 by 1, 2 by 2, 4 by 4, and 8 by 8 feet--from rooted tip cuttings in 1972. The plantations were small, ranging in size from 16 by 36 feet for the 1 by 1 foot spacing to 48 by 144 feet for the 4 by 4 and 8 by 8 foot spacings. Small plots can produce biased results, so larger plots will be needed for final confirmation of the data.

Leaf biomass of canopies was estimated by two methods: (a) litter sampling and (b) destructive sampling. Indirectly, the equilibration of leaf biomass in the sampled stands was estimated by measuring light under canopies.

In late summer of 1975, six 0.5 by 0.5 meter litter traps were placed in each of the four plantations and litter sampled at biweekly intervals until mid-September; subsequent litter sampling was done at weekly intervals. Leaves were separated from other litter components, dried at 70°C, and weighed. Results from the six traps were averaged and expanded to hectare basis (table 1). The data indicate that the leaf biomass of the 1 by 1 and 2 by 2 foot plantations reached, or approached, the equilibration quantity, i.e., the biologically attainable quantity for the type of the plantations studied under the existing environmental conditions. The ratio between the specific leaf weight of leaves in the litter and those collected (green) from standing trees was 1.57, i.e., leaf biomass estimated from litter trapping must be multiplied by 1.57 to obtain an estimate of leaf biomass of living canopies. For example, for the 1 by 1 foot plantation, in which litter sampling reached 3.3 metric tons per hectare, the corresponding dry weight of green leaves is about 5.18 metric tons per hectare (standard deviation 0.63 metric tons per hectare). These values are likely to be underestimates of true leaf biomasses because in small plantations some leaves may be lost due to wind.

Leaf biomass of the stands was also estimated from destructive sampling. Three trees were destructively sampled in the 1 by 1, 2 by 2, and 4 by 4 foot plantations. Diameters of all branches were measured 2.5 centimeters from the stem and leaves from a 10-percent sample of branches separated, dried, and weighed. Dry weights of leaves (dependent variable) were related to branch diameters (independent variable) and the regression used in estimating total leaf biomass of individual sample trees. Finally, total leaf biomass of sample trees (dependent variable) was related to tree dbh

Table 1.--*Leaf litter, leaf biomass, and light regime in 3-year-old plantations of* Populus Tristis

Spacing (feet)	Leaf litter per hectare		Canopy leaf biomass per hectare		Light intensity		Light in the open
	Mean	Range	Mean	$S_{y.x}$	Mean	Range	
	Metric tons	Metric tons	Metric tons	Metric tons	Foot-candles		Percent
1 by 1	3.30	2.69-3.90	6.24	0.68	37	19-58	0.53
2 by 2	3.23	2.74-3.76	5.41	1.07	39	14-83	.57
4 by 4	2.60	1.30-3.17	3.61	.30	66	45-310	1.87
8 by 8	1.58	1.21-1.83	n.a.		3215	70-7,200	45.5

(independent variable) and used to calculate leaf biomass of total plantations (excluding border trees). Results were similar to those obtained from litter sampling after the quantities of leaf litter were adjusted by the ratio of 1.57 (table 1).

Light was measured about 30 centimeters above ground with a photometer around noon on a clear day on July 30, 1975. The readings were taken under canopies at points systematically located along three transects in each plantation. Light in the open was measured between measurements along each successive transect. Average light intensities under the 1 by 1 and 2 by 2 foot plantations were only 0.53 and 0.57 percent of the light in the open, and the absolute light intensities were 37 and 39 foot-candles, respectively (table 1).

Results indicate that the canopy leaf biomass of about 6 metric tons per hectare (or 3.5 metric tons per hectare of leaf litter) may be the upper limit that can be attained under field conditions. In the same experimental area, leaf biomasses ranging from about 2 to 4.8 metric tons per hectare were determined by Ek and Dawson (in press) in other 3- and 4-year-old plantations of *Populus tristis*. Although not strictly comparable to *Populus* canopies, canopy biomasses of natural red alder stands in Oregon averaged about 5.5 metric tons per hectare and remained stable between ages 4 and 30 years (Zavitkovski and Newton 1971). It seems unlikely that the leaf biomass of *Populus tristis* can increase much beyond 6 metric tons per hectare because even on sunny days photosynthesis of the lowermost leaves probably does not reach a compensation point. On cloudy days the situation becomes even more critical.

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COOPERATIVE AND RELATED FOREST RESEARCH AT THE INSTITUTE OF PAPER CHEMISTRY

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Investigations underway that relate to the maximum yield research program include: (1) The Mass Production of Conifer Tree Hybrids--a program using tissue culture and protoplast fusion techniques to produce large numbers of useful hybrids, (2) Bark Characteristics of Important Pulpwood Species--a study of the fundamental bark characteristics important to segregating, pulping, and/or use of bark as fuel, and (3) The Production and Intensive Management of Genetically Improved Aspen--a program aimed at obtaining maximum per acre cellulose yield and improved fiber quality.

The Institute of Paper Chemistry has three projects that relate in various ways to the maximum yield research being undertaken by the USDA Forest Service. The objectives, methods, and progress of each project are briefly reviewed here.

PROJECT 3223 "THE MASS PRODUCTION OF CONIFER TREE HYBRIDS"

The primary objective of this research program is to find ways to mass produce conifer tree hybrids using tissue culture and protoplast fusion techniques. Another extremely important objective is to develop a procedure that will make it possible to start with single cells in suspension and go to embryoids and then to plantlets and finally to trees. The potential of hybridization in conifers has not been developed sufficiently to meet our future wood raw material requirements. The difficulty of producing large numbers of conifer tree hybrids was determined as one of the principal reasons conifer hybrids have not been widely grown in the past. The goal of this research program is to inexpensively mass-produce conifer tree hybrids and/or genetically superior selections using tissue culture techniques.

The program employs the scientific know-how from the field of biochemistry, electron microscopy, and plant physiology. Early emphasis has been on the differentiation of shoots on stem and cotyledon callus and the production of embryoids in cell suspensions. The work on protoplast fusion is being delayed until adequate progress has been made in the cell suspension work. Biochemical and morphological comparisons between several sources of callus and young organized tissue are underway. The two species under investigation are Douglas-fir and loblolly pine.

Early progress has been good, with Douglas-fir shoots being produced from a special source of callus from 11 different Douglas-fir clones (fig. 1). Embryoidlike structures have been developed in both Douglas-fir and loblolly pine cell suspensions and work is underway to trigger these structures to continue to develop into true embryos and eventually into plantlets (fig. 2). The program, despite its highly technical nature, has a very practical objective and the procedure is envisioned as starting in the laboratory

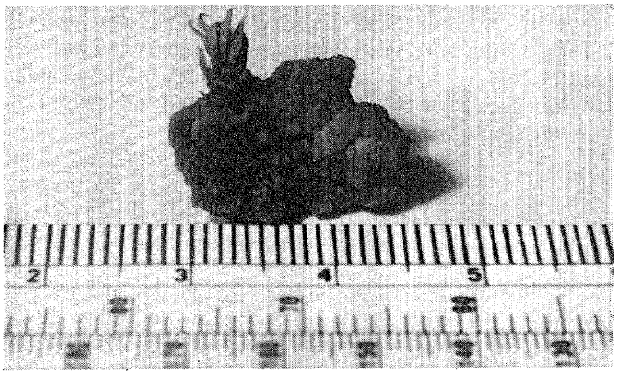

Figure 1.--*One of the first shoots produced on Douglas-fir cotyledon callus. Magnification--6X.*

Figure 2.--*Embryoidlike structures developed in Douglas-fir cell suspensions. Magnification--490X.*

and ending with the production of container-grown plantlets produced in the greenhouse.

PROJECT 3212 "BARK CHARACTERISTICS OF IMPORTANT PULPWOOD SPECIES"

The objective of this project is to provide information on the fundamental properties of bark (and wood) for 32 pulpwood species. The information is expected to help member companies determine the usefulness of a particular tree species as a raw material and assist in determining how the species might be harvested and handled to adequately segregate wood from bark. Emphasis is also being given to providing the information required to determine the consequences of pulping bark and use of bark as fuel.

Some standard tests have been set up to characterize the bark for each tree species. Included in the characterization for each species is the following information: silvicultural characteristics and geographic range, wood and bark morphology, wood and bark specific gravity and extractives, bark fibrous yield, wood/bark adhesion, bark strength and toughness, water flotation behavior, total ash and calcium, and fuel value of the bark.

The bark characteristics of 20 species have been investigated to date. Major differences in dormant season wood/bark adhesion, ash and calcium content of the bark, fibrous material in the bark, and strength of the bark have been discovered (table 1). Most conifer bark contains no fiberlike elements while most hardwood barks investigated contain a modest amount of fiber (fig. 3).

Screening and mechanical treatments that capitalize on the differences in strength between wood and bark seem to offer the most promise as ways of reducing bark levels in wood chip/bark mixtures. For hardwoods, a good correlation seems to exist between bark specific gravity and bark removal (high specific gravity gives best removal). This does not seem to be true for the conifers investigated. For conifers, bark thickness particularly the outer bark, seems to be a factor. Removing bark by hammermilling has been less effective for conifers than hardwoods (table 2). In this test, pure fractions of either wood or bark are fed into the hammermilling apparatus, caught in a cloth bag, and screened.

The information illustrated and the other basic tests are designed to identify the pulp and paper industry's bark problem and make it possible to take advantage of whole-tree chipping techniques and the promising short-rotation forest management systems being developed.

PROJECT 3250 "PRODUCTION AND INTENSIVE MANAGEMENT OF GENETICALLY IMPROVED ASPEN"

This project is a streamlined version of two larger research projects. The

Table 1.--*Bark pulp yield and usable fiber*
(In percent)

Hardwoods	Bark pulp yield	Usable bark fiber[1/]	Conifers	Bark pulp yield	Usable bark fiber[1/]
Quaking aspen	34	10	White spruce	21	0
Eastern cottonwood	35	9	Balsam fir	26	0
Sweetgum	35	5	Jack pine	19	0
Sugar maple	34	3	Loblolly pine	24	0
White birch	36	0	Slash pine	24	0
Northern red oak	28	5	Douglas-fir	18	5
Southern red oak	31	4	Western hemlock	36	0
Northern white oak	35	3	Lodgepole pine	27	0
Southern white oak	37	3	Ponderosa pine	29	0
			Engelmann spruce	24	0
			Western larch	28	1

[1/] Usable bark fiber is the fiber retained on 60- and 100-mesh screens. The percentage given is the yield based on whole bark samples.

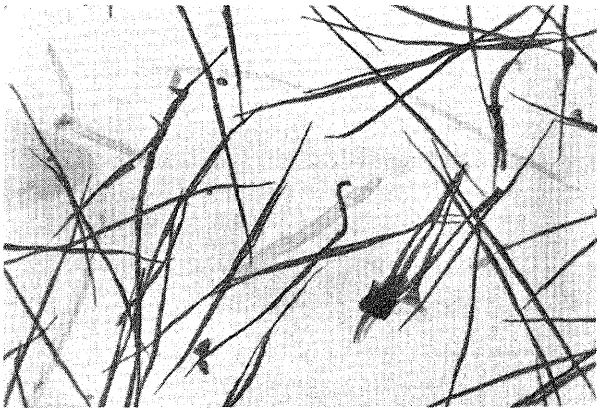

Figure 3.--*Aspen bark fiber retained on a 60-mesh screen. Magnification--75X.*

program combines the aspen genetics research that has been underway since 1955 with an aspen intensive management program started in 1968. The objective of the new program is to bring together the knowledge acquired over the past 20 years and formulate a forest management plan for aspen hybrids that will obtain the maximum per acre fiber production and improve fiber quality.

The genetics phase of the program employs selection, hybridization, and polyploidy in an effort to produce trees that grow faster and have better wood properties than native aspens. The intensive management phase of the project has investigated the possibilities of

Table 2.--*Hammermilling results*[1/]
(In percent)

Hardwoods	Bark removed	Wood loss	Conifers	Bark removed	Wood loss
Quaking aspen	34	5	White spruce	23	4
Eastern cottonwood	18	5	Balsam fir	44	6
Sweetgum	32	7	Jack pine	26	5
Sugar maple	29	5	Loblolly pine	34	6
White birch	38	6	Slash pine	36	5
Northern red oak	34	10	Douglas-fir	28	4
Southern red oak	46	6	Western hemlock	24	3
Northern white oak	37	5	Lodgepole pine	31	4
Southern white oak	38	3	Ponderosa pine	26	4
			Engelmann spruce	25	4
			Western larch	26	6

[1/] Based upon simulated hammermilling, followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.

converting low-quality northern hardwood stands to hybrid aspen. It includes test plantings of aspen hybrids and native sucker stands that have been fertilized and irrigated to determine the biological potential of such procedures and the impact of rapid growth on wood quality.

We have produced a number of aspen hybrids that grow twice as fast as native aspen and have superior fiber properties (fig. 4, table 3). Arboretums are being established with several of the cooperating companies to facilitate the mass production of the better hybrids. Growth response from fertilization and irrigation has been similar to that for other tree species. Specific gravity was decreased 6 to 8 percent and fiber length increased 4 to 6 percent by treatments that increased volume growth about 100 percent. The aspen hybrids have responded better to fertilization than the native aspen trees. A recently completed economic analysis indicates that a rate of return of 6 to 6-1/2 percent can be expected from growing aspen hybrids compared to much less wood production and a rate of return of 5 to 5-1/2 percent from growing red pine in northern Wisconsin.

Figure 4.--*Three-year-old triploid hybrid clone growing in northern Wisconsin.*

Table 3.--*Wood and kraft pulping properties of triploid hybrid aspen*

Type of material	Wood specific gravity	Pulp fiber length	Screened pulp yield	Handsheet properties[1/]		
				Tear	Burst	Tensile
		mm	*Percent*			
Mature native aspen	0.349	0.91	52.6	75.7	51.5	10.3
15-Year-old native aspen	.350	.79	52.1	73.0	48.0	9.9
10-Year-old triploid hybrid aspen	.420	.94	53.5	88.0	55.7	10.1
15-Year-old triploid hybrid aspen	.401	1.00	51.2	96.0	58.0	10.4

[1/] Measurement at 750-ml Schopper-Riegler freeness; tear and burst are TAPPI factors; tensile is breaking length in km.

DETERMINING MOISTURE-NUTRIENT REQUIREMENTS FOR MAXIMUM FIBER YIELD

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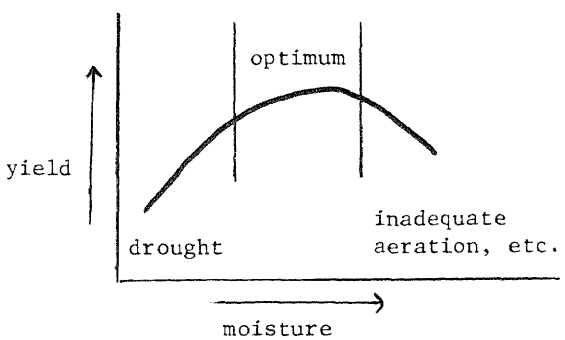
Nutrient-moisture requirements for maximum fiber yields will be determined in a series of growth room, greenhouse, and field studies. Irrigation and fertilization indices will also be developed for use in management systems.

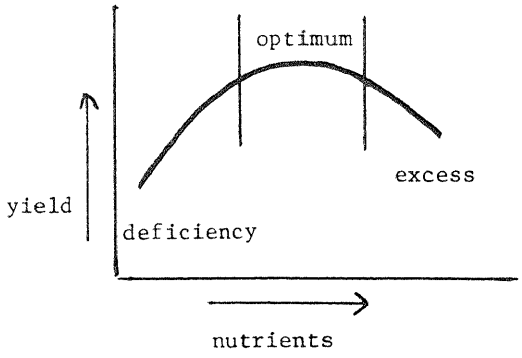
There have been no project studies on the nutrient-moisture aspects of maximum yield forestry specifically, although some cooperative growth room-greenhouse studies were conducted at Iowa State University (Dykstra 1974, Domingo and Gordon 1974). Irrigation and fertilization of current field test plots is based on the best available information on tree nutrition combined with good farming practices. However, we wish to move beyond just creating and maintaining *good* growing conditions; we want to establish as precisely as possible nutrient and moisture levels necessary for *maximum* yield. In addition, we want to examine the influence of various levels of input on yield, determine the effects of maximum-yield management on wood quality, and develop the capability for matching species and clones to nonirrigated but intensively managed sites. To accomplish this, we will look at the effects of nutrient-moisture variables on the growth of many species and clones in a series of growth room, greenhouse, and field studies carried out over many years.

The general relations between nutrient and moisture effects on plant growth are well established. Plant growth usually increases with increasing moisture supply up to some optimum level:



Eventually a moisture level is reached (with the exception of "swamp species") at which other factors become limiting to growth. Inadequate soil aeration is one such factor sometimes encountered (Domingo and Gordon 1974). One project objective is to define the optimum water levels for several different tree species and clones.

Plants respond to fertilization in much the same way they do to water (Morrison 1974):



There is an area of deficiency, an optimum range, and an area of excess. Another project objective is to define the optimum nutrient levels for the same tree species and clones.

Determining optimum nutrient-moisture conditions is complicated by the fact that they are interdependent. Generally, plant growth increases with increasing moisture and nutrient levels (fig. 1). However, because of this water-nutrient-growth interaction, nutrient requirements may be decreased at low moisture levels as depicted by the hatched band. In fact, heavy fertilization can retard growth on dry sites because excessive nutrients in the soil can increase salt content creating plant water stress (Dickson 1971, Black 1965). This can also happen under fairly high soil moisture conditions. On the other hand, excessive soil moisture can sometimes cause inadequate soil aeration thereby reducing growth.

We want to define the combinations of fertilizer and water necessary for optimum growth as depicted by the circled area in figure 1. A few published studies on foliar nutrient levels required for maximum growth showed little difference among the *Populus* species tested (table 1). However, we still need to see if this holds true for our particular hybrids because

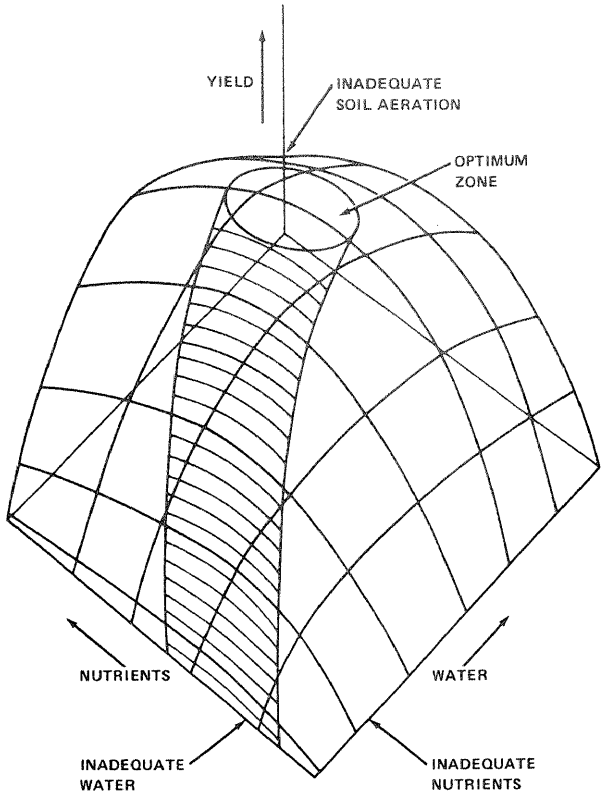


Figure 1.--*Effect of nutrient-moisture interactions on tree yields.*

nutrient-water requirements for maximum growth may vary from clone to clone. This potential for different requirements will be checked in a series of studies with our cooperators. To gather this information will require growth-room studies of interclonal variation and (if differences exist) field tests to check results over a rotation period. Eventually we will have the information necessary to grow each clone under its optimum conditions. Optimum growing conditions are necessary in order to make valid comparisons in clonal screening tests and in yield studies in large plantations.

Table 1.--*Foliar concentration for maximum growth*
(In percent by dry weight)

Species	Nitrogen	Phosphorous	Potassium	Calcium	Magnesium	References
E. cottonwood *(Populus deltoides)*	3.5-4.5	0.5-0.7	3.0-4.0			Bonner and Broadfoot 1967
Quaking x E. gray pop. *(Populus canescens x P. tremuloides)*	4.3-4.4	.51-.60	2.8-3.3	0.56-0.63	0.35-0.45	Einspahr 1968
Bigtooth x E. gray pop. *(Populus grandidentata x P. canescens)*	4.0-4.3	.58-.65	2.8-3.0	.40-.62	.23-.40	Einspahr 1969

Although it is essential to determine the nutrient-moisture requirements for maximum growth, much additional information is required before maximum yield forestry can be adapted into a management system. Some of the necessary areas of research are as follows:

1. Determine the water consumed in dense irrigated plantations to aid in designing irrigation system capacity.

2. Determine the optimum amount and timing of irrigation and develop an irrigation index. Soil water monitoring to determine when to irrigate is complicated by the fact that the rapidly elongating root system of young trees penetrates to ever greater depths, thus continually changing any relation between soil water availability as indicated by a sensor and that available to the plant roots. Therefore, an index based on plant water potential rather than soil water will probably provide better irrigation control.

3. Investigate the extent of inter-tree transfer of nutrients and water through root grafts and/or closely associated roots. If such inter-tree transfers occur, we would need larger test plots and buffer strips to isolate one treatment from another. However, irrigation and fertilization could then be less uniform in a managed plantation because inter-tree transfers would tend to lessen any differences in application.

4. Monitor the uptake of nutrients by the plant so as to maintain nutrition at optimum levels. A tissue test should be developed so that nutrient status can be determined early in the growing season and fertilizer applied in the amounts and at the time it does the most good.

5. Determine the growth potential of selected *Populus* clones and other species when grown without irrigation but with otherwise optimum conditions. Then drought resistant clones can be selected for nonirrigated sites where the trees must depend on the available water in the soil profile.

6. Monitor the effect of intensive forest practices on groundwater contamination and soil changes. Although such effects will probably not be any greater than those from standard agricultural practices, any such changes should be documented. If severe, ways should be determined to reduce their impact by modifying cultural practices.

Because of the nature of the project mission, some added criteria influence research strategy. First, we are concerned with *maximum* yields so we would like to be as precise as possible in our recommendations for irrigation and fertilization. Second, because of the long rotations involved (compared with agricultural crops), undesirable clones must be rapidly screened out in order not to waste time and money in full-scale field tests (see paper by Paul Wray in this Proceedings). These two factors dictate that we use "quick" growth-room or greenhouse tests in many instances before moving into long-term field studies. This approach requires measurement techniques that can be applied regardless where or how a study is done so as to provide a common data base for extrapolating results from study to study. Consequently, water potential and nutrient measurements will be concentrated on the plant itself rather than on the much more variable soil-plant environment. This will involve plant water potential measurements with a pressure bomb and/ or thermocouple psychrometer, and plant tissue analysis for nutrient status.

However, soil moisture and nutrient data will still be collected in field studies. Whereas plant water potential measurements determine *when* to irrigate, soil moisture measurements are necessary to determine *how much* water to add to bring soil moisture back to field capacity. Likewise, soil nutrient data will complement the tissue data and together may eventually provide a firmer basis for fertilization recommendations.

In summary, the research strategy is to initiate a series of growth-room, greenhouse, and field studies (some project studies, some cooperative) emphasizing plant measurements for nutrients and water. The objectives are to define optimum growing conditions for various clones and species, develop the capability for matching species to nonirrigated sites, and to develop the necessary cultural techniques and indices for full-scale management for maximum yields.

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SOME PROBLEMS OF ESTABLISHING AND MANAGING INTENSIVELY CULTURED PLANTED STANDS

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The need for intensive site preparation and competition control for converting hard-to-plant sites to fast growing stands of economically desirable species is discussed. Jack pine, red pine, white spruce, and hybrid Japanese-European larch seedlings raised in 3-M polymer blocks and Spencer-Lemaire Rootrainers grew larger and survived outplanting better than stock grown in two sizes of Polyloam blocks. Average survival for all species for these two best containers was 68 percent. Intensive site preparation followed by factorial combinations of Casoron and Roundup herbicide to control weeds resulted in lower survival where Casoron was applied.

A key step in establishing and managing intensive culture plantations is removing the existing vegetation and establishing in its place improved plant material better adapted to the site. The fact that most sites needing reforestation support stands of trees or shrubs makes the task totally different than it was 40 or 50 years ago. Effective methods must be found, therefore, to prepare sites before planting and suppress subsequent weed growth at least until the new plantation has occupied the site and weed competition is no longer a deterrent to survival and growth.

Equally important to successful plantation establishment is the vigor and physiological state of the tree seedlings to be planted. If the trees are in poor condition at the time of planting, due to desiccation or root damage, for example, successful competition with weeds becomes even more difficult.

To deal with these problems, we are studying two approaches that together may enhance the trees' early competitive ability: (1) the effect on tree growth and survival of mechanically and chemically removing or suppressing competing vegetation, and (2) the use of container-grown seedlings for planting stock.

Containerized seedlings are grown in individual containers in the greenhouse to plantable size. After a period of hardening outdoors, the trees are outplanted with or without the containers, depending on the containers used. The big advantage of containerization is that the seedling root system is protected against disturbance and drying (fig. 1).

Figure 1.--*The Spencer-Lemaire "Rootrainer."*

In April 1974 we began a preliminary study to evaluate several elements of plantation establishment and management: (1) species, (2) container systems, (3) herbicidal effects on the trees and competition, and (4) site preparation.

GREENHOUSE TEST

Seeds of white spruce (*Picea glauca* (Moench) Voss), red pine (*Pinus resinosa* Ait.), jack pine (*Pinus banksiana* Lamb.) and a hybrid larch (*Larix decidua* x *L. leptolepis*) were sown in the following containers: (1) The Spencer LeMaire "Rootrainer,"[1/] a folding type of plastic container with cavities each holding 10 cubic inches (164 cubic centimeters) of a 3:1 peat moss and vermiculite mix; (2) rectangular Polyloam blocks (polyurethane foam) of two sizes--2¼ and 5 cubic inches (37 and 82 cubic centimeters); and (3) rectangular blocks 5 cubic inches (82 cubic centimeters) in size formed by bonding a 3:1 peat moss and vermiculite mix with a hygroscopic polymer (3-M Co.). Fertilizer was applied about every 2 weeks to the 3-M polymer blocks and Rootrainer seedlings. The Polyloam reportedly contained sufficient slow-release fertilizer to maintain plants for about 5 months. Artificial light was given to extend the photoperiod to 20 hours per day.

During the early stages of the study, two problems were encountered that appeared to be related to the properties of the different containers. In the Polyloam containers, germination of white spruce and jack pine seed was noticeably slower than in the other containers and in many blocks germination failed to occur. This was probably due to the difficulty in maintaining a proper moisture content in the Polyloam blocks.

Root rot caused some mortality in the Rootrainers. Better aeration properties of the other blocks probably prevented a buildup of the disease in these containers. In late July, after 4 months, the seedlings were removed to a lath house and allowed to harden under outdoor conditions for about 4 weeks before planting. At this time, significant differences in the growth of all species due to container type showed up: generally, the Rootrainer and 3-M polymer containers produced taller seedlings than the Polyloam (table 1).

Table 1.--*Average shoot lengths of four conifer species grown in four containers* (In centimeters)

Container [1/]	Jack pine	Red Pine	White spruce	Larch
Large Polyloam block	9.3	5.9	3.2	11.8
Small Polyloam block	9.3	6.1	2.2	9.9
Rootrainer	12.8	10.1	7.3	11.8
3-M polymer block	13.6	10.8	6.4	20.3

[1/] There are statistically significant differences between container systems, but analysis to identify differences between individual systems has not been run at this preliminary stage of the study.

OUTPLANTING TEST

The planting site is part of the Three Lakes Ranger District, Nicolet National Forest, Wisconsin. The vegetation on the site was mostly sod with some scattered aspen, indicating a history of severe fire. Soils are a sandy loam of the Padus Series.

The site was prepared in cooperation with National Forest personnel. A crawler tractor with straight blade leveled and cleaned the site so it could be disced with a farm tractor (fig. 2). The leveling operation removed much of the top layer of soil. Rocks exposed by the crawler tractor interfered with discing.

A completely randomized block design was used for outplanting. Seedlings were spaced at 6 feet in square 16-tree plots.

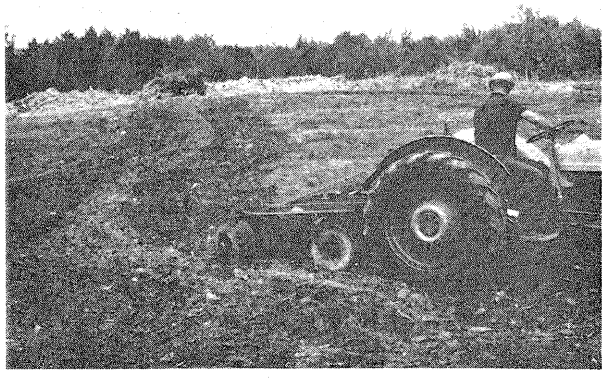

Figure 2.--*A light farm tractor with disc removed weeds before planting.*

[1/] *Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

The jack pine, red pine, white spruce, and hybrid Japanese-European larch were planted separately so comparisons among species were not part of the design. All combinations of the following container system and competition control factors were replicated by random assignment in each of four blocks:

	Container	*Competition Control Treatment*
1.	Large Polyloam block	Control
2.	Small Polyloam block	Casoron G4 herbicide at 147 kilograms per hectare
3.	Rootrainer	Casoron G4 herbicide and Roundup at 2.26 kilograms per hectare (acid equivalent)
4.	3-M polymer	Roundup at 2.26 kilograms per hectare (acid equivalent)

The pre-emergent herbicide, Casoron, was applied in bands after planting in the fall of 1974. The Roundup was applied as a direct spray in early July 1975 (fig. 3).

FIRST YEAR SURVIVAL

After one growing season containers had affected survival of all species. The Rootrainer and 3-M polymer survival consistently outperformed the large and small Polyloam (table 2). At present, seedlings from the Rootrainer and 3-M polymer blocks appear to perform equally well. However, differences in growth or survival may occur later. The competition control treatments also affected survival: survival was consistently lower on plots treated with Casoron (table 2).

DISCUSSION

The two container systems with the best survival--the Rootrainer and 3-M polymer block--should be evaluated further. Survival of seedlings from both systems was high enough to indicate that container planting outside of the spring planting season is possible, provided competition control (provided here primarily by site preparation) is adequate.

The lower initial survival in the plots treated with Casoron compared with the control plots was unexpected. This may indicate a toxic effect, or it may indicate that the shading by the herbaceous vegetation in the control plots provided a more favorable environment for the trees by reducing transpiration and soil moisture evaporation. The control and Roundup treatments were similar because the herbicide effect was only present during the latter part of the season. The final effect of competition control will have to be evaluated on growth and survival beyond

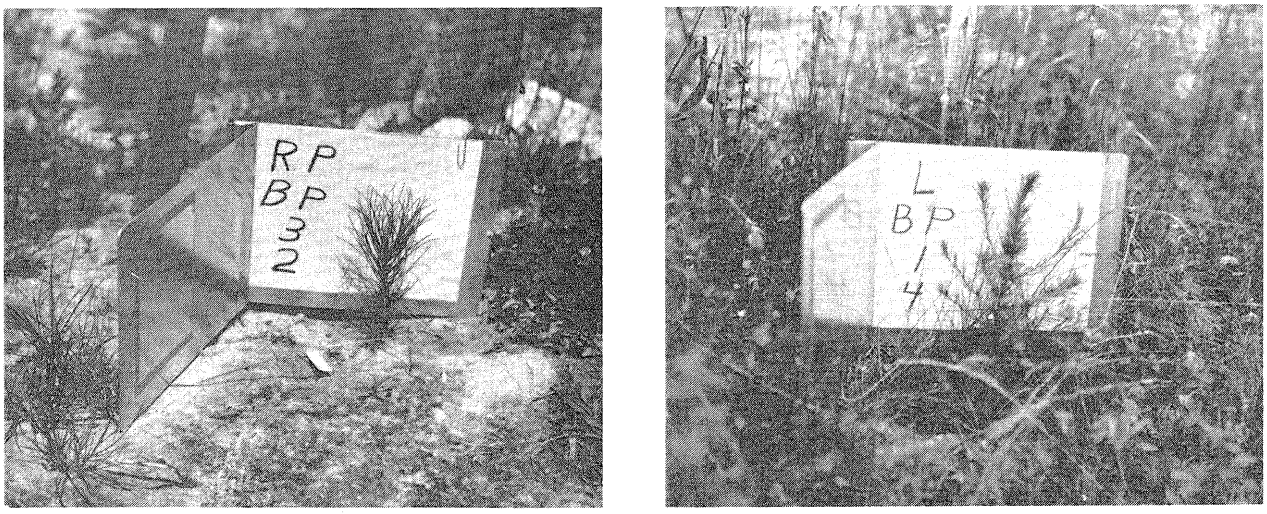

Figure 3.--*A red pine seedling on a Casoron treated plot (left), and larch on a Roundup plot (right).*

Table 2.--*Seedling survival for four conifer species by container and competition control treatment*

(In percent)

Container and competition control treatment[1]	Species			
	Jack pine	Red pine	White spruce	Larch
Large Polyloam block				
Control	38	52	35	59
Casoron	--[2]	--	15	--
Casoron/Roundup	--	39	23	36
Roundup	41	34	41	67
Average	39	42	29	54
Small Polyloam block				
Control	42	44	48	52
Casoron	--	--	--	--
Casoron/Roundup	33	36	25	28
Roundup	53	33	50	59
Average	43	38	41	46
Rootrainer				
Control	97	73	88	94
Casoron	83	62	53	--
Casoron/Roundup	84	36	61	47
Roundup	91	73	87	86
Average	89	61	72	75
3-M polymer block				
Control	97	92	83	92
Casoron	88	83	--	--
Casoron/Roundup	83	75	45	44
Roundup	97	83	89	95
Average	94	84	72	77

1/ There are statistically significant differences between container systems and treatments, but analysis to identify individual differences has not been run at this preliminary stage of the study.

2/ Not planted.

this initial establishment period. There is need to evaluate and develop better site preparation methods that will concentrate moisture and nutrients, especially organic matter, in the root zone of these containerized seedlings to attain truly superior growth.

FUTURE RESEARCH

Other problems to be studied include the efficiency of mixed conifer-hardwood plantations. One of the basic principles of increasing forest productivity is to quickly occupy the site with species of economic importance, such species combinations as rapidly growing *Populus* hybrids and spruce may have distinct possibilities. These plantings would have to be designed to permit mechanical harvesting of the faster growing species. We need plantations that need no noncommercial thinnings.

We are also working with the Genetics Project in learning how best to establish and grow genetically improved yellow birch, and have begun a small study to evaluate requirements for yellow birch plantations.

We anticipate finding alternatives to natural regeneration on sites cleared by the total tree harvesting systems. These sites obviously offer better opportunities for planting than the traditionally clearcut areas where slash is a problem.

Cooperative studies involving the "Engineering Systems and Mechanization for Northern Forest Stands" Work Unit at Houghton, Michigan, are of special importance in this problem area. Once silvicultural research has determined the physiological needs of the seedling and the proper environment for growth, the information is of little value if the equipment required to put the practices into effect on a commercial basis is not available. Current high labor costs dictate mechanization of woods operations, and increased mechanization requires more extensive engineering. Consideration of engineering requirements together with physiological requirements for growth will enhance the potential of achieving a commercially acceptable system of establishing and managing intensively cultured planted stands.

INCREASED YIELDS OF INTENSIVELY MANAGED PLANTATIONS OF IMPROVED JACK PINE AND WHITE SPRUCE

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Increased growth resulting from provenance selection and breeding based on progeny tests and the direct use of vegetatively propagated superior individuals of white spruce and jack pine are discussed. Volume increases in provenance selection of 20-30 percent in white spruce and 10-20 percent in jack pine are expected. The direct use of cloning of superior individuals may increase the gains 100 percent in white spruce and 50 percent in jack pine provided research can develop needed techniques. Some silvicultural aspects of intensive plantation management are also considered.

Intensive plantation management is not a new concept. For many years European foresters have grown selected provenances with nurse-crops after substantial site preparation and with control of competing vegetation often using hand labor. In the United States, the system has not been used in the past.

For the purpose of this paper, we will recognize four essential elements of intensive plantation management:

1. Site selection.
2. The use of improved genetic stock.
3. The production and use of improved planting stock.
4. Site preparation and plantation establishment and maintenance, including the choice of spacing and in some cases the choice of species combinations.

This paper will primarily consider the genetic aspects of intensive plantation management and will limit itself to jack pine and white spruce. The breeding goals for jack pine and white spruce are to achieve:

1. Maximum yield of fiber in the shortest possible time commensurate with the site quality and the investment in site preparation and maintenance. We anticipate maintenance in terms of control of competing vegetation, but not control of competition between the planted trees themselves. In other words, we anticipate a management system that will not require thinning or only a minimum of thinning during the rotation.

2. Adaptation to the climate in the region.

3. Resistance to insects and diseases.

In this paper we discuss what might be achieved in a tree improvement program primarily in terms of increased growth rates or yields. The results, with one exception, represent the growth that can be achieved with genetically improved material in "good" plantations. We specifically mention a 5-year-old white spruce test, where growth may approach what can be achieved under intensive plantation management. We also attempt to estimate how close we are to the actual delivery of improved seed on a commercial scale. Finally, we suggest some stand formations that perhaps should be tested in connection with the management of intensively cultured plantations of genetically improved material.

HOW MUCH IMPROVEMENT MAY WE EXPECT?

Improvement may be achieved at three levels:

1. The use of seed collected in stands of proven genetic superiority. This process is simple and inexpensive. But often it is possible to obtain only limited improvement in this way. In most cases, however, such a program can be mounted rapidly on the basis of existing provenance tests.

2. Continued breeding programs based on progeny testing and selection require much more investment and a longer period of time to achieve improvement.

3. At present, the third method is used only for species that propagate readily from cuttings, such as poplar. It is based on the selection of outstanding individual genotypes and mass production by means of vegetative propagation. Not until recently has this technique been suggested as an approach to improving hard-to-root species of conifers. For such species the method would depend on juvenile selection and propagation of young material still within the easy-to-root age.

Use of Improved Provenances

White Spruce

The amount of improvement that can be achieved in the Lake States by selecting the best provenances of white spruce may be estimated from three studies within the region. The oldest and perhaps most reliable data are from a seed-source test of white and Norway spruce established in 1936 in northeastern Wisconsin and Minnesota with 2-2 transplants. The study has demonstrated the superior performance of white spruce material from southeastern Ontario. In the Wisconsin test, using the simple formula d^2 x height x survival as a measure of volume per plot,[1/] the collection from Douglas, Ontario, at 29 years after planting surpassed that of the local seed source from Florence County, Wisconsin, by 12 percent. Unfortunately, the local seed source was only represented in a single 100-tree plot, whereas the measurements for the Ontario seed source are based on the average from six 100-tree plots.

Assuming thinning from below, the final harvest would be based on fewer but larger trees. Therefore, it is possible that the increases in yields would be greater. Comparing the tallest one-third of the measured trees in the Ontario provenance with the tallest trees in the control-plot suggests a volume superiority of more than 37 percent Four other seed sources from the Lake States and Ontario are represented and better replicated in the test. The Douglas, Ontario source exceeded all four sources in cubic volumes per plot by 24 to 98 percent (based) on all measured trees) (King and Rudolf (1969).

In the test of the same material in northern Minnesota, the differences in height and d.b.h. between the southeastern Ontario and the local Minnesota sources are not significant. However, the Douglas, Ontario source, because it survived better, did surpass the local source by 68 percent in cubic volume per plot. Newer tests have substantiated the better performance of Ontario sources in northern Minnesota. In a test established in 1958 and measured 15 years after planting, average tree volume for the five best seed sources, all from southeastern Ontario, ranged from 0.81 to 0.94 cubic feet, whereas the control trees from three different Minnesota nurseries ranged from 0.35 to 0.63 cubic feet per tree (Stellrecht *et al.* 1974).

It would be tempting to conclude from these data that all white spruce genotypes in Minnesota are inferior and should be completely disregarded as a source of parent material in a white spruce breeding program. This is not correct, since superior individual trees have been identified in other tests. It is correct, however, to state that seedlots used in commercial nurseries in Minnesota in 1958 were of inferior quality and that the use of southeastern Ontario seed could have significantly improved the yields in white spruce plantations in the State. There is little reason to think that seed now used in the State differs greatly from the seed used in 1958.

The most recent rangewide test of white spruce has essentially substantiated the results of the older tests (figure 1). In

1/ *A plot was 50 by 50 feet, planted with 100 trees.*

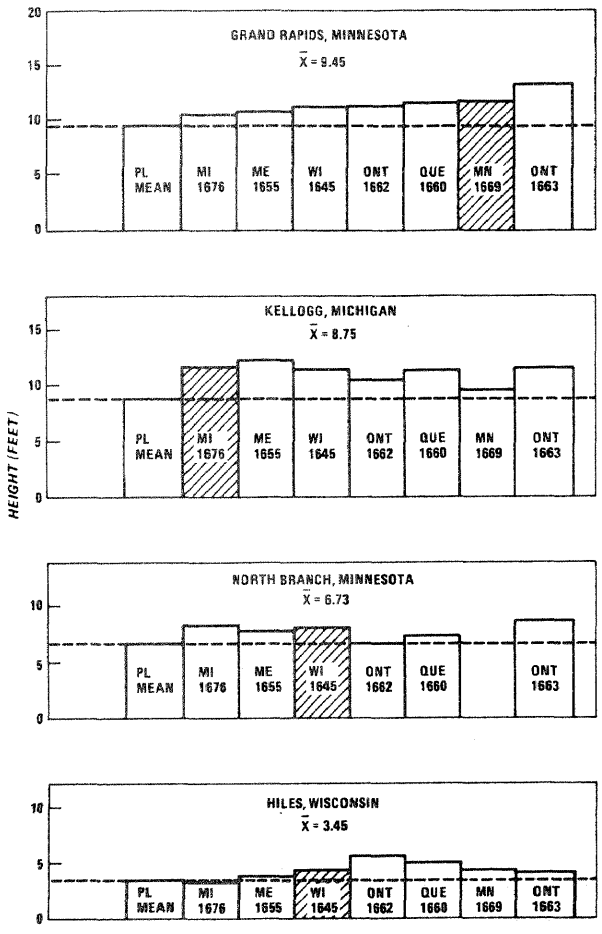

Figure 1.--*Mean heights 14 years from seed of white spruce provenances at four test sites in the Lake States. The shaded bars are the Lake States seed sources from the environments that resemble the test site the closest.*

Lake States plantings, heights of provenance material from southeastern Ontario has surpassed the growth of local seed sources by 1 to 15 percent (see also Nienstaedt 1969).

In summary, using superior white spruce provenances such as the southeastern Ontario source mentioned here, it is realistic to expect increases in height growth at mid-rotation from 10 to 15 percent and in volume growth between 20 and 30 percent.

Jack Pine

Gains from provenance selections in jack pine may be estimated from a test of 26 Lake States seed sources measured 20 years after planting in 15 field tests in the three States. The data from these tests are now being prepared for publication.

The preliminary volume estimates (table 1) show two important points: (1) Individual tree volumes of selected provenances exceeded the mean plantation tree volumes in 30 of 40 comparisons by 1 to 31 percent. (2) Although none of the 10 seed sources is consistently superior in all 4 tests, some seed sources are particularly noteworthy. Source 1601 from Minnesota exceeds plantation means by 7 to 15 percent in three tests and is slightly below average in the fourth, while 1617 from Michigan is 14 to 31 percent above the mean in three tests and 7 percent below in the Beltrami County, Minnesota, test. More reliable seed source selections must be based on the complete set of data, but these measurements suggest that volume increases from 10 to 20 percent may be expected on the average in jack pine through the use of the right provenances.

Use of Individual Tree Progeny Testing and Selection

White Spruce

The most detailed information on the performance of individual progenies of white spruce in the Lake States is in a test of open-pollinated progenies at Lake Tomahawk, Wisconsin (61 progenies); Wabeno, Wisconsin (39 progenies); and Moran in the Upper Peninsula of Michigan (55 progenies). There were highly significant differences between families at all three test sites (fig. 2). For example, at 9 years from seed, family 1886, selected in a plantation in Menominee County, Wisconsin exceeded the plantation mean height by 24.5, 13.3, and 14.0 percent in the Lake Tomahawk, Wabeno, and Moran plantations, respectively. Families 1886 and 2521 were common to all three tests and ranked 1 and 2, 10 and 7, and 6 and 11 at Lake Tomahawk, Moran, and Wabeno; 2517 rated 3 at Lake Tomahawk and 5 at Moran. In other words, selecting the best third of the families as the basis for a continued breeding program would have included the three families.

On the other hand, families such as 1898 and 2525 are average or below average in all of the tests. Number 1898 ranks 46th at Lake Tomahawk, 37th at Moran, and 48th at Wabeno. All of the six families are from Wisconsin stands: 1886, 2517, and 2521 were selected in a plantation in Menominee County

Table 1.--*Average individual tree volumes*[1/] *of jack pine at age 20 in four Lake States provenance tests*
(In percent of plantation mean)

Source	Lake County, Minnesota	Beltrami County, Minnesota	Marinette County, Wisconsin	Ontonagan County, Michigan
1589 MN	113	88	101	106
1596	100	114	98	105
1600	99	106	108	103
1601	115	115	98	107
1605 WI	87	107	105	113
1606	103	103	102	106
1610	103	114	95	110
1613 MI	106	93	109	106
1617	114	93	127	131
1618	88	114	102	118
Plantation mean ($ft.^3$)	0.91	0.86	1.29	1.26

1/ Volume ($ft.^3$) = 0.1174 x 0.3453(D^2H).

(the original seed source probably of local Lake States origin); 1892 and 1898 are from a stand in southern Ashland County; and 2525 is from a stand in northern Ashland County, Wisconsin. All the families represent the Lake States, so the plantation means shown in figure 2 are good values to use for comparisons. The Moran, Michigan, planting, however, included an additional control, i.e., standard nursery stock from Toumey Nursery of Ottawa National Forest origin. This seed source was, at the time of establishment, used extensively for planting on the Ottawa, Nicolet, and Chequamegon National Forests. It was much below the plantation mean and was exceeded in growth by the two better families (2517 and 1886) by 56 and 49 percent.[2/] As will be mentioned later, some of the selections from Menominee County have been used in tests of controlled pollinations. They have in all instances performed well, yielding progenies superior to controls.

2/ *The difference between the control and the best families does not represent genetic differences alone, because the commercial control was raised at Watersmeet, Michigan, and not Rhinelander, Wisconsin, where all the test material was raised. The results, however, are typical of all the Work Unit's tests of jack pine and white spruce. The planting stock from Toumey has been inferior in all cases.*

Jack Pine

Information available for jack pine is not as detailed or as well substantiated as the white spruce information. Several open-pollinated progeny tests are in progress in the Lake States and will, in a few years, give us much more reliable estimates. Here we report 4-year height growth of full-sib families represented in two plantations in northeastern Wisconsin. The 2 tests have 51 families in common and are all of Lake States origin. Plantation means, therefore, are a good value to use for comparison (fig. 3). On the better site, the best of the six families exceeded the mean by 10 to 19 percent, while the superiority of these families at the poorer site was only 4 to 8 percent. The relative performance on the two sites of this limited number of families was strongly correlated. This was also the case when all families were considered.

The variability within jack pine appears to be somewhat less than the variability in white spruce. As a gross simplification, we can say that white spruce is one of the most variable native conifer species followed closely by jack pine. With this information, it is clear that the potential for genetic improvement is high in white spruce and jack pine. However, it is too early to predict the specific gains that may be achieved through selection and breeding.

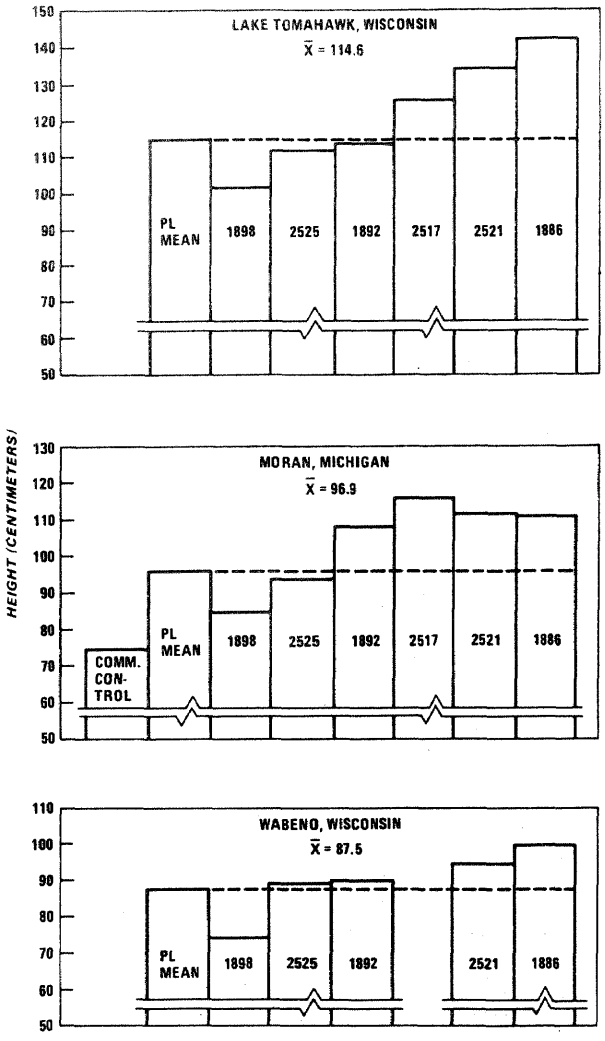

Figure 2.--*Mean heights 9 years from seed of white spruce. Progenies at three test sites in Wisconsin and Michigan.*

Direct Use of Superior Clones

Superior, individual genotypes have been used directly in some forms of plantation management using species readily propagated by means of rooted cuttings. At present, the maximum fiber yield concept is essentially based on clonally propagated material of *Populus*. Recently, a number of studies have suggested that this approach may be feasible for spruce and pine provided: (1) selections are made in juvenile material and screened for rooting ability while young, and (2) the rooting ability can be maintained by special techniques such as hedging or repeated rooting. The Genetics Work Unit is studying both the physiological and the genetic aspects of the problem.

White Spruce

The use of juvenile selections as an approach to tree improvement has been questioned in the past. The following is offered as evidence of its possible usefulness with white spruce: about 700 white spruce seedlings were selected for superior height in nursery beds in a northeastern Wisconsin nursery. They were paired with immediately adjacent average seedlings and planted in the field. After 22 years from seed, the selected seedlings still exceed the control plants in height by more than 27 percent. With this information, an increasing effort has been made to select superior juvenile spruce. The following test is an example:

In a well replicated test of controlled pollinated progenies of Menominee, Wisconsin, white spruce, 32 trees exceeding 160 centimeters (5¼ feet) were selected in four of the best families at age 5 (fig.4). Three control populations were included in the test: 1645, a stand collection from near Monico, Wisconsin; 4485, a Nicolet National Forest

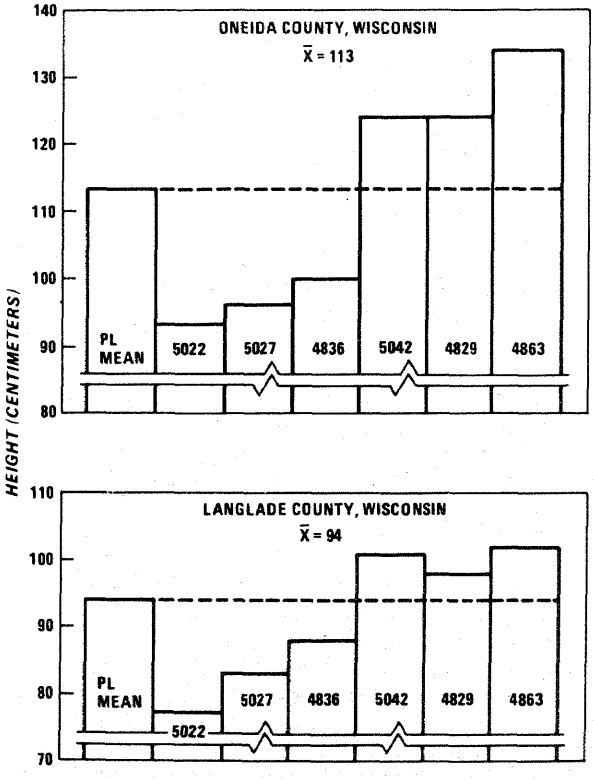

Figure 3.--*Mean heights 4 years from seed of jack pine progenies at two test sites in Wisconsin.*

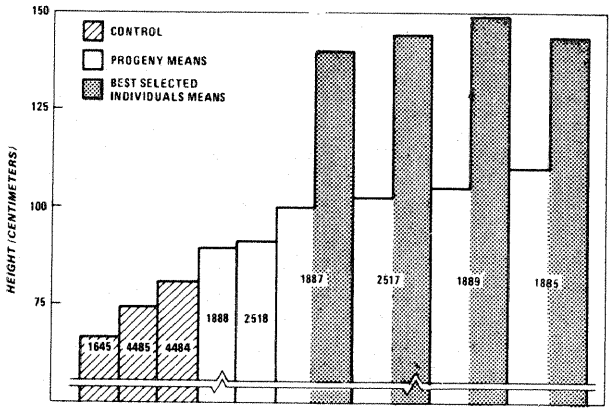

Figure 4.--*Mean heights at age 5 from seed of best selected white spruce individuals compared with the mean heights of the sibling progenies and of control populations.*

area collection; and 4484, seed from the Oconto River white spruce seed production area. The means of the four best families exceeded the controls in height by 23 to 61 percent. (Note that the best control, 4484 from a white spruce seed production area, exceeds the "commercial" area collection (4485) by 9 percent.) In comparison, the average heights of the best individuals of the same four families exceed the controls by 104 to 154 percent.

Thirty of the selected trees have been screened in a preliminary test for their ability to root. Although it was impossible to maintain optimum rooting conditions throughout the test, rooting exceeded 30 percent in 10 of the 30 trees and 80 percent in one tree. Future tests must verify the rooting ability and the superior growth must be thoroughly tested in properly designed replicated clonal tests. If the work is successful, it is clear that gains approaching 100 percent may be achieved in white spruce cheaply and quickly.

This test was established with containerized stock at 2 by 2 foot spacing and maintained essentially weed-free. Water levels were optimized during the growing seasons, but nutrient levels were not optimum throughout the 5 years of growth. The tallest trees exceeded 180 centimeters (6 feet) in height 5 years from seed and the best family averaged 110 centimeters (almost 4 feet). This probably approaches the performance of the intensively managed plantations of the future.

Jack Pine

In a similar test the five best full-sib jack pine progenies out of more than 70 families exceeded plantation mean height by 9 to 19 percent (fig. 5). Height superiority of the five tallest individuals within the same five families ranged from 26 to 33 percent.

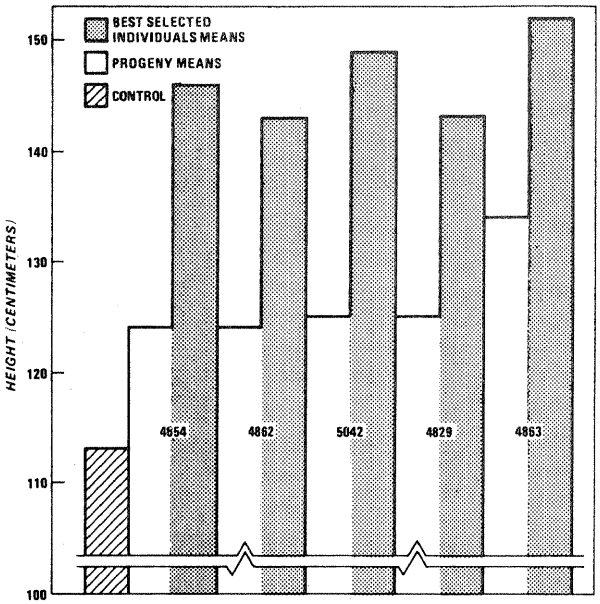

Figure 5.--*Mean heights at age 4 from seed of the five best selected jack pine individuals compared with the mean heights of the sibling progenies and of a control population.*

It should be pointed out that whereas the spruce families resulted from controlled pollination with pollen mixtures of eight trees, the jack pine families involve full-siblings involving a mother tree and a single male parent. This, of course, would tend to reduce variability in the jack pine families.

As previously mentioned, jack pine appears to be less variable than white spruce at the family level. On the basis of the above discussion, it is probably also reasonable to state that the within-family variation is less in jack pine than white spruce. Even so, jack pine is endowed with great potential for genetic improvement.

HOW SOON WILL IMPROVED GENETIC MATERIAL BE AVAILABLE?

Seed production areas are considered an interim phase of tree improvement that will

assure seed of known origin, good physiological quality, and, in some cases, possible small genetic gains. As mentioned, seed from the Oconto River Seed Production Area in one test has demonstrated 9 percent superiority over area collections at age 5. Seed from the other National Forest white spruce seed production areas has not been tested but has performed well in the nurseries. The seed production areas, in fact, are so productive that the Wisconsin Department of Natural Resources is considering obtaining excess seed from the two Wisconsin areas for the State nurseries. All white spruce planting stock used in the National Forests in the Lake States today is raised from seed production area seed.

White spruce seed orcahrds have been established by Region 9 and are beginning to produce modest amounts of seed. Within the next 5 years, production should increase greatly, and within 10 years, we can expect all white spruce seed for National Forest use to be produced in seed orchards. We cannot yet estimate the gains that might be achieved in the orchards, because all the parents in the orchards have not been progeny tested. We expect the improvement to exceed that for seed production areas, but we cannot expect gains of more than 20 percent until the orchards have been rogued on the basis of progeny tests.

Small amounts of seed from controlled crosses of known high quality genotypes representing the quality seed that can be expected from continued breeding programs are now available from the Genetics Work Unit. The crosses are being repeated annually and seed can be made available to cooperators for testing in plantings from one to a few acres in size. On the basis of early growth, they represent improvements of 25 to 50 percent.

A small experimental seed orchard representing the best available genotypes will be established by Region 9 in 1977. The orchard will start producing seed almost immediately, and by the mid-1980's should produce tens of thousands of seed annually. However, because of the rather narrow genetic base of the parent material, the seed is not intended for any extensive planting program.

The use of clonally propagated superior white spruce individuals is some years in the future. We will continue screening the 32 juvenile selections we have for rootability. If we manage to successfully root any of these, a number of re-rooting cycles will be necessary to build up enough stock plants to make seedlings available in sufficient numbers for commercial planting operations. Thereafter, it will be necessary to develop methods for maintaining the rootability of the selected clones. If we succeed all along the way, hundreds of thousands of seedlings should be produced annually early in the 1980's. Meanwhile, the search for and screening of superior juvenile white spruce should be continued.

Improved jack pine is not now available in the Lake States. However, the State of Minnesota in 1975 began to convert a proven stand into a seed production area. Based on the 1954 Lake States jack pine seed source study, this superior stand was selected at St. Croix Park in Minnesota. Roguing started in 1975, so the first seed representing any degree of improvement should be available for collection in 1977. A gradual up-grading of the stand will be achieved as trees are removed for seed harvest.

This source of seed will be perpetuated and improved through replanting in the area with the same provenance and by continued selection for growth rate and quality. Modest increases in yield from 5 to 8 percent may be achieved from this area.

The Michigan Department of Natural Resources and Michigan State University cooperated in establishing seed orchards with open-pollinated jack pine progeny. The Potlatch Company in Minnesota established an orchard in 1974 and in 1975 Region 9 established tests to be converted into seedling seed orchards. Modest amounts of seed can be expected from such orchards in 6 to 8 years. Yield increases from 15 to 25 percent may be achieved through an approach combining the best provenances with the best genotypes within provenances in the orchards. Subsequently, from 5 to 8 percent more improvement may be achieved per generation of future breeding (King 1973).

Jack pine improvement based on clonally propagated superior individual trees probably will present more of a problem than white spruce. Although the species roots readily from cuttings in the juvenile stage, it will probably take longer to build up a base population from which cuttings can be obtained for mass production. This is because the crown structure of jack pine probably would not permit as severe pruning as

PROPAGATION RESEARCH IN THE ESTABLISHMENT OF MAXIMUM YIELD PLANTATIONS

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The advantages of containerized plant materials in establishing intensive culture plantations are briefly described. Environmental factors that can be used to manipulate plant growth during the production phase are outlined and examples from the literature are given to show how they might be used to improve plant performance in the field. Results of some plant propagation studies underway in the Maximum Yield Project are summarized and a direction for future research is proposed.

Establishing intensive culture plantations is expensive, especially when improved plant materials are used. Therefore, practices that ensure the best possible survival and growth of seedling and cutting material will be of critical importance in obtaining maximum yields and returns from these plantations.

Containerized seedlings or cuttings show great promise in the establishment of these plantations. Many types of containers have been developed. Some are made of nondegradable plastic from which the seedling may or may not be removed before planting; others are biodegradable plastic or other material that remains with the seedling; still others consist of a block of molded or compressed materials with no actual container walls (figs. 1 and 2). Procedures for growing these seedlings vary, but commonly employ controlled environmental conditions (temperature, light, water, and fertilizer) in a greenhouse.

The most obvious advantage of this type of planting stock is that it can be transported and planted with minimum disturbance or damage to its root system. Survival and early growth should be better than for bare-root stock, especially when planting conditions are unfavorable. Thus, planting need not be limited to only a short period in the spring or fall.

As important as the container itself may be, it is only one of many important parts of the entire system. Plant materials

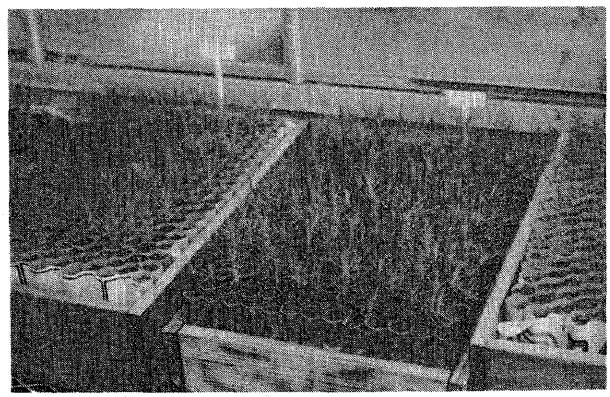

Figure 1.--*Pine seedlings growing in two types of biodegradable containers--an experimental plastic (center) and paper (left and right).*

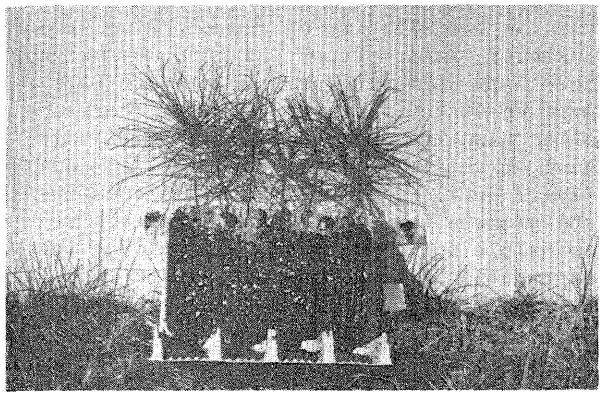

Figure 2.--*Four-month-old jack pine seedlings raised in a greenhouse in a nondegradable plastic container that may be opened to remove seedlings before planting.*

of the proper genetic origin must first be selected and the correct environmental conditions provided during the production phase. The control of the environment at this stage offers perhaps the greatest opportunity for obtaining the full potential from these selected plant materials.

By manipulating certain environmental factors both the physical components and physiological state of seedling growth may be modified. For example, seedlings may be caused to enter a state of temporary (quiescence) or permanent (rest) dormancy by regulating such factors as water, nitrogen, temperature, and photoperiod. By imposing the proper degree of dormancy on the trees before outplanting, their resistance to adverse conditions of the planting site will be increased and their establishment facilitated (Etter 1972, Tinus 1972). Relations have also been found between the nutritional status of the seedling and its ability to withstand low temperatures and perhaps drought conditions after outplanting.

Susceptibility of seedlings to frost and drought damage can be decreased by applying various amounts of nitrogen, potassium, or phosphorus to different species of conifer seedlings in the nursery (Benzian 1966, Shirley and Meuli 1939). Growth retardants may also prove useful in hardening plant materials if applied in the proper amounts and at the proper time (Irving and Lanphear 1968).

Seedling growth may also be influenced by altering one or more of the above-mentioned environmental factors. Extended photoperiods can accelerate shoot growth and increase leaf production. Increasing the light intensity may increase lateral branch production and dry weight of shoot and root. Elevated carbon dioxide levels can increase shoot length as well as dry weight. The predominantly "red" quality of fluorescent lighting produces "stocky" growth whereas incandescent light with a greater proportion of "far-red" promotes stem elongation. Response to any of these factors will in most cases depend upon the balance or levels of the other factors (Larson 1974).

In addition to evaluating several promising types of containers (refer to article by Phipps and Noste in these proceedings), we have been investigating the effects of various "soil" mixes or growing media on the growth and outplanting performance of several conifer species. Horticulturists, who have been using containerized plants for years, have done much research on the effects of the medium on the early phases of plant growth. But, until recently, studies involving tree seedlings or cuttings for forest plantings have been few.

In the early 1970's we compared the effects of various growing media on containerized red pine and white spruce seedlings (Phipps 1974). Significant differences in growth due to the media were found after 5 months in the greenhouse and, in a later outplanting test, these differences were found to persist even after 2 years. The best medium had a pH of 5.5 and high cation exchange and moisture-holding capacities. However, the lack of close correlation between these properties and seedling growth in the other media indicated the influence of other factors that would need identification before an optimum "mix" could be prescribed.

Similarly, research is needed to determine how factors such as those mentioned above may be used to improve the propagation and establishment of plantations of selected clonal material by cuttings. Many of these factors are known to affect rooting performance of cuttings, both before as well as after the cuttings are taken from the stock plant. Rooting of softwood cuttings of some *Populus* clones in commercially

manufactured containers has proven to be a reliable method for the establishment of Maximum Yield Project research plots. However, the rooting performance of the different clones is highly variable, and a particular propagation technique or method may not be suitable for all clones. We found in a recent study that various rooting media (consisting of different proportions of sand, peat moss, and vermiculite) affected both the rate and the form of rooting.

Containerization of hardwood cuttings also appears to be a promising method for plantation establishment. One method of containerization we are studying involves molding a block of rooting medium and a plastic polymer around the cutting (fig. 3). After rooting has taken place the cutting is planted with its block.

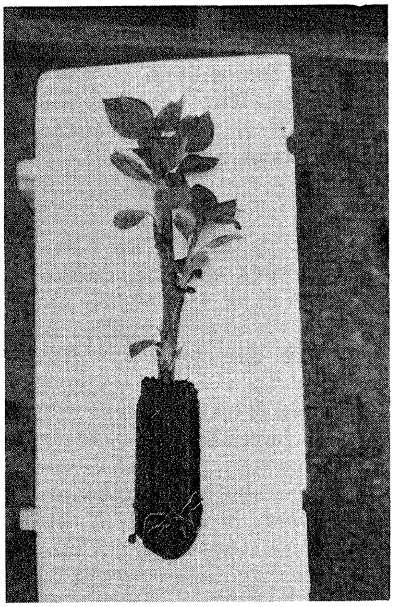

Figure 3.--*A* Populus *hardwood cutting rooted in a block molded from peat moss, sand, and a plastic polymer.*

Although we may be able to manipulate plant growth and produce seedlings with certain measurable characteristics, we cannot yet predict with any certainty whether a particular type or "quality" of plant will survive or grow better than a plant with different characteristics. Several criteria, such as overall size of the seedling, stem diameter, ratio of top and root dry weight, have been used with partial success for many years to predict seedling performance after planting, but beyond this our judgment of seedling vigor is largely subjective. Until we are better able to define and promote the physiological factors responsible for seedling vigor, we must rely on empirical trials and attempt to correlate measurable seedling characteristics with good field performance.

Evaluation of various container systems for both seedlings and cuttings will be continued with emphasis on studies to determine the principal environmental factors that will produce plants of superior vigor and favor their establishment. When these factors have been determined for various species, intensive culture plantations can then be established on a prescribed operational basis.

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EPIDEMIOLOGY AND IMPACT OF MELAMPSORA MEDUSAE LEAF RUST ON HYBRID POPLARS

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Melampsora medusae *leaf rust began from aeciospores on larch (*Larix laricina*) in late May at Rhinelander, Wisconsin. Uredospores were present in large numbers after mid-July. At Rosemount, Minnesota, and Ames, Iowa, primary infection was from airborne uredospores from the north and large numbers of uredospores were found a month later than at Rhinelander. Host infection was correlated with spore trap data at three locations. Height growth was only slightly affected by rust infection, but basal diameter growth was reduced about 20 percent in a moderately resistant clone due to rust.*

Melampsora medusae Thüm is the most common native leaf rust of poplars in the United States and Canada east of the Rocky Mountains. It is a long cycle rust with alternate hosts: *Larix* spp. (especially *L. laricina* (Du Roi) K. Koch) and *Populus* spp. It has been found on all native and introduced poplars grown within eastern North America (Arthur and Cummins 1962).

Rust infection begins in the early spring, soon after the new larch needles begin to elongate. However, larch needles are susceptible to infection for only a short time, and because aeciospores of *M. medusae* formed on larch infect poplars but cannot reinfect other larch, this rust probably does little damage to larch.

In contrast, uredospores produced on poplar can reinfect other poplar trees throughout the summer, and serious epidemics of leaf rust can occur on susceptible poplars. Although larch does not occur naturally very far south of the Great Lakes (Little 1971), spores from infected poplars within the range of larch are wind disseminated, and poplars as far south as the Gulf of Mexico become infected each year (Filer 1975).

Because rust on poplars is confined to leaves, any damage to trees will be caused by leaf damage and defoliation (Schipper and Dawson 1974). Severely rusted poplars are known to be more susceptible to other diseases (Meiden and Vloten 1958). Rust on other species increases winter injury (Kessler 1970), but how much growth is lost due to poplar leaf rust has not been reported.

To determine the type of inoculum causing primary infection of poplars and to follow the buildup of rust, we monitored numbers of aeciospores and uredospores in relation to date, weather, and host development at Ames, Iowa; Rosemount, Minnesota; and Rhinelander, Wisconsin. To evaluate the effect of leaf rust on growth and ultimately on yield of usable wood of poplars, we measured growth of hybrid poplars in plots at Rhinelander and Rosemount.

MATERIALS AND METHODS

Epidemiology

Six vaseline-coated microscope slides were exposed horizontally as spore traps at each location. Slides were retrieved weekly, stained with acid fuchsin in lactophenol, and examined for aeciospores and uredospores

of *M. medusae*. The number of spores of each type was counted in three passes at X250 magnification with a microscope across separate widths of each exposed spore trap.

Larch and poplar at Rhinelander were examined every other week during the spring and early summer for *M. medusae* infection and plant development. Rhinelander is the only location sampled that is within the natural range of *L. laricina*.

Measurement of the Poplar Host

The clones used in this study were NC 5261 (*Populus deltoides* x *P. balsamifera* 'Northwest'), NC 5339 (*P. alba* x *P. grandidentata* 'Crandon'), and NC 5377 (*P.* x *euramericana* 'Wisconsin No. 5'). At Rhinelander, NC 5339 is highly resistant to leaf rust, NC 5377 is moderately resistant, and NC 5261 is highly susceptible (Dawson 1974).

Plots were established at each location using a modified Latin square design, with five rows of five plants each and surrounded by two rows of buffer trees to reduce edge effects. Plots were planted at a stocking density of 10,000 stems per ha. Four replications of the basic plot were established at each location: two replications were treated with the fungicide maneb-Zn every other week to reduce or exclude rust; the other two replications were left unprotected.

In early June, late July, and early September of 1975, each plant in the plots was measured for growth and rust severity. Values recorded were total height, basal stem diameter, and number of leaves. Rust severity was estimated according to Schreiner (1959). Briefly, rust infection on leaves was estimated as light, medium, or heavy and given a numerical value of 1, 5, or 25, respectively. Then the percent of the leaves rusted was estimated at less than 25, 26 to 50, 51 to 75, or greater than 75 and given a numerical value of 1, 2, 3, or 4, respectively. Multiplication of the two numerical values gave a rust severity rating (RSR) of from 0 (immune) to 100 (very highly susceptible).

RESULTS

At Rhinelander, the larch leaves first appeared between April 30 and May 5. Poplar leaves first appeared about May 10, and first leaves were fully expanded by May 21. Aecia were found first on larch needles on May 19, and aeciospores were found on exposed spore traps during the following week (fig. 1). Aeciospores were found on spore traps between May 25 and July 1.

Uredial pustules first were observed on poplar leaves on June 16 and thereafter throughout the summer until defoliation in the fall. On spore traps, a few uredospores were found during the week ending June 2. Uredospores were not found again until the week ending June 23. Uredospore numbers were small until July 14, after which numbers of spores increased rapidly and remained large until after September 15.

At Rosemount, no aeciospores were found on spore traps (fig. 2). Uredospores first were found in small numbers during the week ending July 6, and numbers remained small until the week ending August 18. Uredospore numbers were large until the week ending September 23, after which the spores were found in small numbers, even though leaves remained on some clones until early November.

At Ames, uredospores first were found during the week ending June 23, were absent for 2 weeks, and then were present in small numbers again in July (fig. 3). However, large numbers of uredospores were not present until August 18, and the most uredospores were found in September, remaining abundant until the middle of October.

No rust was found on leaves of NC 5339 in the plots at Rhinelander or Rosemount, although older trees of this clone planted elsewhere at Rhinelander did become lightly rusted late in the growing season (figs. 4 and 5). No differences were found in number of leaves, height, or basal diameter at either Rhinelander or Rosemount for this clone.

Leaves of NC 5377 were lightly rusted at Rhinelander in late July (fig. 6). By September, rust on unsprayed leaves developed to a severity of RSR 28, while sprayed leaves were rusted to a severity of RSR 12. This amount of rust caused premature defolition of unsprayed plants and reduced both height growth and basal stem diameter growth of unsprayed plants.

At Rosemount, no rust was found on leaves of NC 5377 until August, and by September, unprotected plants were rusted to RSR 10, while protected plants were rusted only to RSR 2 (fig. 7). This small amount

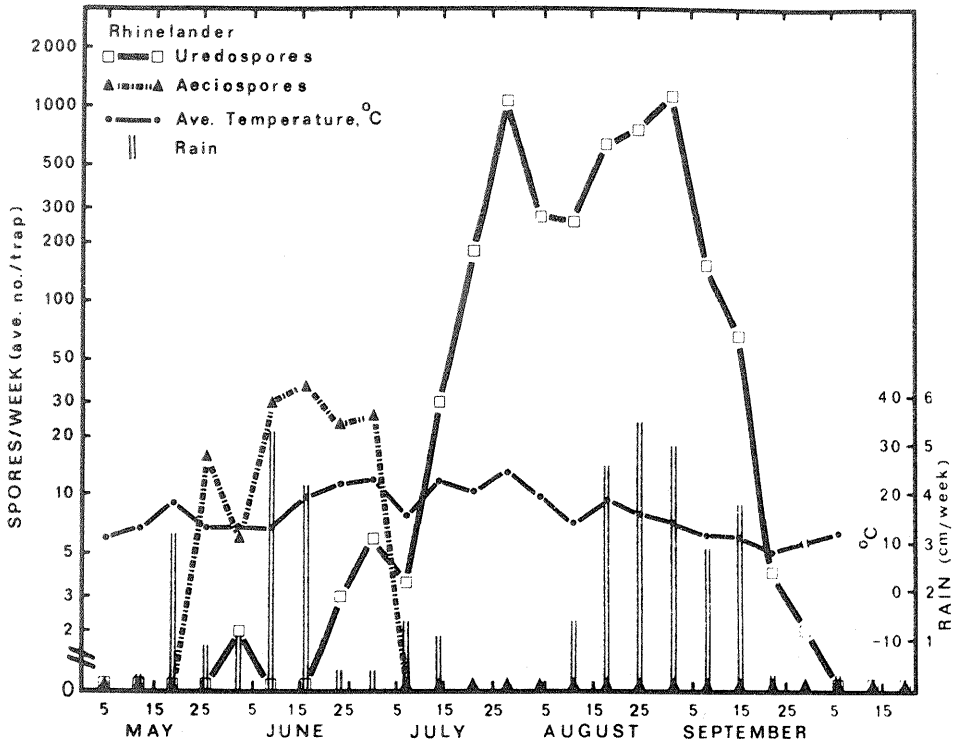

Figure 1.--*Average number of aeciospores and uredospores collected on slide spore traps at Rhinelander, Wisconsin, during the growing season of 1975.*

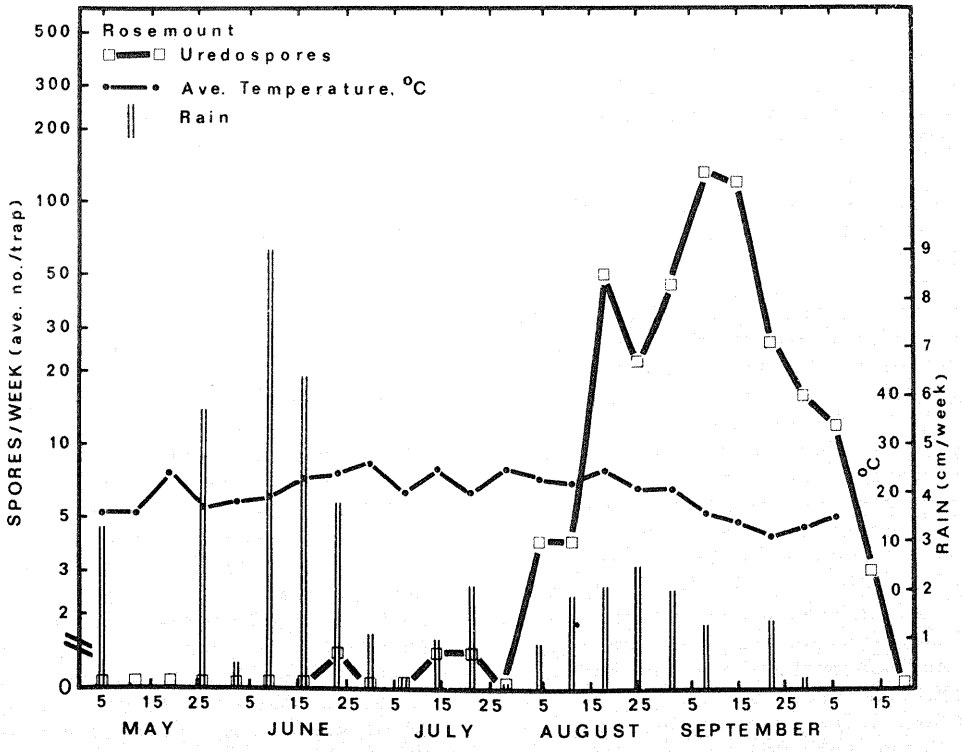

Figure 2.--*Average number of uredospores collected on slide spore traps at Rosemount, Minnesota, during the growing season of 1975.*

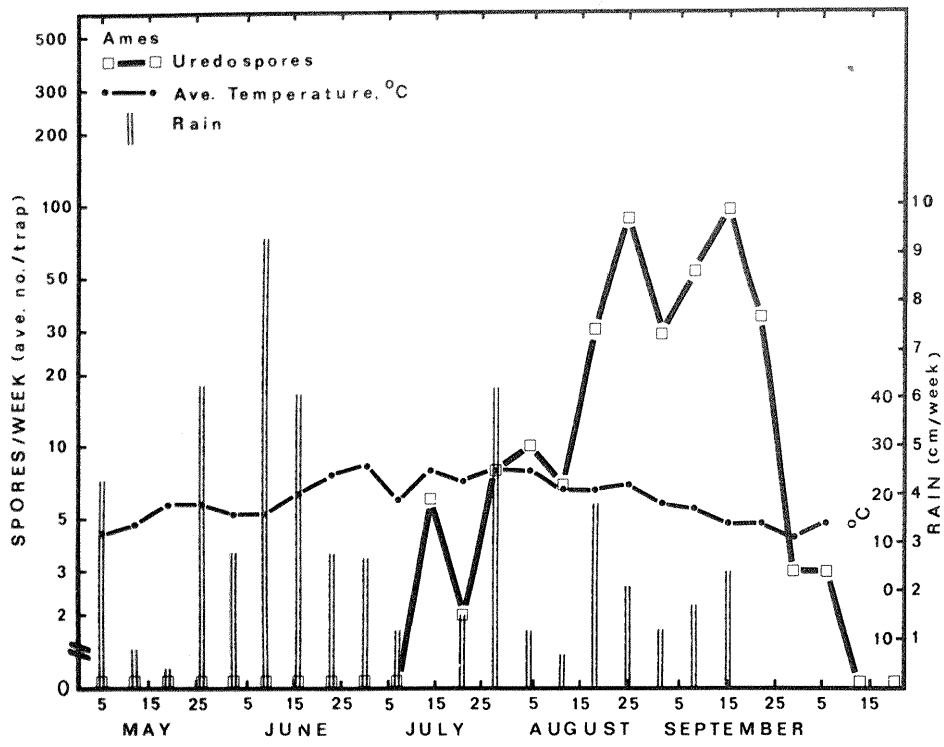

Figure 3.--*Average number of uredospores collected on slide spore traps at Ames, Iowa, during the growing season of 1975.*

of rust did not have a significant effect on leaf retention, height, or basal diameter, although basal diameter seemed to be less in unprotected plants.

Unprotected leaves of NC 5261 at Rhinelander had a rust severity of RSR 19 by the end of July, whereas sprayed leaves had a severity of only RSR 3 (fig. 8). Rust infection was severe on both protected and unprotected plants after July, so that in September, unprotected plants had a severity rating of RSR 100, while protected plants had a rating of RSR 91. The same sort of rust development took place at Rosemount (fig. 9). At Rhinelander, unprotected trees of NC 5261 had lost 47 percent of their leaves by September, while protected trees still retained almost as many leaves as in July. Unprotected trees were slightly, though not significantly, taller than protected trees and only a small difference was found in basal diameter. At Rosemount, where both protected and unprotected trees of NC 5261 became heavily rusted, defoliation by September was 83 percent for unprotected trees and 65 percent for protected trees. Height and basal stem diameter were affected by the rust in both treatments, but because the fungicide treatment offered some protection, treated trees grew significantly taller and had greater basal diameters.

The plot at Ames was destroyed by a flood of the Skunk River in June of 1975.

DISCUSSION

The epidemiological studies showed that rust infection on poplars at Rhinelander, and by extension anywhere within the geographic range of eastern larch, began from aeciospores formed on larch needles and became severe early in the growing season. At Rosemount and Ames, severe rust infection did not occur until a month after it began at Rhinelander, apparently because rust infection did not begin until uredospores from the north arrived at Rosemount and then at Ames. This delay is possibly one of the reasons that clones at Rosemount grew taller than those at Rhinelander, even though the latitude and average temperature were similar. Other factors, such as soil type, fertility, and rainfall, may also have accounted for some of the difference in height.

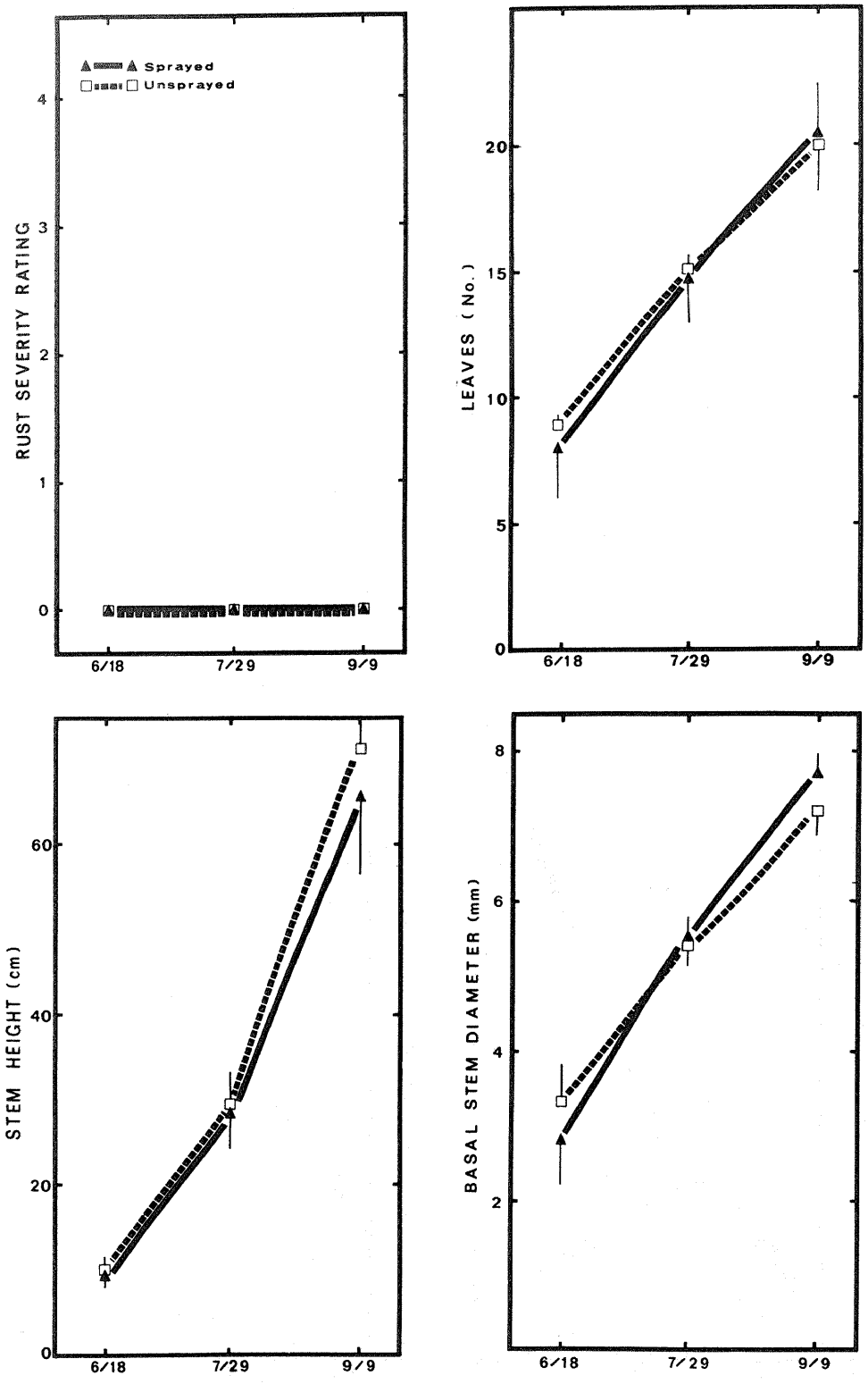

Figure 4.--*Rust severity rating, number of leaves, stem height, and basal diameter of protected and unprotected trees of clone 5339 at Rhinelander, Wisconsin.*

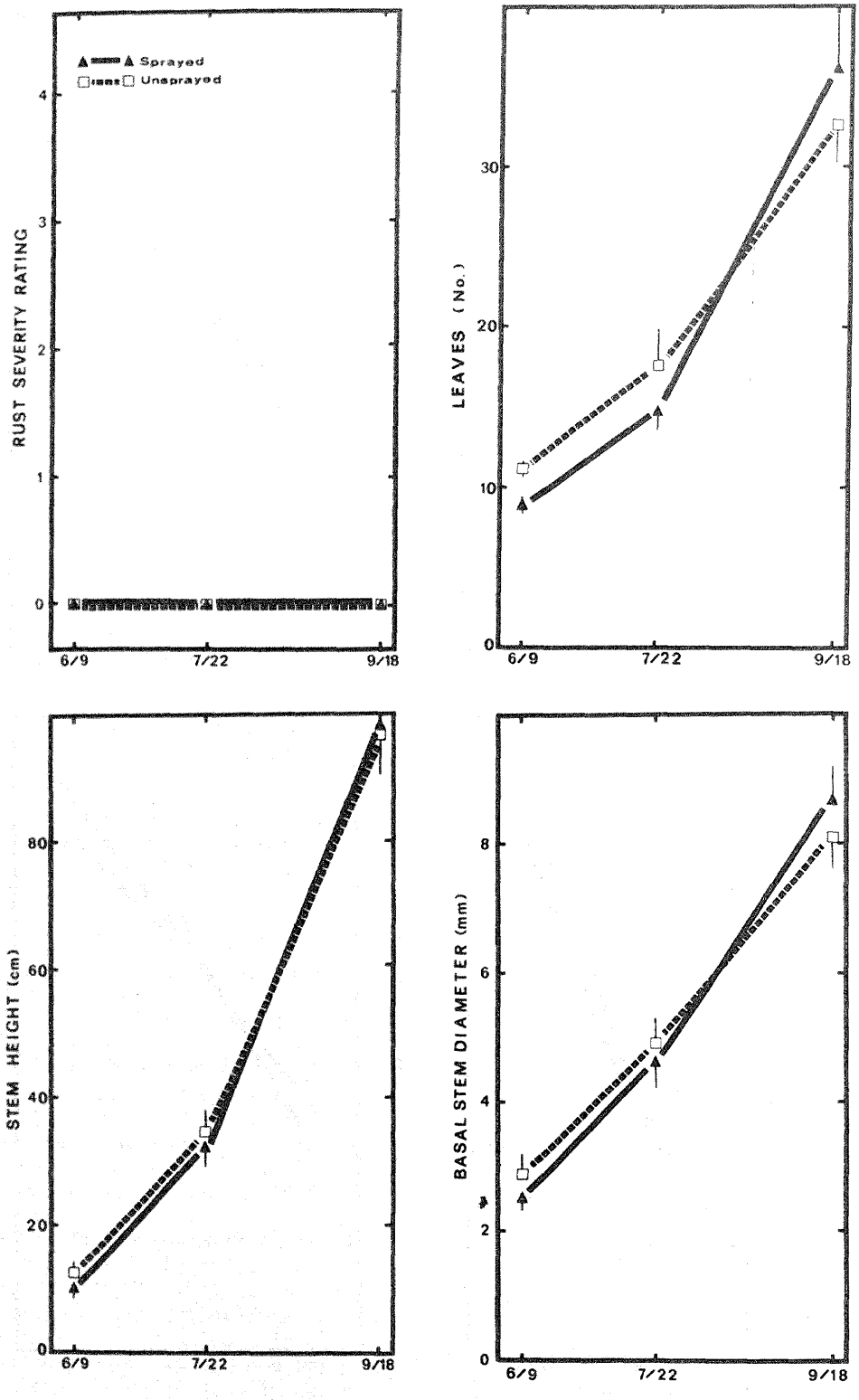

Figure 5.--*Rust severity rating, number of leaves, stem height, and basal diameter of protected and unprotected trees of clone NC 5339 at Rosemount, Minnesota.*

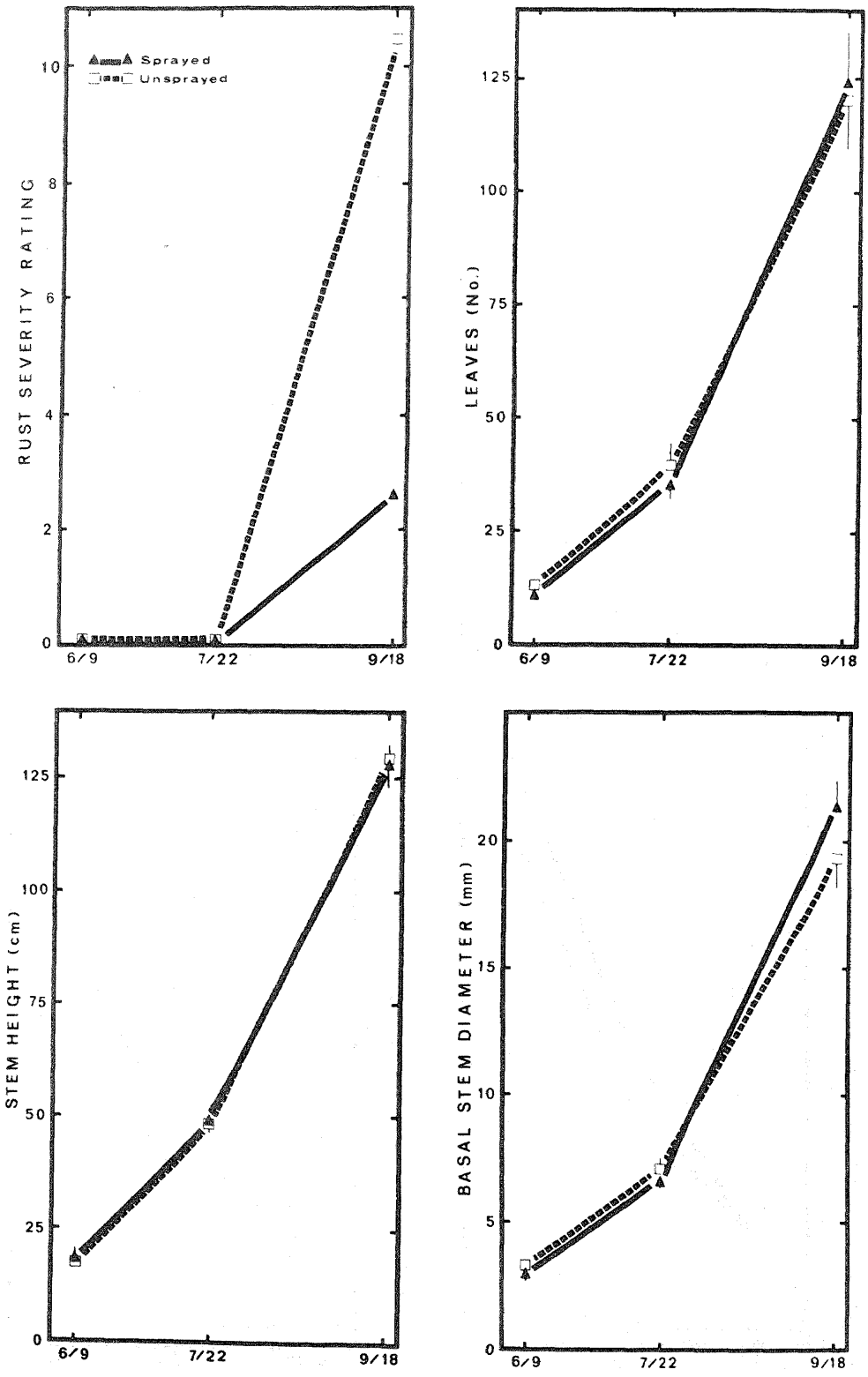

Figure 6.--*Rust severity rating, number of leaves, stem height, and basal diameter of protected and unprotected trees of clone NC 5377 at Rhinelander, Wisconsin.*

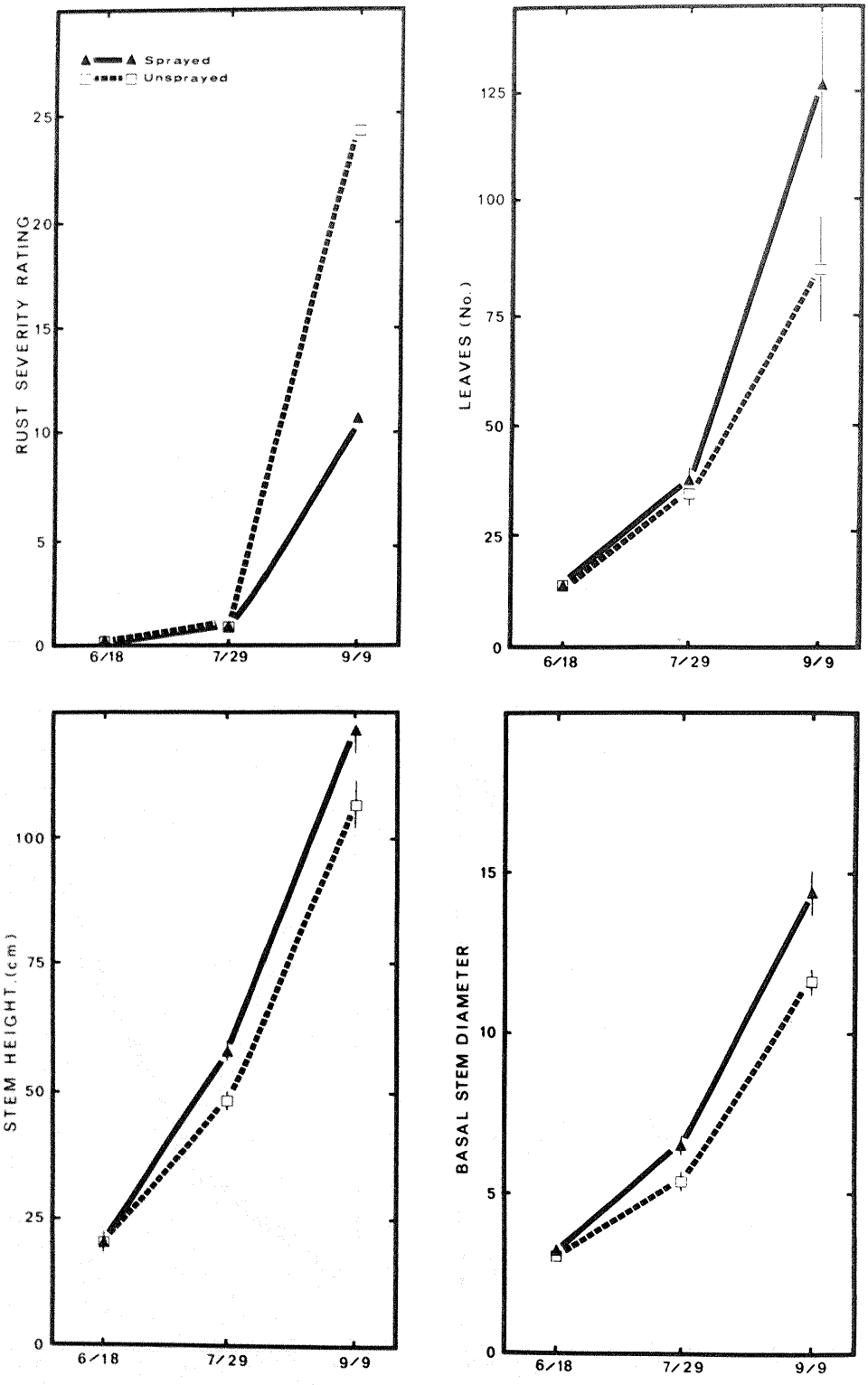

Figure 7.--*Rust severity rating, number of leaves, stem height, and basal diameter of protected and unprotected trees of clone NC 5377 at Rosemount, Minnesota.*

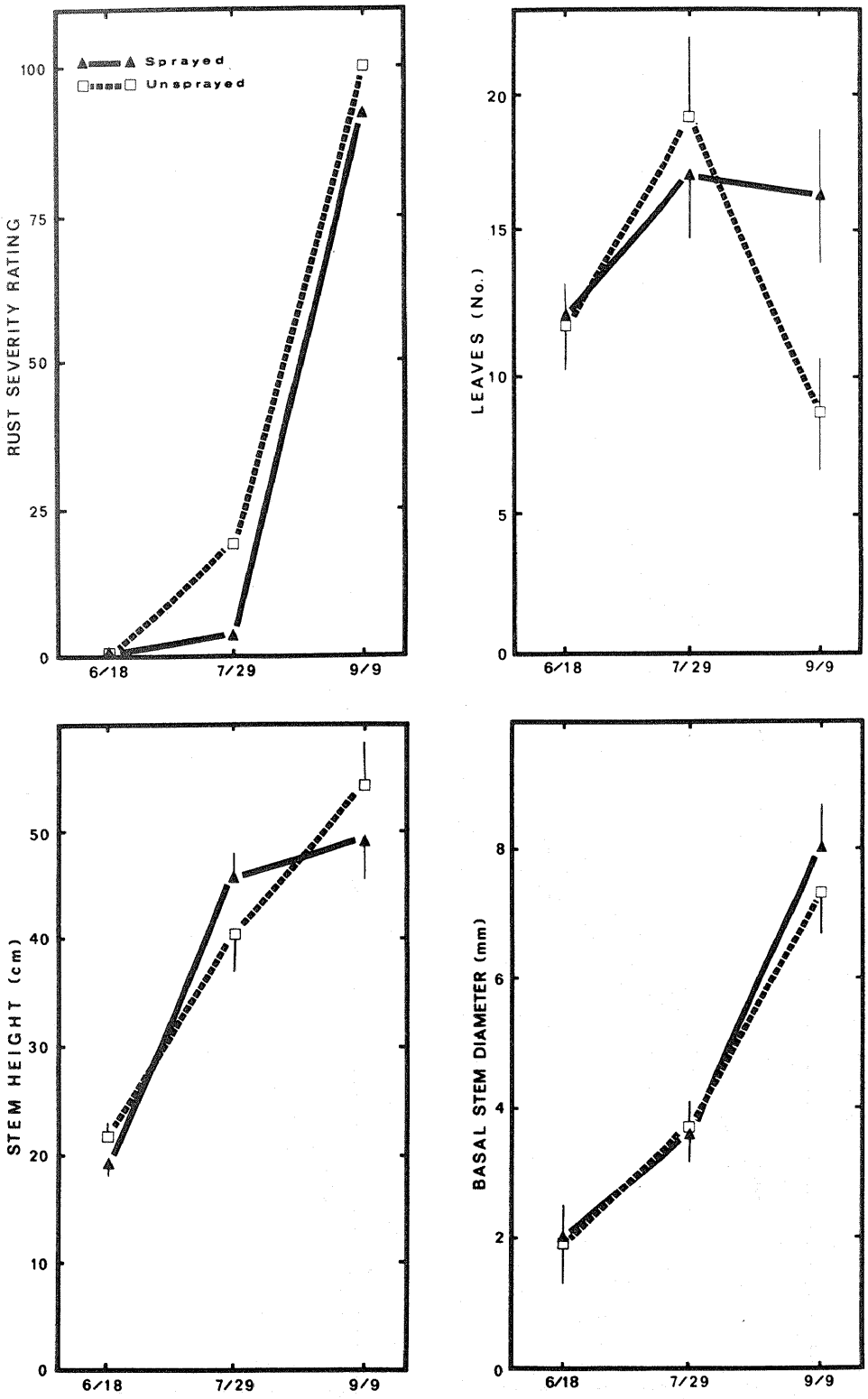

Figure 8.--*Rust severity rating, number of leaves, stem height, and basal diameter of protected and unprotected trees of clone NC 5261 at Rhinelander, Wisconsin.*

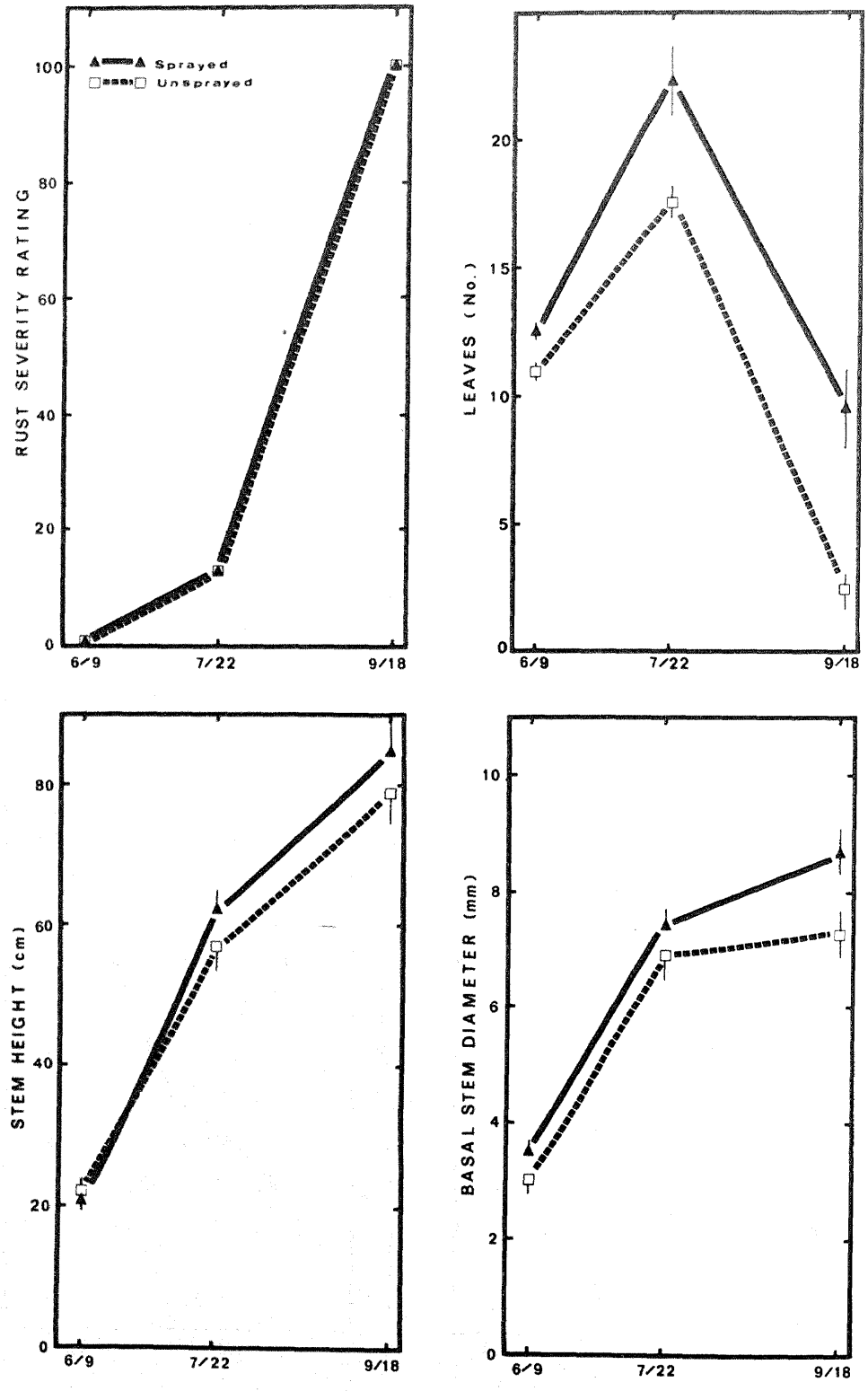

Figure 9.--*Rust severity rating, number of leaves, stem height, and basal diameter of protected and unprotected trees of clone NC 5261 at Rosemount, Minnesota.*

Although leaves of all ages can become infected, infection in nature is usually more severe on lower leaves than on upper leaves. (See Schipper article on p. 81.) Even though the trees in this study were spaced far apart, lower leaves still were more severely infected, primarily because they developed earlier and were exposed to uredospores for a longer time. Donnelly (1974) has shown that the upper portion of poplar stems is supplied with photosynthate by upper leaves, whereas the lower parts of stems are supplied by lower leaves. Therefore, loss of lower leaves has most effect on growth of the lower portions of the tree.

Because of lighter rust infection on upper leaves, height growth was only slightly reduced during the first year, although apparently rust infection did influence height because trees sprayed with fungicide were slightly taller than unprotected trees. In all three clones at each location, the percentage increase in basal diameter was greater in sprayed than unsprayed trees, and most increases were significantly greater. Basal diameter growth was more severely affected because the lower leaves, which contribute most to basal growth, were most severely infected with rust. Basal diameter growth was reduced 23 percent by rust in NC 5377 at Rhinelander. A 23-percent reduction in diameter growth with no decrease in height growth means that the volume of wood produced was reduced by about 41 percent. If the fungicide used to protect trees from rust had been more effective, protected trees might well have grown even larger than unprotected trees.

The rust severity on protected and unprotected trees of each clone was well correlated with the number of leaves remaining on those trees late in the growing season. Because leaf abscission will occur when at least 50 percent of a leaf surface is covered with uredial pustules (Filer 1975), many of the lower leaves of severely rusted trees will be lost before normal defoliation in the fall. Clone NC 5339 was not affected by the rust at either location, so number of leaves per stem was identical for both protected and unprotected trees. At Rosemount, trees of clone NC 5377 became only lightly rusted. Height in both protected and unprotected plots was about the same. Basal stem diameter of unprotected trees was slightly less than protected trees. At Rhinelander, rust was much more severe on unprotected trees than on protected trees, and the effect of the rust is reflected in leaf loss, reduced height growth, and reduced basal stem diameter of unprotected trees. The impact on basal stem diameter of leaf rust is particularly evident for clone NC 5377 at Rhinelander. Clone NC 5261 is so susceptible to leaf rust that the fungicide used was ineffective in preventing severe rust on sprayed trees. However, fungicide protection did delay defoliation, and at Rosemount, the delayed defoliation contributed to both increased height and basal stem diameter growth.

Of particular interest is that although unprotected trees of the moderately resistant clone NC 5377 were only lightly to moderately rusted, the infection significantly slowed basal diameter growth and thereby volume growth. NC 5261 grew more slowly after July than before, although the other clones grew more rapidly between July and September. At both Rhinelander and Rosemount, trees of this clone set a terminal bud in August. However, protected trees usually set the terminal bud later than unprotected trees, and the lack of accelerated growth during August and early terminal bud set at both Rosemount and Rhinelander are probably due more to leaf rust than to a genetic pecularity of that clone.

Therefore, it is evident that poplar leaf rust does have a significant impact on the growth of infected poplars and that the growth loss may be more severe than previously suspected. Clone NC 5377 at Rosemount was rusted to an RSR of only slightly above the cutoff limit set by Schreiner (1959), but suffered a growth loss of more than 20 percent. Perhaps poplars planted within the geographic range of *L. laricina* should be even more resistant to leaf rust than previously suspected.

Because poplars at Rhinelander growing close to larch became severely infected more than 1 month earlier than poplars growing south of the natural range of eastern larch, plantations of poplars should not be established close to natural or planted stands of larch or hemlock (*Tsuga canadensis* (L.) Carr.). Isolates of *M. medusae* hybridize on eastern larch and *M. abietis-canadensis* on eastern hemlock, and therefore planting resistant poplars close to the alternate host can lead to development of rust that can become severe on previously resistant poplars. Ultimately, increased poplar plantation

acreage close to alternate hosts may increase the rust hazard to poplars planted outside of the range of the alternate host.

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HYBRID POPLAR DISEASES AND DISEASE RESISTANCE

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Three foliage diseases and one canker disease were found on hybrid poplars in clone nurseries at Ames, Iowa, and Rhinelander, Wisconsin, during the 1975 growing season. Marssonina brunnea *and* Septoria *sp. were the most serious foliage diseases at Ames, while* Melampsora medusae *leaf rust infection was serious on only a few of the clones. One clone was lightly infected and six were heavily infected by an as yet unidentified canker disease. At Rhinelander,* Marssonina *and* Septoria *were present but not serious;* Melampsora *leaf rust was serious on a number of clones. The resistance of the clones to diseases is compared and recommendations are made for selecting clones to minimize foliage and canker disease.*

Research on species and hybrids of poplars is underway to select clones and culture techniques most suitable for maximum wood fiber production from plantations in the north-central United States. One way to produce maximum wood fiber is to reduce tree disease to a minimum.

In Europe, where poplars have been grown in plantations for many years, several diseases are important. Among these are *Dothichiza populea* Sacc. and Briard canker (Schönhar 1960), *Marssonina brunnea* (El. & Ev.) Magn. leaf blight (Gremmen 1965), *Melampsora* spp. leaf rusts (Meider 1958), and *Pollacia radiosa* (Lib.) Bald & Clif. shoot blight (Weisgerber 1968). In the United States, poplar plantation research in the East and South has shown that *Melampsora medusae* Thüm leaf rust (Schreiner 1959), and *Septoria musiva* Peck leaf spot and canker (Filer 1975, Waterman 1954) can damage young trees. Much less research on diseases of poplars in plantations has been done in the north-central United States, although *M. medusae* has been found to be important in plantings in Wisconsin (Dawson 1974, Schipper and Dawson 1974).

Tree disease can reduce growth and kill trees in plantations, so we need to know which diseases will be important to poplar plantations in the north-central States and how best to control those diseases. Toward this end, poplar clone nurseries in Iowa and Wisconsin were examined for disease problems and clonal resistance to the diseases studied.

METHODS

Two hybrid poplar clone nurseries established in 1971 were examined in July and September of 1975. One of the nurseries was located on the Iowa State University experimental farm at Ames, Iowa (lat. 42° 0' 45", long. 93° 38' 10"), and the other on the Hugo Sauer State Tree Nursery at Rhinelander, Wisconsin (lat. 45° 39' 3", long. 89° 29' 5"). The same clones had been planted at each nursery. A survey was made at each location to determine which foliage and stem diseases were present and important. Subsequently, each tree of each of 35 clones was examined and the severity of the individual foliage and stem diseases present was rated by the method developed by Schreiner (1959). The amount of leaf rust or other foliage disease is rated as light, medium, or heavy and given numerical values of 1, 5, or 25, respectively. The percent of total leaves infected is then rated as less than 25 percent,

26 to 50 percent, 51 to 75 percent, or greater than 75 percent, with a numerical rating of 1, 2, 3, or 4, respectively. The product of the two numerical ratings gives a disease severity rating of from 0 (immune) to 100 (highly susceptible). Stem canker severity was determined by counting the number of cankers per main stem of each affected tree in the clone.

RESULTS AND DISCUSSION

At Ames, three foliage diseases and one canker disease were found on hybrid poplar clones (table 1). *Marssonina brunnea* (El. & Ev.) Magn. infection on leaves of hybrid poplar clones was rated as heavy on 12 clones in July and on 14 clones in September (fig. 1). Clones especially susceptible to the disease were NC 4878, NC 5258, NC 5270, NC 5321, NC 5324, NC 5328, and NC 5373. (The NC number is an accession number assigned each clone at the North Central Forest Experiment Station.) Each of the above clones had a disease severity rating of 100 in July; one of them, NC 5270, was about 75 percent defoliated in July (fig. 2) and had only a few remaining leaves in September. The other clones with a severity rating of 100 suffered some defoliation in July and more in September.

Septoria sp. leaf spot (probably *S. musiva* Peck) also was more severe on some cultivars than on others (fig. 3). In July, 12 of 32 cultivars were heavily infected; the same clones were still infected in September, but no additional clones had become heavily infected. Evidently *Septoria* is a disease of the spring and early summer and does not increase in severity during the summer, while *Marssonina* becomes more severe as the growing season progresses. In some cases, both *Marssonina* and *Septoria* were heavy on leaves of the same clone, but in many cases, either one disease or the other was heavy on a clone. Thus, although most clones were moderately to highly resistant to either *Marssonina* or *Septoria*, only eight clones were sufficiently resistant to both diseases to warrant further consideration in a location where both *Marssonina* and *Septoria* are likely to be present.

None of the clones at Ames was even moderately infected by *Melampsora medusae* Thüm leaf rust in July, and only three clones were moderately to severely infected in September.

Heavy cankering was found on clones NC 5263, NC 5264, NC 5266, NC 5268, and NC 5334 at Ames, while NC 5325 had a few cankers (fig. 4). With the exception of NC 5335, all these clones also were heavily infected with *Septoria* leaf spot and the cankers appeared

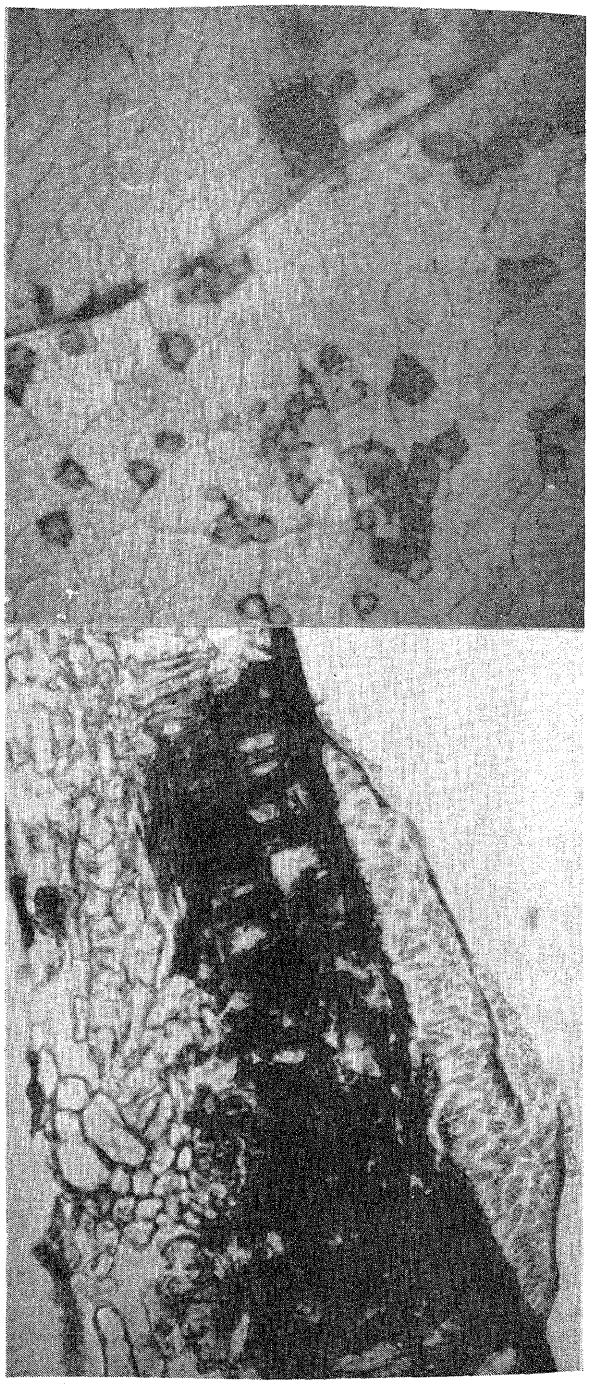

Figure 1.--*Top.* Marssonina brunnea *leaf spot of hybrid poplars. Bottom. Photomicrograph of a hybrid poplar leaf showing* M. brunnea *infection.*

Table 1.--*Foliage disease severity by species and clone at Ames, Iowa, and Rhinelander, Wisconsin, in 1975*

Cultivar identification number	Parentage and cultivar designation	Foliage disease severity by cultivar in 1975											
		Ames, Iowa						Rhinelander, Wisconsin					
		Marssonina		*Melampsora*		*Septoria*		*Marssonina*		*Melampsora*		*Septoria*	
		7/24	9/24	7/24	9/24	7/24	9/24	7/27	9/9	7/27	9/9	7/27	9/9
4877	*Populus alba* 'PI 343437'	VL[1]	0	0	0	VL	2	--	--	--	--	--	--
5339	*P. alba* x *P. grandidentata* 'Crandon poplar'	--	--	--	--	--	--	0	0	1	10	0	0
5264	*P. angulata* x *P. platierensis* 'NE 376'	20	20	0	17	100	100	0	0	1	10	0	0
5334	*P. angulata* x *P. trichocarpa* 'NE 258'	12	3	0	7	94	[2]20	0	0	VL	4	0	0
5265	*P. angulata* x *P. trichocarpa* 'NE 274'	31	77	0	20	89	100	0	0	1	50	0	0
5266	*P. angulata* x *P. trichocarpa* 'NE 372'	60	100	0	20	100	100	0	0	50	50	0	0
5331	*P. berolinensis* x *P. trichocarpa* 'NE 219'	12	40	0	4	59	40	0	0	1	4	0	0
5332	*P. berolinensis* x *P. trichocarpa* 'NE 298'	80	100	0	4	18	12	0	0	2	4	0	0
5262	*P. candicans* x *P. berolinensis* 'NE 387'	9	4	0	4	85	84	0	0	0	4	0	0
5263	*P. candicans* x *P. berolinensis* 'NE 386'	4	3	0	20	90	100	0	0	VL	4	0	0
5271	*P. charkowiensis* x *P. deltoides* 'NE 19'	6	4	0	4	8	4	0	0	0	4	0	0
5318	*P. deltoides* 'D 37'	4	7	0	6	4	4	20	20	2	4	0	0
5319	*P. deltoides* 'D 45'	8	20	0	4	3	4	3	20	10	20	0	20
5273	*P. deltoides* '44-52'	93	100	0	50	10	10	0	20	15	100	0	0
5261	*P. deltoides* x *P. balsamifera* 'Northwest'	5	21	10	100	69	100	0	def[3]	91	def	0	def
5267	*P. deltoides* x *P. caudina* 'NE 366'	4	4	0	20	83	100	0	0	1	50	0	0
5268	*P. deltoides* x *P. trichocarpa* 'NE 216'	20	20	0	15	100	100	0	0	5	50	0	0
5335	*P. deltoides* x *P. trichocarpa* 'NE 348'	52	52	0	12	78	100	0	0	5	50	0	0
5270	*P. deltoides* x *P. trichocarpa* 'NE 205'	100	[4]100	0	17	20	20	0	0	25	100	0	0
4878	*P.* x *euramericana* 'PI 343438'	20	20	0	14	4	4	0	0	4	20	0	0
4879	*P.* x *euramericana* 'PI 343439'	100	100	0	8	3	4	0	0	3	75	0	0
5321	*P.* x *euramericana* 'Negrito de Granada'	100	100	0	7	3	3	0	0	50	75	0	0
5322	*P.* x *euramericana* 'Jaconetti 78B'	73	100	0	17	4	4	4	0	50	50	0	20
5323	*P.* x *euramericana* 'Canada Blanc'	20	22	0	20	3	6	10	20	10	35	0	10
5324	*P.* x *euramericana* 'DN 26'	100	100	0	31	3	4	0	0	20	20	0	0
5325	*P.* x *euramericana* 'Ostia'	19	13	0	20	3	4	0	0	25	100	0	0
5326	*P.* x *euramericana* 'Eugenii'	60	50	0	0	VL	11	0	0	1	20	0	0
5327	*P.* x *euramericana* 'I 214'	18	20	0	9	3	4	--	--	--	--	--	--
5328	*P.* x *euramericana* 'Guinier'	100	100	0	6	4	5	0	0	20	20	0	0
5377	*P.* x *euramericana* 'Wisconsin #5'	20	50	0	4	VL	4	0	0	1	20	0	0
5272	*P. nigra* x *P. laurifolia* 'NE 1'	VL	7	0	0	95	20	0	0	0	1	0	0
5260	*P. tristis* x *P. balsamifera* 'Tristis #1'	8	21	0	21	VL	7	0	0	2	4	0	0
5258	*Populus* sp.	100	100	0	4	VL	4	0	0	2	4	2	10
5351	*Populus* sp.	--	--	--	--	--	--	0	0	40	100	0	0
5253	*Populus* sp.	--	--	--	--	--	--	4	20	15	20	0	0

1/ VL = very light infection; i.e., 1 to 10 pustules per leaf.

2/ A decrease in disease severity at September readings indicates defoliation of leaves heavily infected in July. Readings in September were made from remaining leaves.

3/ def = defoliated before reading made.

4/ NC 5270 was 75 percent defoliated in July. By September, only a few leaves per tree remained. Readings were made from the remaining leaves.

similar to *Septoria* canker (Filer 1975, Waterman 1954). However, isolations from these cankers have yielded *Alternaria* sp., *Fusarium* sp., and *Septoria* sp. Inoculation studies are not complete, so a pathogen cannot yet be linked to these cankers. All of the cankers were within 1.5 m of the ground and appeared to be centered around a lenticil.

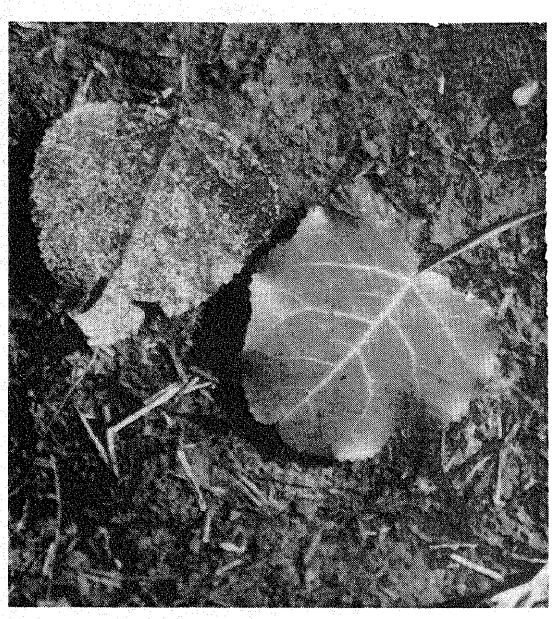

Figure 2.--*Severe infection of* Marssonina-*susceptible clone NC 5270 (*P. deltoides *x* P. trichocarpa*) on left compared with* Marssonina-*resistant clone NC 5318 (*P. deltoides*) on the right. The two trees were adjacent.*

Some of the main stems of these clones had as many as 20 cankers in the lower 1.5 m.

At Rhinelander, only *Melampsora* leaf rust was found to be a serious problem (table 1). Although *Marssonina* and *Septoria* were present, none of the clones was more than lightly infected with either disease. In contrast, several clones (notably NC 5261, NC 5266, NC 5321, and NC 5322) were heavily rusted by the end of June. Other clones were only lightly infected with rust in July but by early September were heavily infected. Of the 33 clones rated for leaf rust severity at Rhinelander, 14 would be disqualified from further consideration as plantation planting stock if disease impact were the sole criterion for selection. *Melampsora* infection was lighter at Ames than at Rhinelander because at Rhinelander, infection starts in early June from spores produced on nearby larch (*Larix laricina* (Du Roi) K. Koch), while at Ames, infection begins in August from windblown uredospores from the north, and infection does not become heavy until September.

The nurseries examined at Ames and Rhinelander each contained 30 of the same hybrid poplar clones. In addition, the nursery at

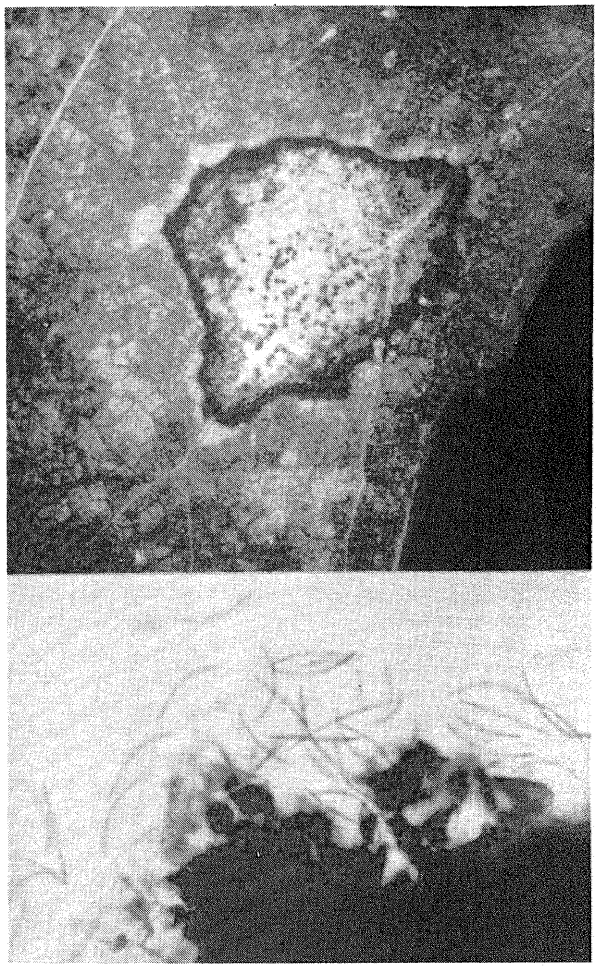

Figure 3.--*Top.* Septoria *sp. leaf spot of hybrid poplar. Note the typical dark border and light center of the leaf spot and the dark pycnidia in the center of the spot. Bottom. Photomicrograph of a* Septoria *pycnidia showing the spores.*

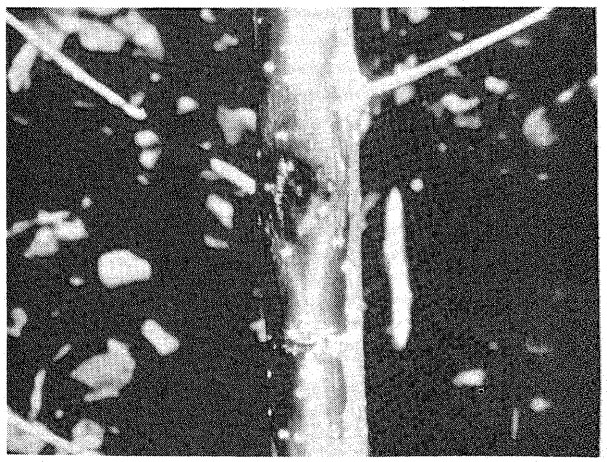

Figure 4.--*Canker of hybrid poplar at Ames.*

Ames had two clones not planted at Rhinelander and the one at Rhinelander had three clones not planted at Ames. The clones, obtained from various tree breeding sources, represented 14 species and hybrids of *Populus*. Because six of the species and hybrids were represented by two or more clones, comparing their resistance to three foliage diseases and one canker disease was possible. Although the sample population is too small to draw general conclusions about the suitability of various hybrids, a wide diversity of resistance and susceptibility was found and several interesting differences in resistance within hybrids observed. For instance, at Ames, one of the three clones of the hybrid *P. angulata* x *P. trichocarpa*, NC 5334, was resistant to *Marssonina*, while the other two were susceptible. However, all three clones were susceptible to *Septoria* leaf spot, and NC 5334 was severely defoliated by *Septoria* infection. At Rhinelander, NC 5334 was rust resistant, NC 5265 exhibited early season resistance but late season susceptibility to rust, and NC 5266 was susceptible to rust throughout the season.

P. berolinensis x *P. trichocarpa* was represented by two clones. NC 5331 exhibited midseason resistance to *Marssonina*, although it was moderately infected in late September. NC 5332 was heavily infected with *Marssonina* in July. However, resistance to *Septoria* was exactly reversed: NC 5331 was susceptible and NC 5532 was moderately resistant. Both clones were resistant to rust at Rhinelander.

P. berolinensis x *P. candicans* was also represented by two clones. Both were resistant to *Marssonina* at Ames and both were very susceptible to *Septoria*. At both locations, these clones were rust resistant.

Three clones of *P. deltoides* were planted at each location. NC 5318 and NC 5319 were resistant to all three diseases at both locations, while NC 5273 was resistant to *Septoria* but susceptible to *Marssonina* and *Melampsora*.

For three clones of *P. deltoides* x *P. trichocarpa*, NC 5268 was resistant to *Marssonina* but susceptible to *Septoria*, NC 5335 was susceptible to both diseases, and NC 5270 was resistant to *Septoria* but was the clone most susceptible to *Marssonina* of those examined at Ames. All three clones were susceptible to *Melampsora* at Rhinelander but were rated as resistant at Ames. This apparent resistance was because rust at Ames develops much later than at Rhinelander (see Widin and Schipper article on p. 63) and apparently only becomes heavy on extremely susceptible clones when planted far enough south to avoid early season infection.

P. x *euramericana* was represented by 11 clones. All of these clones were resistant to *Septoria* infection, but seven were susceptible to *Marssonina*. At Ames, only clone NC 5324 was moderately susceptible to *Melampsora*, while at Rhinelander, five of the clones were moderately to highly susceptible to *Melampsora*.

Seven other clones were planted at both Ames and Rhinelander. However, because each represented a single hybrid, no information is available about resistance or susceptibility within the hybrid. Of these clones, NC 5271 was highly resistant to the three diseases at both locations.

Four additional clones were planted at either Ames or Rhinelander. Of these, NC 4878 and NC 5339 were highly resistant to the three diseases and probably would perform satisfactorily at both locations.

Some of the clones checked are suitable for planting at one location but not at the other. For instance, NC 4877,[1/] NC 5323, and NC 5327 could be planted at Ames but would be heavily infected by *Melampsora* leaf rust at Rhinelander. Thirteen clones (NC 5253,[1/] NC 5258, NC 5262, NC 5263, NC 5264, NC 5272, NC 5326, NC 5328, NC 5331, NC 5332, NC 5334, NC 5339,[1/] and NC 5377) could be planted at Rhinelander but would be too susceptible to *Marssonina* or *Septoria* to be planted at Ames. Only five clones, NC 4878, NC 5260, NC 5271, NC 5318, and NC 5319, could be planted at both locations without fear of growth loss due to the diseases prevalent at Ames and Rhinelander during 1975. Clones NC 4877 and NC 5339 probably could be added to this list but were not planted at both locations.

Because the diseases encountered in hybrid poplar clone nurseries in Iowa and Wisconsin were so different, it appears likely that the diseases encountered by hybrid poplar clones in the north-central United States will vary at least from north to south, if not by location, within the region. Therefore, clones must be rated for resistance to the prevalent diseases in each geographical region before large plantings of hybrid poplars are made. Clone nurseries such as those at

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1/ See table 1 for details of disease infection of these clones.

Ames and Rhinelander seem ideal for assessing diseases likely to be locally important on hybrid poplars and for screening clones for resistance or susceptibility to the important diseases.

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The Ames, Iowa, plots are supported by the Iowa Agriculture and Home Economics Experiment Station; Project 2033; H. S. McNabb, Jr., and L. C. Promnitz cooperating. The Rhinelander, Wisconsin, plots are supported by the North Central Forest Experiment Station, Institute of Forest Genetics.

POPLAR PLANTATION DENSITY INFLUENCES FOLIAGE DISEASE

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Melampsora *leaf rust was more severe in hybrid poplar plots planted to high densities than in plots of the same clones at low densities. A compromise between high density to maximize wood production and low density to reduce disease must be reached in plantation density recommendations.*

Stand density, the number of trees per hectare (ha), is important in forest plantation establishment. Within certain limits, more trees per ha mean more product per ha. Density also influences tree form, self-pruning, root crowding, and use of soil by the plants. As trees are planted closer, lower branches tend to die and self-prune earlier. Because of the desire to produce the most product per ha, high stand density is often a goal of forestry research.

However, the higher the density, the more favorable becomes the environment for foliage diseases. As density increases, air movement through the foliage decreases and moisture evaporates from the leaves more slowly. Because most foliage pathogens require free moisture on leaves for spore germination and infection, slower moisture evaporation tends to increase infection.

To determine the influence of density on hybrid poplar growth, and ultimately to establish density recommendations for poplar plantation establishment in the north-central region experimental plantings were established at Ames, Iowa, and Rhinelander, Wisconsin. In one experiment set up by the Iowa State University, Department of Forestry, and duplicated at Ames and Rhinelander, 4 hybrid poplar clones were planted at densities of 15,000 stems/ha (0.8 m between trees), 10,000 stems/ha (1.0 m between trees), and 5,000 stems/ha (1.4 m between trees).

In September of 1975, I examined the plantations at Ames and Rhinelander to determine what influence these three stocking densities had on the severity of *Melampsora* leaf rust. This rust, caused by the fungus *Melampsora medusae* Thüm, is the predominant hybrid poplar disease at Rhinelander plantings (Schipper and Dawson 1974, see article by Schipper on p. 75).

METHODS

The hybrid poplar clones planted in the experimental plots were NC 5321 (*Populus* X *euramericana* 'Negrito de Granada'), NC 5323 (*P.* X *euramericana* 'Canada blanc'), NC 5326 (*P.* X *euramericana* 'Eugenii'), and NC 5377 (*P.* X *euramericana* 'Wisconsin No.5'). These clones were selected because of growth and wood characteristics. When rated for leaf rust resistance in 1971 and 1972 (Dawson

1974) each was considered to be moderately to highly resistant.

Each spacing plot at Ames and Rhinelander contained 49 trees of only 1 clone, planted in a square and surrounded by 2 border rows at the same spacing. In order to avoid edge effects as much as possible in such small plots, only the 10 center-most trees in each plot were rated for rust.

Trees were rated for leaf rust by the method developed by Schreiner (1959). In this method, the plant is scored as lightly, moderately, or heavily infected and given a numerical rating of 1, 5, or 25, respectively. Then the percent of leaves per tree infected with rust is estimated and given a numerical rating as follows: less than 25 percent = 1, 25 to 50 percent = 2, 51 to 75 percent = 3, and greater than 75 percent = 4. The numerical rating of leaf infection is multiplied by the numerical rating derived from percent of each tree infected to give an estimate of tree infection ranging from 0 (immune) to 100 (very highly susceptible). In order to avoid bias in estimating leaf infection and percent of tree infected, I rated each leaf on each tree as uninfected, lightly, moderately, or heavily infected and averaged the leaf ratings per tree. The percent of tree infected also was determined from these data and multiplied by average leaf rating to arrive at a rust severity rating for each clone at each planting density.

RESULTS

Rhinelander Plots

At the widest tree spacing (low density), NC 5326 and NC 5377 had a rust severity rating (RSR) of less than RSR 25 and both cultivars retained the low rating at the intermediate spacing (fig. 1). At the narrow spacing (high density), however, both cultivars had rust severity ratings of almost 50. Schreiner (1959) stated that for ratings made late in the growing season, cultivars rated at RSR 25 or greater "should not be recommended for planting in the localities where such tests have been carried on." Thus at the low and intermediate stocking density, both NC 5326 and NC 5377 exhibited sufficient resistance to leaf rust to be considered for planting stock. However, at the highest density, neither cultivar could be recommended.

NC 5321 and NC 5323 both had a rust severity rating of about 35 at the widest spacing, and exhibited an almost direct relation between density and rust severity. If wider spacings had been tested, these clones also would have reached a rust severity rating no longer influenced by density. Presumably the lower limit of rust severity for these cultivars also would have been below RSR 25. However, at the spacings used in this study, neither clone could be considered sufficiently resistant to warrant further consideration as planting stock.

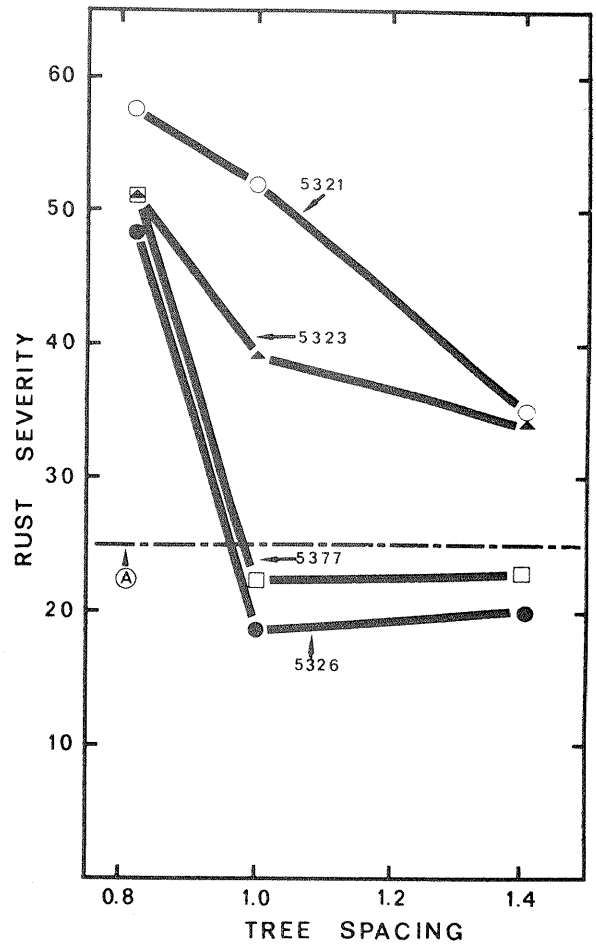

Figure 1.--*Rust severity on leaves of four poplar clones in relation to tree spacing. At a tree spacing of 0.8 m, 15,000 stems/ha can be planted, at 1.0 m, 10,000 stems/ha, and at 1.4 m, 5,000 stems/ha. The dashed line at A is the arbitrary limit for rust susceptibility set by Schreiner. Cultivars more heavily rusted than RSR 25 should be excluded from selection programs. Because spacing affects rust severity, poplars should not be rated for resistance when planted at unusually close spacings.*

Ames Plots

Data from density plots at Ames showed a similar relation between stocking and rust severity, although rust was less severe. Incidence of *Marssonina brunnea* (El. & Ev.) Magn. was also scored in these plots, with similar results. *Marssonina* leaf spot of poplars is a potentially serious foliage disease that can cause premature defoliation of susceptible poplars (see article by Schipper on p. 75).

DISCUSSION

Some of the reasons for altered rust severity with different planting density involve the changing space between adjacent tree crowns (fig. 2). At establishment, the plants are widely spaced. As they grow and branches develop, the crowns occupy increasingly large areas and the edges of the crowns become closer together until at the highest stocking density the crowns are merged. When crowns merge, as shown for the highest stocking density at 3 years, little air movement through the foliage occurs and leaves remain wet for longer time periods after rain, dew, or irrigation. Under such conditions of prolonged free moisture, foliage pathogens are best able to infect leaves. Thus, even though the actual resistance of the clones is not altered, trees at narrow spacings are exposed to conditions suitable for infection for longer periods than trees at wider spacings.

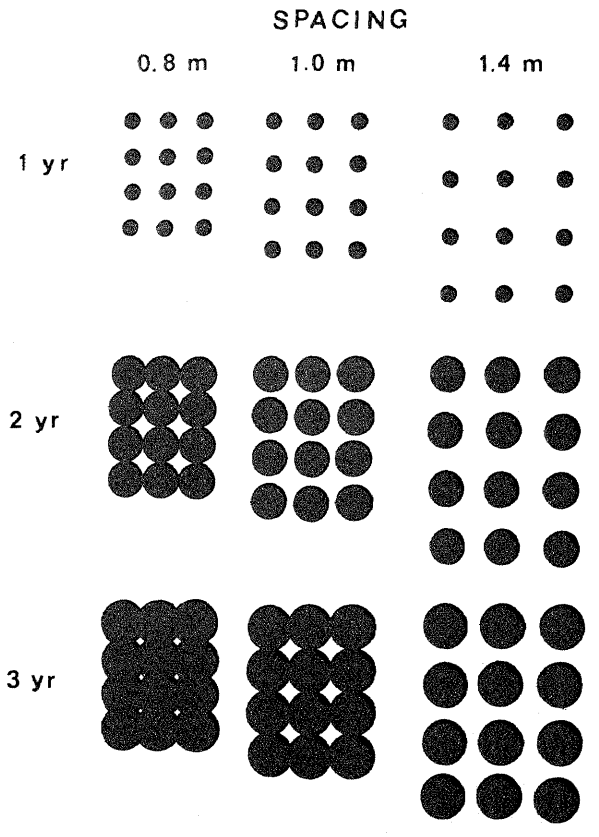

Figure 2.--*Relation between stocking density and crown closure over a 3 year period.*

These data have implications beyond the mere fact that trees planted closely together can become more heavily infected with foliage pathogens than at wider spacings. First, Widin and Schipper (see article on p. 63) have shown that leaf rust can reduce hybrid poplar height and diameter growth compared to protected plants of the same cultivar, when infection occurs early enough in the season. It is reasonable to assume that the impact on tree growth is related to the severity of leaf rust, and to date at which rust begins in the spring. Thus planting hybrid poplars at closer spacings, which will increase rust severity, will cause greater growth loss. In addition, growth data from density experiments where the trees were not protected from disease must be carefully considered before they are used to make stand density recommendations. At narrow spacings tree growth will be reduced because of rust attack, while at wider spacings growth will be closer to that realized with protected hybrid poplars under optimum conditions.

Even if growth data from density plots indicate that close spacing yields more harvestable dry matter, the effect of rust on health in general must be considered. Hybrid poplars heavily infected with leaf rust will be more susceptible to other diseases that affect trees under stress, such as canker diseases. For example, hybrid poplars in Europe infected with *Melampsora larici-populina* leaf rust are more susceptible to *Dothichiza populea* canker (Meiden and Vloten 1958). Also, rust-infected trees have been found to be more susceptible to frost damage (Kessler 1970), and will enter dormancy with less stored reserve than less severely infected trees.

A WORD OF CAUTION

In establishing density recommendations for hybrid poplars, we must consider its effect upon plant health. Foliage diseases will be minimized, to a point, by decreased stocking density while dry matter production will be maximized, to a point, by increased stocking density. Therefore, a compromise between plant health and production will have to be reached. In general, if stocking density is low enough so that crown closure does not occur until the 3rd or 4th year, the hybrid poplars will have been given the best opportunity to establish sound root systems and to adapt to the plantation conditions. After crown closure, the upper crowns of the trees will still be more widely dispersed so that rust and other foliage diseases in these portions of the tree will be minimized.

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DETECTION AND ELIMINATION OF VIRUSES IN POPLARS

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There is a need to identify and to characterize all the viruses that may infect poplars and to develop efficient indexing procedures for detecting them. A tissue culture method already is available for eliminating viruses from poplar clones, so developing a certification program for producing and distributing virus-free poplar stock depends largely upon the development of methods for detecting virus infections. Significant clonal deterioration is not likely to occur in short-rotation plantings of poplars started with disease-free stock.

In the north-central States, the intensive culture of certain species and hybrids of poplars presents the greatest opportunity to achieve maximum wood fiber production, provided that adequate provision can be made for control of the many insects and diseases that may attack them. The fact that poplar wood constitutes the most important component of the industrial wood supply within the region (Spencer and Thorne 1972) also makes the poplars attractive candidates. Further, more than a century of experience in many European countries has established the biological feasibility of intensive poplar culture (FAO 1958, Schreiner 1959).

The inevitable trend toward monoculture in such a program increases the vulnerability of the cropping system to insects and diseases. The greatest potential for insidious disaster due to virus diseases is with monocultures of vegetatively propagated perennial crops. In the long term, monocultures of natural quaking aspen (*Populus tremuloides* Michx.) propagated generation after generation from root sprouts may be as vulnerable to infectious degenerative problems as intensively managed black (Aigeiros) and balsam (Tacamahaca) poplar clones propagated by stem cuttings.

Although catastrophic losses due to insects and diseases have occurred in monocultures of intensively managed agricultural crops as well as unmanaged forests, technology can be developed and applied in an intensive management system to reduce greatly the possibility of such occurrences. Ways of dealing with potential insect and fungal disease problems are dealt with elsewhere. The purpose of this paper is to examine the possible significance of virus diseases in the intensive culture of poplars and to discuss tissue culture methods for the elimination of viruses from infected poplar clones.

NATURE, SIGNIFICANCE, AND CONTROL OF INFECTIOUS DEGENERATIVE DISEASES OF CLONAL CROPS

Virtually all vegetatively propagated agricultural and ornamental crops of the world have been exposed to infectious, degenerative diseases that have threatened the continuity of their economic production (Hollings 1965). A flourishing international trade and the prevalence of monoculture

promise to make matters worse. Without disease control, many of the affected crops could not be maintained, except in certain regions.

In many examples of progressive degenerative problems in vegetatively propagated crops, single or multiple persistent infections by viruses have been found responsible. These disorders have been referred to by many names such as quick decline, slow decline, running-out disease, dieback, little leaf, yellows, and degeneration. In some plants, infections by systemic pathogens, including viruses, may increase in severity during succeeding generations and result in a gradual increase of the degeneration problem (Brierley and Lorentz 1957, Cadman 1952, Olson 1959). This kind of problem rarely results in the death of the affected plants; the major effect being a drastic reduction in growth and yield (Cadman 1952, Chambers 1961, Krietlow *et al.* 1957).

There are presently no practical methods to cure virus-infected plants once they are set out in the field. The production and distribution of virus-free propagating stock is the most practical method of controlling virus diseases of many crops. A more advanced technology will allow for its application to a wider array of agricultural crops, including forest trees.

Control through the use of virus-free stock aims to curtail disease spread by the dilution of infective plants with healthy, virus-free planting stock. To realize this objective, techniques for eliminating viruses from plants first must be developed. Present techniques include (1) exploiting erratic virus distribution in the plant, (2) meristem-tip culture, (3) chemotherapy, (4) thermotherapy (Hollings 1965), and (5) tissue culture (Abo El-Nil 1974, Omuemu 1975, Sushak 1975).

Some viruses occur erratically throughout the plant; thus, isolation and propagation of small pieces of plant tissue may yield virus-free clones. For example, many gladiolus cormels removed from virus-infected mother corms proved free of cucumber mosaic virus (Brierley 1963).

Morel and Martin (1955) obtained virus-free dahlia and potato plants by propagating plants directly from small pieces of tissue cut from the growing tips of virus-infected plants. This technique, termed meristem-tip culture, currently is being used to produce and maintain virus-free stocks of many agricultural crops (Hollings 1965, Holmes 1968).

Claims of the cure of virus-infected plants by the use of chemical therapeutants, such as cytovirin, have been made, but none has been confirmed. The only present practical use of antiviral chemicals may be to supplement the effectiveness of meristem-tip culture.

Heat treatment is the most successful and widely used therapeutic method, especially when used to augment meristem-tip culture (Brierley 1957, Campbell 1962). Many of the viruses infecting horticultural plants might be eliminated by heat treatment (Kassanis 1957). Heat treatment inhibits the spread of certain viruses into apical growing tips of plants; tip-cuttings then taken and propagated are likely to produce virus-free plants (Hollings 1965, Nyland and Goheen 1969).

For several clonal crops, tissue culture has proven the most effective method for eliminating systemic pathogens. In this paper, the term tissue culture is defined as the aseptic technique involving the production of callus from apical shoot tips (0.5 to 1.0 mm long) and the differentiation of plantlets from the callus. The other methods described above are likely to eliminate some, but not all, of the pathogens. For example, in our work with diseased cassava clones, heat therapy consistently eliminated the mosaic disease agent, but not the leaf curl disease agent; meristem-tip culture eliminated both agents from about 50 percent of the cultured material, but tissue culture eliminated both disease agents from 100 percent of the cultured material (Omuemu 1975). Tissue culture has consistently eliminated tobacco ringspot virus from geraniums (Abo El-Nil 1974) and all apparent virus infections from gladiolus (Sushak 1975); other methods have not. Elimination of disease agents from geranium and cassava clones by tissue culture resulted in dramatic increases in the vigor and growth rates of the plants (Abo El-Nil 1974, Omuemu 1975).

DETERIORATION OF POPLAR CLONES

From about 1937 to 1954, Emeritus Professor A. J. Riker and associates, especially J. E. Kuntz, accumulated at the University of Wisconsin one of the world's

largest collections of poplar species and hybrids. The collection included more than 1,000 clones of black (Aigeiros) and balsam (Tacamahaca) poplar species and hybrids.

These clones were evaluated in small replicated plots. Most of them proved unsuitable for use in Wisconsin for a variety of reasons and were discarded. Approximately 0.1 percent of them appeared promising. They had at least field resistance to the then known poplar diseases of economic significance and were selected for resistance to attack by the poplar-and-willow borer, *Cryptorhynchus lapathi* (L.). They grew rapidly, and a representative clone produced a wood comparable in quality to that of the quaking aspen (Laundrie and Berbee 1972).

These highly selected clones have been observed through two and a half 12-year or longer rotations. Near the end of the first rotation, a decline and dieback problem of unknown origin began to appear. The severity of this decline problem seemed to increase with succeeding generations. By 1970, it was evident in the nursery that randomly selected, open-pollinated eastern cottonwood seedlings were outperforming our most highly selected Aigeiros poplar clones. Cooper and Randall (1973) of the USDA Southern Forest Experiment Station reported somewhat similar results comparing their highly selected eastern cottonwood clones with full-sib families of eastern cottonwood seedlings. The families of seedlings performed better than the clones.

Only one Aigeiros clone in the entire Wisconsin collection of poplars has not deteriorated. This female clone, NE 244, was sent to us by the USDA Northeastern Forest Experiment Station as an intraspecific hybrid between *P. deltoides angulata* and *P. deltoides virginiana*. Unfortunately, this rapidly growing, decline-resistant clone proved susceptible in Wisconsin to winter injury, resulting in stem basal damage on the southwest side of the trees. Although somewhat more difficult to root from stem cuttings than many other poplar clones, NE 244 should be a candidate for intensive culture within the southern range of *P. deltoides*.

Clonal deterioration also has occurred in monocultures of quaking aspen naturally regenerated from root sprouts, both in the eastern and western United States (Schier 1975). Schier presented a plausible physiological explanation for the deterioration of aspen clones, but acknowledged that deterioration might be caused by viruses.

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The only poplar virus that has been thoroughly studied is poplar mosaic virus. This rod-shaped virus (Brčák and Blattný 1962, Navratil and Boyer 1970) is widespread in Europe, causes growth reductions in nursery stock, and reduces the specific gravity of poplar wood (Biddle and Tinsley 1971a, 1971b). It has been reported in Canada (Navratil and Boyer 1970), but has not yet been found in the United States. A widespread, aphid-transmitted, leaf-spotting disease of aspen species and hybrids in Canada described by Boyer (1962) may be caused by a virus (Boyer and Navratil 1970). This disease is very likely present and widespread in the United States.

Our efforts to detect viruses in Aigeiros and quaking aspen clones exhibiting decline symptoms have resulted in the isolation of an apparently new poplar virus. It has been recovered from five different Aigeiros clones. The herbaceous host range of this virus, symptoms it produced in several susceptible host plants, and its morphology as revealed by electron microscopy distinguished the new virus isolate from poplar mosaic virus. It is a flexuous rod with an average length of 750 nm. Purified preparations of the virus proved infectious. It belongs to the potato virus Y group. A virus isolate recovered consistently from a deteriorating quaking aspen clone may be identical to isolates recovered from Aigeiros poplar clones.

Additional work is needed to develop efficient methods for detecting this virus in poplars, to determine its effect on growth rate, and to determine its role, if any, in the deterioration of poplar clones.

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promise to make matters worse. Without disease control, many of the affected crops could not be maintained, except in certain regions.

In many examples of progressive degenerative problems in vegetatively propagated crops, single or multiple persistent infections by viruses have been found responsible. These disorders have been referred to by many names such as quick decline, slow decline, running-out disease, dieback, little leaf, yellows, and degeneration. In some plants, infections by systemic pathogens, including viruses, may increase in severity during succeeding generations and result in a gradual increase of the degeneration problem (Brierley and Lorentz 1957, Cadman 1952, Olson 1959). This kind of problem rarely results in the death of the affected plants; the major effect being a drastic reduction in growth and yield (Cadman 1952, Chambers 1961, Krietlow *et al.* 1957).

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Three different sequences of three culture media have been required to tissue culture various poplar clones.

To date, 7 different Aigeiros poplar clones have been tissue cultured to produce more than 200 different subclones. During this process, the original parent clones were rejuvenated, as was evidenced by an ontogeny of tissue-cultured plantlets similar to that of seedlings. The tissue-cultured subclones were all virus symptomless, but efficient indexing procedures remain to be developed to establish them virus free.

The growth performances and forms of 162 different subclones derived from 5 different *P.* x *euramericana* parent clones and from a clone of *P. nigra* L. cv. 'italica' were compared at Wilson State Nursery, Boscobel, Wisconsin. There was no significant difference between the performance of subclones derived by tissue culture before thermotherapy and of those derived after thermotherapy (36°C, 3 to 12 weeks) from a given parent clone. There were significant variations in the growth rates and in the branching habits not only among the subclones derived from any one parent clone, but even among the clones derived from individual callus cultures. This unexpected result provided an opportunity to select subclones with various desired combinations of characteristics and possibly to increase the biological efficiencies of poplar clones. However, approximately 10 percent of the tissue-cultured subclones exhibited conspicuous genetic damage.

The variation among subclones of single origins could be due to total elimination of systemic pathogens from some of the subclones and elimination of only some variable proportion of them in others. The success of tissue culture in eliminating all pathogens from several other crops negates this explanation, however. A still unknown genetic basis for the phenomenon seems more likely.

DISCUSSION

Experience with the intensive culture of vegetatively propagated agricultural and ornamental crops suggests that viruses cause gradual deterioration of clonal plant materials, including poplars, unless appropriate measures are developed and applied to avoid it. The problem develops in plant clonal material because (1) plants do not have immune systems comparable to those of animals that destroy invading pathogens and, thus, once a plant becomes infected with a virus, it usually remains infected for life; (2) plants may become systemically infected with any number of unrelated viruses that cumulatively may increase both the rate and ultimate severity of the deterioration of the affected clone; and (3) accumulating virus infections are carried through succeeding crop generations by vegetative propagation, but relatively infrequently through seed.

Requirements for minimizing the risk of clonal deterioration in intensive poplar culture include (1) indentifying the viruses that may infect poplars and development of efficient indexing procedures for their detection; (2) determining the alternate natural hosts and the modes of transmission of poplar viruses as a basis for formulating measures to minimize their spread; (3) developing and applying methods for eliminating viruses from infected poplar clones; and (4) organizing a program for maintaining and distributing disease-free planting stock of clonal purity.

The detection, isolation, and partial characterization of an apparently new virus associated with deteriorating poplar clones are essential first steps in our investigation of poplar viruses. However, this phase of our work still is at an early stage. There is no conclusive evidence that this virus contributes to the deterioration of poplar clones. An efficient indexing procedure for detecting it in poplars is needed. Its natural hosts and mode of transmission and the effects of the virus on the growth and performance of different poplar clones remain to be determined. In addition, other viruses probably will be found infecting poplars and each of these will require study.

A method for eliminating systemic pathogens, including viruses, from infected Aigeiros poplar clones is available (Berbee *et al.* 1972). In dealing with poplars that may be infected with many presently undetected viruses, tissue culture involving the differentiation of plantlets from callus

is the preferred approach for producing disease-free clones. The present intent is to determine modifications in cultural sequences required to tissue culture any remaining clones of *Populus* species and hybrids that may be considered for intensive culture. Presently available tissue-cultured poplar subclones will be used for virus inoculation studies designed to determine the effects of virus infection(s) on the performance of different poplar clones.

There are two possible ways to maintain virus-free *Populus* cultivars. A certification program of the kind commonly used to maintain virus-free potato varieties is one possibility. Such programs involve the production of disease-free clones of varieties, cultural isolation, and direct chemical control for protecting the foundation stocks from virus infections, continual indexing of the clones to detect symptomless virus infections, elimination of all infected materials from the foundation stock, and repeated inspections of a seed producer's fields as a requirement for certifying his seed potatoes essentially free of specified pathogens. This approach can be applied to *Populus* cultivars only after all the viruses infecting them become known and efficient indexing procedures for detecting them become available.

An alternative approach involves maintaining virus-free *Populus* cultivars as callus cultures. This would be the most inexpensive and the most effective method if *Populus* callus cultures remained genetically stable indefinitely and retained their potential for differentiating plantlets. Further research is needed to evaluate this possibility for clonal preservation.

Avoiding virus infections in field plantings will be much more difficult but possibly less important than avoiding them in the foundation stock. Starting with vigorous disease-free stock establishes an inoculum dilution factor and may reduce the time required for trees to attain the size at which substantial wood growth begins. Clones of many other crops have deteriorated slowly as a consequence of the gradual accumulation of infections by unrelated viruses, so new virus infections in plantings of disease-free poplar clones probably will not have a major impact on wood production, especially with the short rotations that are anticipated. Eliminating any plant species that may harbor poplar viruses from the vicinity of poplar plantations is the only practical control other than starting plantings with healthy stock. Although the new virus isolated from poplars probably is an exception, most known viruses of trees in the north-central States fortunately are not insect transmitted. Some of them are pollen transmitted, but transmission by this means within plantings of male *Populus* clones is not possible. Transmission by root grafting is not likely to occur with short rotations. Thus, the probability may not be very great of a rapid accumulation of damaging virus infections in poplar plantations that are started with healthy stock and grown for short rotations.

SUMMARY

1. Poplar species and hybrids are attractive candidates for intensive culture in the north-central region of the United States, but control of the many diseases and insects that may attack them is a prerequisite for success in their use for maximum wood fiber production.

2. Development of efficient crop production technology inevitably increases the extent of monoculture which, in turn, increases the vulnerability of the crop to damage by insects and diseases.

3. Infectious degenerative diseases, caused by viruses and other systemic pathogens, have developed in virtually all monocultures of vegetatively propagated agricultural and ornamental crops. Unless technology is developed and applied to avoid them, such problems are almost certain to develop in intensively managed monocultures of vegetatively propagated poplars.

4. Deterioration of unknown origin has been observed both in clones of Aigeiros poplars propagated by stem cuttings and in natural quaking aspen stands regenerated from root sprouts.

5. The isolation of an apparently new virus from both deteriorating Aigeiros poplar clones and an aspen clone supports the hypothesis that the poplar decline problem is caused by a virus or viruses. No causal relation, however, has yet been established.

Additional viruses probably will be found infecting poplars in the north-central region.

6. Research will be needed on the epidemiology of individual virus diseases of poplars to develop controls based on disease cycle interruptions.

7. The tissue culture technology already developed and applied to produce over 200 virus-symptomless subclones from 7 different virus-infected Aigeiros poplar hybrids and species of the Wisconsin collection can be extended to rejuvenate and to sanitize clones of other poplar species and hybrids that may be considered for intensive culture.

8. An unexpected variability in the growth potentials of symptomless tissue-cultured subclones of single clonal origins may provide an unusual opportunity for improving the biological efficiencies of poplar clones. However, approximately 10 percent of the tissue-cultured poplar subclones that have been evaluated at the University of Wisconsin showed conspicuous genetic damage.

9. If future research establishes that viruses, or other systemic pathogens, contribute significantly to the deterioration of vegetatively propagated poplars, a program designed to produce, to maintain, and to distribute disease-free stock would become a prerequisite for success in the intensive culture of poplars for maximum wood fiber production.

10. Significant clonal deterioration is not likely to occur in short-rotation plantings of poplars started with disease-free stock.

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IMPACT OF INSECTS ON TREES PLANTED FOR MAXIMUM FIBER PRODUCTION

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This report covers current and proposed studies of insect attacks and insect simulated damage to various clones of Populus. *Aphids were the most prevalent pests encountered. Other insects observed included leaf beetles, leaf hoppers, and assorted lepidopterous and coleopterous larvae. Aphids were injuring some of the tree's leaders. Local heavy defoliation was caused by larvae of the mourning-cloak butterfly. Simulated insect damage model proposed for next year is described in detail.*

This report describes a study of insect impacts on trees grown under intensive culture for maximum fiber yield and reports the first-year progress of the 3-year project. The research is a cooperative effort of the Forestry Department at Michigan State University and the North Central Forest Experiment Station, USDA Forest Service.

OBJECTIVES

The overall objective is to assess the potential impact of insects on short rotation hardwood tree crops grown under intensive silvicultural systems. Attention is focused primarily on the genus *Populus*. Specific objectives in the several phases of the study are:

1. To prepare a bibliography of the existing literature on insects in relation to intensive silviculture.
2. To develop a computerized catalog of insects potentially damaging to *Populus* plantations, including identifying characters and type of damage.
3. To observe and document insect activity on *Populus* in nurseries, plantations, and natural stands.
4. To assess probable impact of intensity and type of insect damage on tree growth and form.
5. To devise controls that might be used if infestations do develop.

REVIEW OF EXISTING INFORMATION

Wilson's review (In press) of entomological problems of forest crops grown under intensive silviculture, along with the references cited in it, provides an excellent point of departure for building an index file to the existing literature. Baker (1972) in his book on eastern forest insects condenses and reviews most of the pertinent literature through about 1969, and presents keys for identifying both insects and damage. Graham *et al.* (1963) provide a comprehensive treatment of the ecology and economics of bigtooth aspen (*Populus grandidentata* Michx.) and trembling aspen (*Populus tremuloides* Michx.) in the Lake States region, including a rather complete discussion of the insect complexes associated with these two species. Morris *et al.* (1975) developed a handbook for ready reference to the major insect and disease pests of eastern cottonwood (*Populus deltoides* Bartr.).

Space does not permit a more detailed listing of the literature. However, a

comprehensive computerized index file is being assembled on the CDC 6500 computer system at Michigan State University. The file structure includes cross-referencing for retrieval by host, insect, or type of damage.

REFERENCE COLLECTION OF INSECT SPECIMENS

The project is assembling a reference collection of insects associated with *Populus* both in the nursery research plots and in natural stands. In general, the insects collected from intensively cultured plantations are typical of the complex described by Graham *et al.* (1963) for aspen sucker stands growing under less intensive management. A notable exception that will be discussed further in the next section, however, is the rarity of stem and branch borers. Identification of the specimens collected is continuing. Every attempt will be made to provide sufficient specimens for duplicate collections, one to be housed at the Forest Genetics Institute and the other at Michigan State University. The immature stages of the insects often cause most damage, so companion specimens of immatures and adults will be included wherever possible. Toward this end, attempts to rear immature forms through the adult stage will be increased during the second field season. Both collections will be arranged taxonomically within damage categories.

OBSERVATIONS OF INSECT ACTIVITY

Several studies being conducted at the Hugo Sauer Nursery facilitated comparing insect activity in *Populus* plantations with that in natural stands. A wide range of clones, spacings, and age classes are represented in the nursery, creating a cross-section of conditions that might be encountered in commercial production. All plots in the nursery were examined at irregular intervals, with some being checked every day. The nursery's insect control program precluded continuous collection, but collections were made just before spraying. Defoliators and sucking insects accounted for most of the damage in the nursery. Most prevalent were aphids, leaf beetles, leaf hoppers, and an assortment of lepidopterous and coleopterous larvae.

By far the most abundant and damaging insects in this cultivated situation were the aphids. Severity of attack by these insects ranged from just a few per plant to thousands, lending a blue-gray cast to the top 8 to 10 inches of the terminal leader. Clonal preferences seemed to be indicated, so a survey was made to verify this. Thirteen clones were evaluated for severity of attack by these aphids, tentatively identified as *Chaitophorus populifoliae* (Oest.). The results showed definite differences in severity of attack among some of the clones, corroborating the observations reported by Graham *et al.* (1963). The frequency with which aphids occur in *Populus* plantations, coupled with their potential for rapid increase, has led us to consider testing control by systemic pesticides.

Other insect damage in the nursery research plots was caused primarily by defoliators. Locally heavy defoliation was caused by larvae of the mourning-cloak butterfly, *Nymphalis antiopa* (L.), until controlled by chemicals. Several types of defoliation were observed, with windowpane damage by leaf beetle larvae being common. Insects appeared to concentrate on coppice stems that had been used to produce cuttings in the past, but the importance of this observation has not yet been explored.

Insect activity in less intensively managed stands was observed on the Nicolet and Ottawa National Forests. Areas visited on the National Forests were large (20 to 80 acres), logged-over areas that had formerly been occupied by aspen or aspen-hardwood mixtures but were now supporting young aspen suckers 3 to 7 years old. All districts were visited on both forests except the southernmost Lakewood District on the Nicolet National Forest. On both forests the type and severity of damage was very similar: mainly windowpaning, skeletonizing, and especially blotch mining. Two differences between the nursery plots and the aspen sucker stands were prominent: (1) unlike the nursery, few aphids were observed on the sucker stands; (2) galls were prevalent on both leaves and stems of sucker stands, whereas none were observed in the nursery. Reasons for the differences between nursery and sucker stands have not yet been pinpointed, but water relations and overall vigor are probably important.

DEVELOPMENT OF IMPACT MODEL THROUGH SIMULATED DAMAGE

The principal objective of this study is to assess the probable impact of intensity

and type of insect damage on *Populus* plantation growth. Other portions of the research program on maximum fiber production are designed to provide information on growth rates as a function of species, variety, spacing, fertilization, etc., in the absence of insect damage. Results of these other phases will be available for use in elaborating a growth impact model for insect damage. Given such background information on growth in the absence of insect attack, the goal is to develop an impact model of the general form:

Impact = f(type of damage, severity of damage, timing of damage, competitive status of host plant).

In the context of this study, impact is taken to be failure to realize potential growth, assuming that control would be applied before significant mortality occurred.

The unique nature of the intensive culture environment and the variability of insect activity in natural stands preclude economically obtaining all the data needed to construct the model through observation of insect activity in natural stands. Furthermore, rearing a wide variety of insects on intensively cultured *Populus* material would be both difficult and expensive. Therefore, simulation of insect damage was chosen as the only practical approach to the problem. Even with simulation, however, it would be very difficult and expensive (if not impossible) to duplicate all details of damage by diverse insect pests, especially in the case of aphids, leaf rollers, leaf miners, and phloem feeders. Two physiological effects of insect activity on the plant, however, are of primary importance. One is removal or destruction of photosynthetic tissue through defoliation. The other is impairment of the conductive mechanisms of the plant as a consequence of girdling, boring, puncture wounds, etc. Therefore, a set of four controlled experiments was designed to provide the information on responses to these two general categories of damage.

The first experiment is designed to measure impact in relation to severity, timing, and recurrence of defoliation. The experimental design is a 3 by 3 by 2 by 2 factorial with two completely randomized replications. The first factor is degree of first year defoliation, with the three levels being set at 0 percent (control), 40 percent, and 80 percent. The second factor is degree of second year defoliation, with levels the same as for the first year. The third factor is timing of first year defoliation; early in the growing season or late. The fourth factor is timing of second year defoliation, with levels the same as for the first year. The layout for this experiment is a square planting of rooted cuttings from a single clone with 19 plants on a side and 2-foot spacing. With a two-plant buffer around the treated area to avoid edge effects, this layout provides five, three-plant plots across each width of the seedbed. As noted above, the locations of treatments and replications within the layout are completely randomized by three-plant plot. The 40 percent defoliation treatment is accomplished by removing the second and fourth leaf of every five along the length of the stem. The 80 percent defoliation consists of leaving every fifth leaf along the stem and removing the intervening ones. Response variables to be measured include height; diameters at ground level, 1 foot, and 4.5 feet; and total number of leaves. This experiment was installed in the Hugo Sauer Nursery on June 23, 1975. Planting stock consisted of 361 rooted cuttings of clone 5332 (*Populus ev. Betulifolia* X *P. trichocarpa* Torr. & Gray). Defoliation treatments were carried out on July 17, 1975, and August 23, 1975, with measurements being taken just before defoliation in each case. Eighteen of the 216 crop trees in this experiment died during the 1975 growing season. The cause of this mortality could not be determined; the leaves developed small necrotic areas that later expanded until the entire leaf died and dropped off. There was no evidence of insect activity, and no disease was identified.

The second experiment is designed to provide information on impact of defoliation in relation to clone and spacing. The design is a split-plot/factorial. Main plots are used to test 1- and 2-foot spacing. There are eight main plots with each of the two spacings randomly allocated to four main plots. A 3 by 2 factorial for clone and defoliation is nested in a completely random fashion within each main plot. The first factor is clone, with three clones representing the different levels. The second factor is defoliation, with one level being 0 percent (control) and the other being 75 percent defoliation effected by leaving every fourth leaf along the stem and removing the intervening leaves. Defoliation occurs in 1 year only, with response measurements being taken as described for the first experiment. The experiment was established on August 19, 1975. The clones used in this second planting are:

1--*Populus ev. Betulifolia* X *trichocarpa* Torr. & Gray (5332)
2--*Populus tristis* Fisch. X *P. balsamifera* L. *ev. Tristis* #1 (5260)
3--*Populus spp.* (5351)

Due to the late planting date, defoliation will be done during the 1976 growing season.

The purpose of the third experiment is to determine impact of girdling and boring damage and variability to be expected between clones. The design is a 6 by 3 factorial with two completely randomized replications. Five types of girdling and boring damage plus control constitute the six levels of the first factor. As in the first two experiments, plots consist of three rooted cuttings growing side-by-side in a row. The six types of girdling and boring damage are:

1. control (no damage)
2. 1/3 circumference girdled at 6 inches above the ground
3. 2/3 circumference girdled at 6 inches above the ground by a continuous slit
4. 2/3 circumference girdled at 6 inches above the ground by two opposing 1/3 slits
5. 1/8-inch hole bored straight through the stem at 6 inches above ground
6. two 1/8-inch holes bored straight through the stem at right angles 6 inches above the ground

Girdling is done with paired razor blades to make a double slit; the boring is done with a hand drill. All damage treatments are done in a single year, with response variables measured as for the first two experiments. The planting stock was propagated during the summer of 1975 and outplanted on August 19, 1975. The same three clones were used as for the second experiment. A 2-foot square spacing was used for the field layout. Treatments will be applied during the 1976 growing season.

The purpose of the fourth experiment is to find out how distribution of defoliation within the crown affects impact and whether there are clonal differences in this respect. This experiment has basically the same design as the third one, except that several mechanisms of achieving 75 percent defoliation replace the different types of girdling and boring injury. The defoliation treatments are:

1. leave every fourth leaf along the stem, removing the intervening ones
2. remove leaves on the upper 3/4 of the stem
3. remove every other leaf completely, then remove half of each remaining leaf by cutting at right angles to the midvein
4. cut every leaf in half as described in 3, then cut away half of the remaining half by cutting immediately to the right of the midvein leaving 1/4 of each leaf on the plant
5. remove leaves completely from top half of stem, then remove half of each leaf on lower portion as described in 3
6. control (no defoliation)

As with the third experiment, planting was done August 19, 1975, to ensure that the cuttings would be ready for treatment in 1976.

CONCLUSION

The various phases of this study including review of existing information, assembly of a reference collection, comparative observation of insect activity in *Populus* plantations and sucker stands, and controlled experiments with simulated damage should provide a good basis for assessing the potential impact of insects on hardwoods grown for maximum fiber production under intensive silviculture. Likewise, the results should help in deciding when to apply control measures and what type of control would be most effective.

It seems apparent at the end of the first year of study that defoliators and aphids are likely to account for most of the insect problems associated with intensive culture systems for *Populus* in the Lake States. Potential for use of systemic insecticides in controlling these insects will be part of the research program for the remaining 2 years of the study.

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(1) Minimum required yield per acre per year or the required annually compounded revenue or volume flow.

(2) Minimum required yield per acre at the time of harvest. This required yield is equal to the total compounded costs per acre.

The latter is a more useful management guide because it is at the time of harvest that final yields are being realized. If coppicing takes place, the same stand would go through another production period, usually involving lower expenditures because initial site preparation is no longer necessary. Break-even yields can, therefore, be calculated for the first period comprising all costs from initial establishment to the first harvest, for the second period (from first coppicing to the harvest of the coppice stand) and similarly for the third, fourth, etc., periods.

It is possible to calculate a minimum *average* yield per acre at each of a number of consecutive harvests (not necessarily at equal time intervals) over a production cycle that is required to cover total production costs. *Average* compounded costs per acre at each harvest are the basis for this criterion and can be obtained by solving equation (3) in table 1 for V, average compounded costs per acre each harvest.

This break-even yield, being a weighted average of the minimum requirements for the individual harvest periods, usually will fall between the break-even yield for the first and the following periods and will decrease with the number of coppicings.

The computer program developed for break-even analysis is a cost accounting system; i.e., a system that keeps a record of the magnitude of costs incurred and the time at which expenditures occurred (Rose 1975). The model has, however, a number of other features that make it useful for detailed production planning. A discussion of some of these features will be postponed until the major model inputs have been described. These are:

(1) Condition of the site.--This determines the type of land clearing and site preparation activities necessary for intensive cultures.

(2) Management plan.--The program can simulate any management plan or activity schedule. A plan specifies the type of activities to be applied and the time and frequency of their application.

(3) Rotation ages for planted and coppice stands.--Because coppiced stands have an already existing root system, rotations might be shorter for such stands.

(4) Number of coppicings.--This indicates how often a stand can be harvested without replanting.

(5) Plant size or total acres to be managed intensively.--The model will establish a sustained yield operation. If a rotation of, say, 3 years is used for planted stands, one third of the total acreage will be put into intensive culture each year for 3 years. After one rotation, a sustained harvest of one third of the acreage will be possible.

(6) Stand stocking or tree spacing.

(7) Interest rate or alternative rate of return.

(8) Annual administration costs (including taxes) per acre.

(9) Land cost per acre.--Land cost can be incorporated either as an annual rent or as purchase cost per acre. A resale value of the land can be specified if the land is sold after the production cycle. The purchase cost and resale value of the land are converted into annuities over the production cycle by applying the "capital recovery" and "sinking fund multiplier," respectively. The difference between the two values is the annual land cost per acre.

(10) Assumed delivered value of a dry ton of fiber.

(11) Assumed mean annual growth in dry tons per acre for planted and coppice stands.

(12) Annually compounded real rate of price changes of the product and/or costs.

(13) The cost per acre for all activities used in the management plan.--The program accepts either a specified cost per acre or calculates such a cost from a short-run average cost curve for the activity from internally stored information on a large number of machines used in such production systems. For the latter option, fuel costs, machines, machine production rates, and yearly time constraints on the activity (in hours) have to be specified to facilitate calculation of the average weighted cost per acre for the machines handling the specific job. With this option, economies and diseconomies of scale will be simulated, depending on the scale of the operation, the time constraint, and the machine productivity. A suboptimization should be attempted outside the model in the selection of efficient total machine packages.

Break-even yields are only one of the outputs produced by the model. These re-

quired yields are given separately for the first, second, and total period. The latter is recorded for one harvest block and also for the total sustained yield system (all harvest blocks) to show any economies of scale that might result from a higher utilization of machines.

If a product value (dollars per dry ton of fiber) and a mean annual growth can be estimated, present net worth and internal rate of return are also calculated. Among some of the other outputs useful for production planning are tables showing machine production statistics, annual acreage on which various intensive culture activities are scheduled, associated machines by type and number, machine hours, costs, replacement schedules, and capital requirements. Capital requirements must be considered upper estimates because machines such as tractors can be used for more than one activity during the nonoverlapping working periods. Total discounted costs for each activity and their relative importance are described.

The program can be executed in an interactive mode. Management decisions can, therefore, be improved from one run to another by simply changing any of the previous inputs or factors, especially those that in practice would be under the control of the manager. The model thus lends itself well to analysis of the factors to which break-even yields are most sensitive.

ESTIMATION OF PRODUCTION COSTS

Cost estimating is at the heart of break-even analysis. Various estimates of production costs in intensive cultures are available (Briscoe 1969, Dutrow *et al.* 1970, Dutrow 1971, McKnight 1970, Olawoye 1972, DeBell and Harms 1975, Sunda and Lowry 1975). Some of these sources have become outdated due to inflation and changing technology.

Table 2, largely based on information by DeBell and Harms (1975), and somewhat modified by the authors, describes the range within which various activity costs might be expected to fall, but is not useful for analyzing specific production situations.

Because mechanization will play a substantial role in intensive culture, it is essential to estimate machine operation costs for specific site conditions and scales of operation; i.e., to develop short-run average cost curves. Such curves illustrate how per-unit costs change with different levels of operation.

Table 2.--*Intensive culture costs*[1/]

Type of cost	Definition	Average	Low	High
Land	Land rent	40	20	80
	Land purchase	800	400	1,200
Establishment	Land preparation			
	Mature forest	250	200	300
	Plantation	150	100	200
	Pasture	55	30	80
	Cropland	10	5	15
Management	Planting			
	2 by 4	140	125	155
	4 by 4	85	75	95
	6 by 6	55	45	65
	12 by 12	15	10	25
	Management			
	Admin. (Annual)	3	2	4
	Fertil. (Periodic)	75	25	150
	Weed & Prot. (Rotation)[2/]	20	10	30
	Harvesting-Hauling			
	2-year rotation	80	40	160
	4-year rotation	160	80	320
	10-year rotation	400	200	800
	Rejuvenation	25	10	160
	Regeneration	70 + Planting (varies with spacing)		
	Rehabilitation	70	60	80

1/ Adapted from DeBell and Harms (1975) with some modifications.
2/ Initial weed control included in land preparation costs.

Short-run average cost curves were derived from information collected for the various agricultural and forestry equipment that might be used in intensive silviculture (fig. 1). The relation of cost economies to annual operational size of intensive cultures is of special interest because cost economies will likely be greatest in large units and with full utilization of machinery.

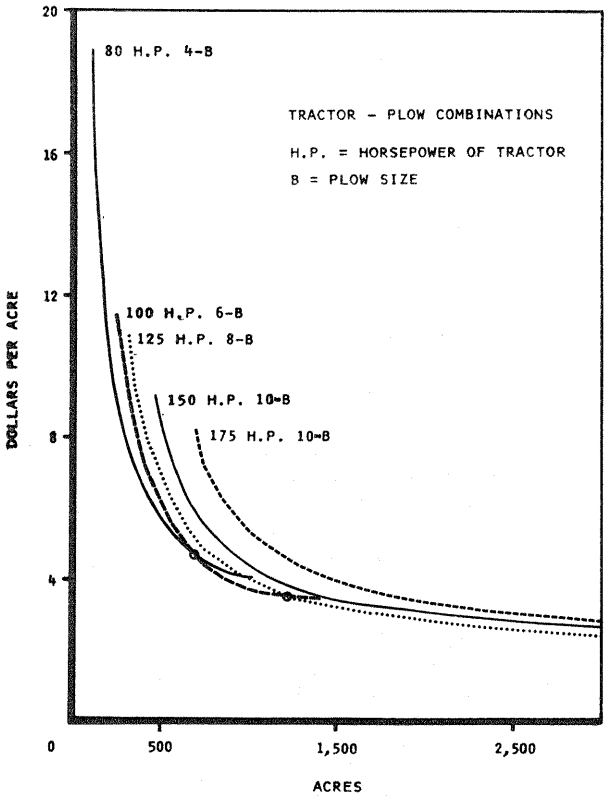

Figure 1.--*Short-run cost curves for plowing.*

Costs per acre decline over all acreages because fixed costs are spread over more acres while variable costs tend to be constant; costs per acre are based on near-linear relations (Heady *et al.* 1955). A different short-run curve exists for each level at which identical factors may be held fixed (e.g., two or more tractors instead of one) or for each possible form of fixed factors (e.g., a large tractor as compared to a small tractor).

Curves for cost per unit of product would be similar to the curves in figure 1 (fig. 2). The curves SAC represent short-run costs for various machine combinations. As production increases for the variable factor or as fixed costs are spread over a greater output, the

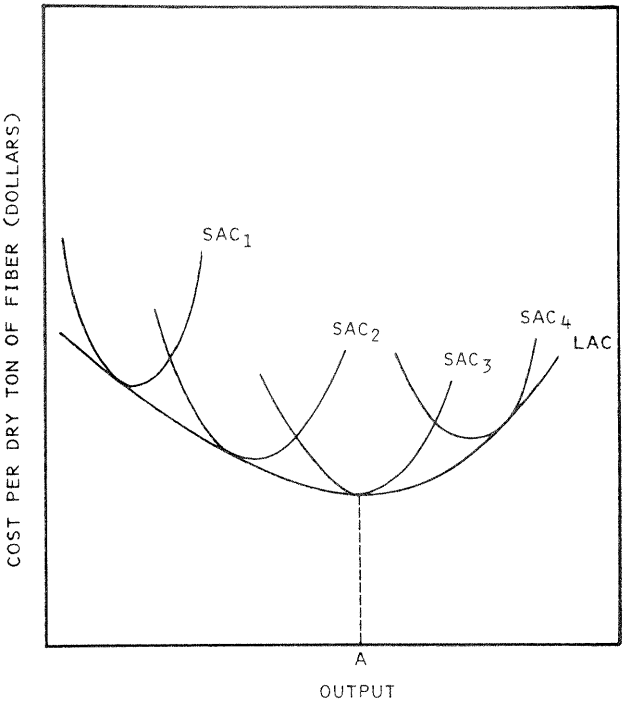

Figure 2.--*Family of short-run cost curves and their envelope.*

cost per unit of output declines. But contrary to the curves in figure 1, costs per unit of product may eventually rise because operation of a machine (combination) on an increasing acreage will eventually lead to untimely operations with resulting lower per-acre production rates and, therefore, higher operating costs. Costs per unit of product increase as soon as production rate decreases and operation cost increases offset further declines in fixed machine cost per unit.

Out of an entire family of short-run cost curves, one particular curve has a minimum point lower than that of any other curve (fig. 2, point a). At that point, the indicated output could be produced at lower per-unit cost than with any other factor combination and represents the optimum production level.

A long-run cost curve for which no single resource is fixed can be constructed for any family of short-run cost curves. It is the "envelope" of the short-run cost curves; i.e., it is tangent to each single curve at one point. Individual short-run curves that have their tangency either to the left or right of their minimum point would represent nonoptimal factor combinations. The short-run curve that is tangent to the long-run curve at its minimum point is the optimal factor combination and short- and long-run average costs are minimum at that point.

COMPARISON OF TWO BASIC ALTERNATIVES

Two basic intensive culture alternatives were selected to describe the range of intensive culture philosophies from extreme short rotations with numerous coppicings to longer rotations without coppicing (table 3). The costs for the various intensive-culture activities are our best estimates at this time and based on available literature and various other sources. Costs for land clearing, piling, and disking (site preparation) were estimated from the long-run cost curve for these activities (figs. 3, 4, and 5). Envelopes were hand drawn to the short-run cost curves for the various activities to derive the respective long-run cost curves (fig. 6). The total long-run cost curve is simply the vertical summation of the long-run cost curves for individual activities (fig. 7). Cost assumptions for the alternatives are summarized in table 4.

Six selected results are reported for each computer run (table 5). It is apparent from the first two runs of each alternative (analyses 1 and 6) that the extreme short-rotation alternative does not offer any investment opportunity under the assumed costs, yield, and product price. The 15-year rotation, on the other hand, offers positive rates of return on the investment, but irrigation does not appear to offer any advantage in the current context.

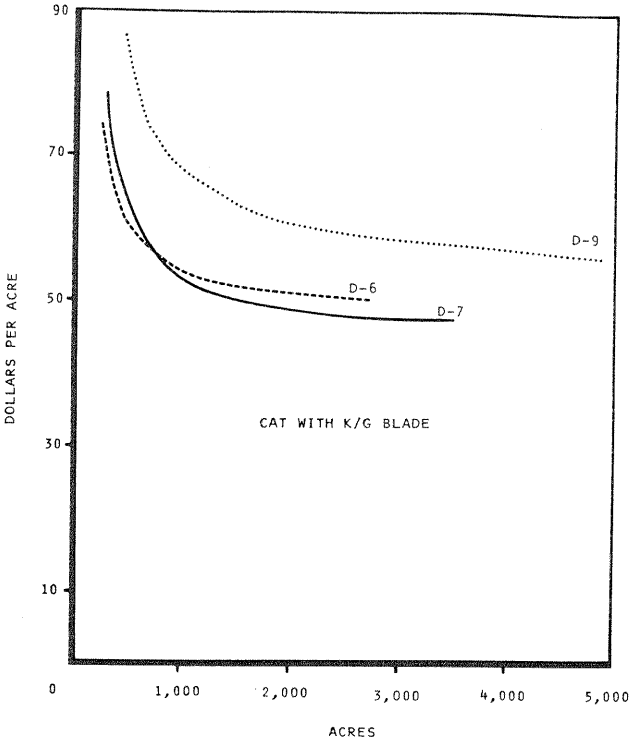

Figure 3.--*Short-run cost curves for land clearing.*

ADDITIONAL COMPARISONS

The number of management alternatives and estimates of production costs, yields,

Table 3.--*Two basic intensive culture alternatives*

	Alternative I	Alternative II
Rotation (no.)	5	15
Coppicings, no.	3	0
Spacing (ft.)	4 x 4	12 x 12
Discount rate (percent)	10	10
Price per ovendry ton, delivered (dollars)	30	30
Growth (tons per acre per year)		
(a) without irrigation	2.5	4.5
(b) with irrigation	4.0	7.8
Annual harvest acres (sustained yield operation)	1,000	1,000
Activity	**Year(s) in which activities take place**	
Land clearing	1	1
Site preparation	2	2
Planting	2	2
Weed control	2,7,12,17	2,3
Fertilization	2,4,7,9,12,14,17,19	2,5,8,11,14
Harvesting-hauling	6,11,16,21	16
Irrigation setup	2	2
Irrigation (maintenance and operation)	2 to 21	2 to 15

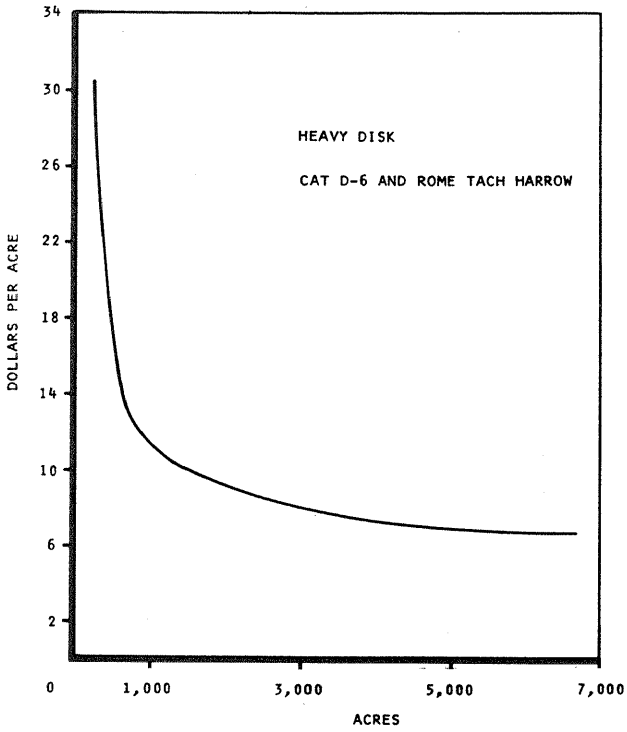

Figure 4.--*Short-run cost curve for heavy disking.*

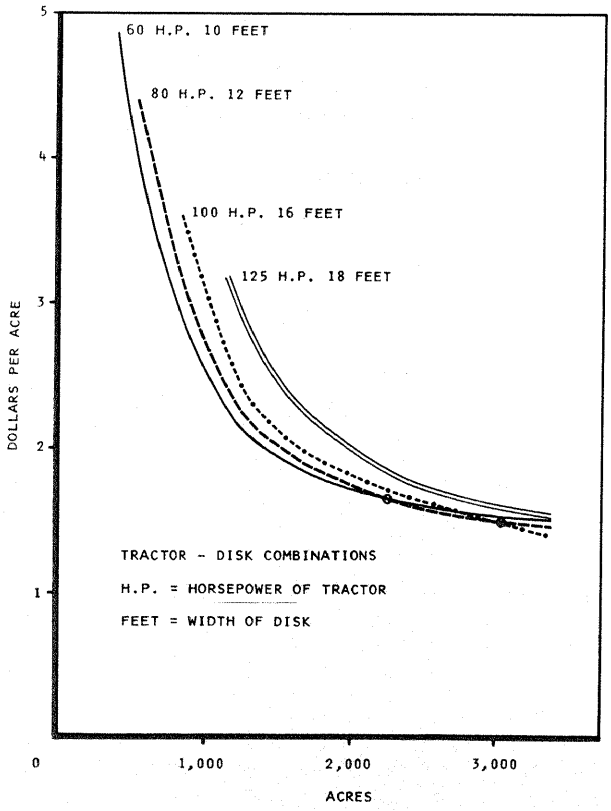

Figure 5.--*Short-run cost curves for agricultural disking.*

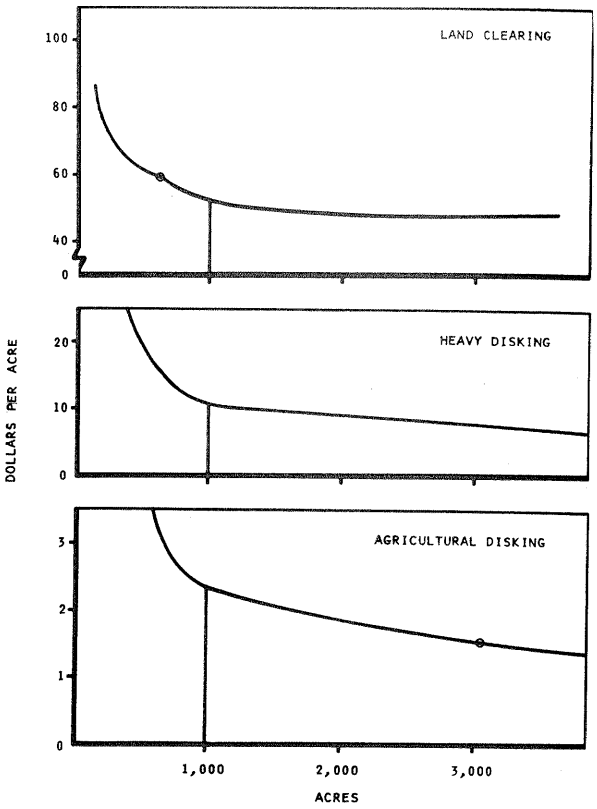

Figure 6.--*Long-run cost curves for land clearing, heavy and agricultural disking.*

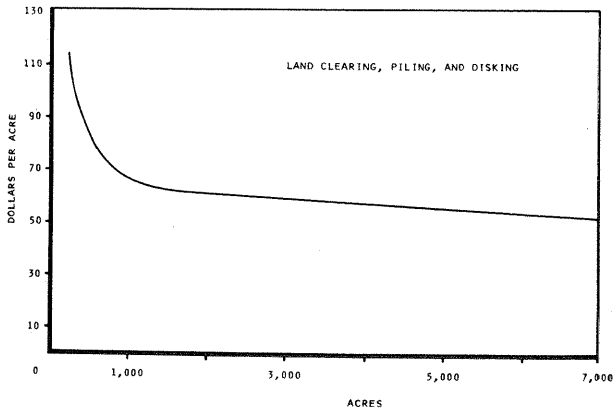

Figure 7.--*Total long-run cost curve for land clearing and other site preparation activities.*

and prices is much too large to allow complete testing of all possible combinations. Fortunately, break-even requirements for a given alternative and cost combination, after changing cost and/or price assumptions, can be calculated without additional computer runs.

The adjustment procedure is simply to multiply the change in total discounted costs per acre due to any cost change by the multiplier M from equation (1) to obtain the adjustment in the average break-even requirement over all individual harvests. To facilitate further sensitivity analysis, table 6 was constructed. It states the multiplier for selected alternatives and the magnitude of adjustments in break-even yield for selected cost changes.

Table 4.--*Cost of two intensive culture alternatives*
(In dollars per acre)

Activity	Alternative I	Alternative II
Land clearing	62	62
Site preparation	2.60	2.60
Planting	85	15
Weed control	14	14
Fertilization	55	55
Harvesting-hauling	250-350	400-600
Irrigation setup	400	400
Irrigation (maintenance and operation--annual)	40	40
Administration costs (annual)	3	3
Land rent (annual)	10	10

The sensitivity of break-even yields to a change in annual costs obviously increases with the length of the rotation. Similarly, the sensitivity of break-even yields to any one-time cost change is greater, the earlier this cost occurs in the production period. In contrast, a change in harvest costs (or any other cost occurring in the last year of the harvest cycle) will affect break-even requirements equally over all alternatives. Any other cost change that occurs at the same time for any alternatives (such as 1, 2, etc., year(s) before a harvest) will change break-even yields equally over such alternatives.

Table 5.--*Economic analysis of two basic alternatives*

Alternative	Analysis	Required mean annual growth	Required yield per acre each harvest	Cost per dry ton of fiber production	Present net worth per acre	Internal rate of return	Payback period	Assumed yield per acre per year	Remarks
		Dry tons	*Dry tons*	*Dollars*	*Dollars*	*Percent*	*Years*	*Dry tons*	
I	1	4.05	20.26	48.63	-295.16	<0	N	2.5	No irrigation
	2	8.09	40.43	60.64	-776.86	<0	N	4.0	Irrigation 1/
	3	7.27	36.36	54.53	-622.07	<0	N	4.0	Irrigation 2/
	4	6.46	32.29	48.43	-467.28	<0	N	4.0	Irrigation 3/
	5	4.72	23.59	35.39	-136.70	1.9	N	4.0	Irrigation 4/
II	6	4.30	64.45	28.94	19.92	10.6	16	4.5	No irrigation
	7	10.94	164.11	42.08	-307.59	6.1	N	7.8	Irrigation 1/
	8	9.53	142.93	36.65	-169.30	7.8	N	7.8	Irrigation 2/
	9	8.12	121.75	31.22	-31.01	9.6	N	7.8	Irrigation 3/
	10	4.74	71.12	18.23	299.57	16.4	16	7.8	Irrigation 4/

1/ Setup cost $400, maintenance and operation $40 per acre per year.
2/ Setup cost $400, maintenance and operation $20 per acre per year.
3/ Setup cost $400, maintenance and operation $0 per acre per year.
4/ Setup cost $0, maintenance and operation $0 per acre per year.

Table 6.--*Sensitivity in break-even requirement to changes in various costs* 1/

Alternative	Multiplier	Change in break-even requirement for a 10-dollar-per-acre change in: Annual cost	First-year cost 2/	Fertilizer cost	Harvest year cost
I	0.7888	68.22 dollars	7.17 dollars	29.41 dollars	10.00 dollars
		3/ 2.27 tons	.24 tons	.98 tons	.33 tons
II	4.5950	359.50 dollars	41.77 dollars	127.79 dollars	10.00 dollars
		11.98 tons	1.39 tons	4.26 tons	.33 tons

1/ All calculations based on 10-percent discount rate.
2/ A $10 change in a second, third, etc., year cost is equal to the discounted value of a first-year cost change.
3/ Based on a price of $30 per ton.

Clearly, break-even requirements must change linearly with changes in a cost factor, and all break-even yields can be generated for any level of that cost factor once one solution has been found (figs. 8, 9, and 10). Furthermore, any cost change--be it an annual, periodic, or a one-time cost--will cause a parallel shift of a specific break-even line.

For further information on the feasibility of any given management alternative, graphs as in figures 8 and 9 can be constructed with the cost factor on the X-axis that is most critical or for which the information is the least complete. Figure 8 thus provides information on how low harvesting costs would have to be to make the alternative economically feasible.

The effect of a change in the product price is the easiest to predict because break-even yields (in tons) are inversely proportional to price; i.e., a doubling in product price will reduce break-even yields by 50 percent. The absolute effect of any price change on break-even yields is greater

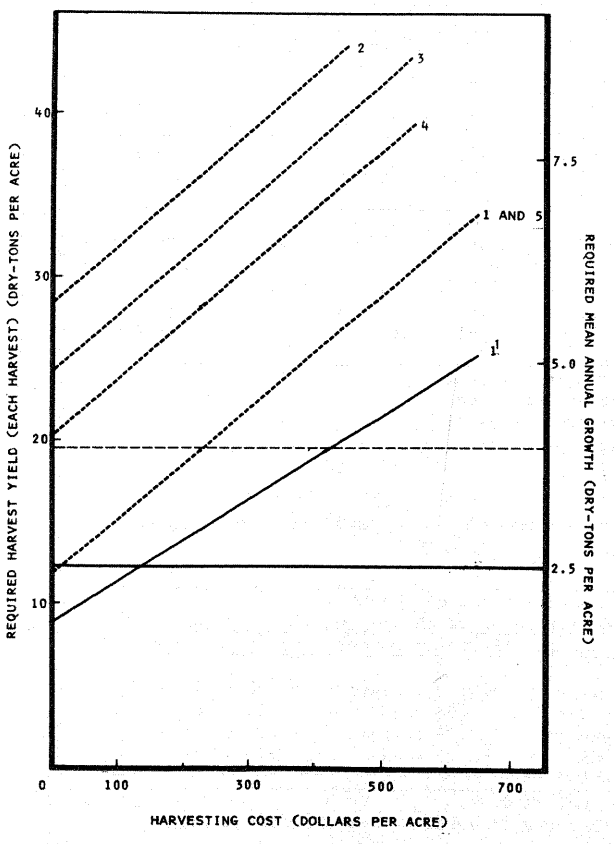

Figure 8.--*Break-even yields for short-rotation alternatives.*

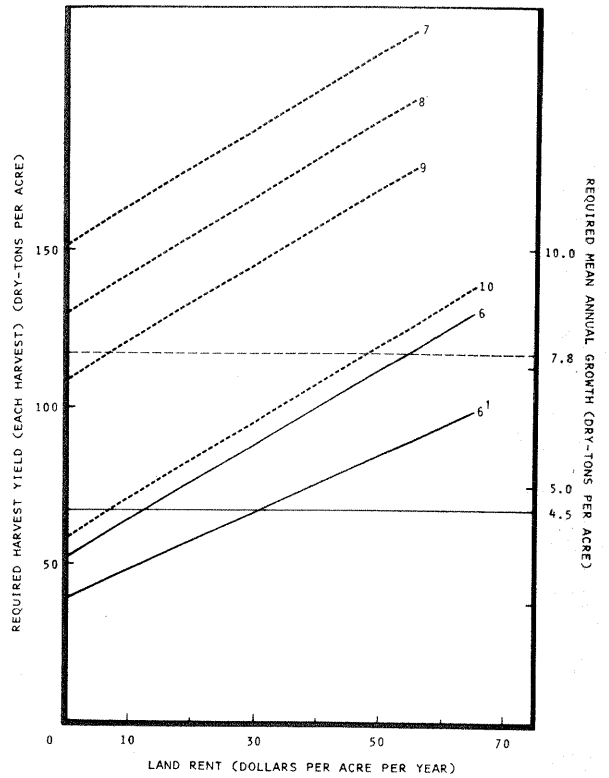

Figure 9.--*Break-even yields for long-rotation alternatives.*

for higher break-even yields. Price changes, therefore, cause changes in the slope of break-even relations, leading to a change in the relative importance of all other cost factors (figs. 8 and 9, lines 1^1 and 6^1).

The assumed yield itself does not influence break-even requirements and is drawn into the illustrations as a horizontal line (figs. 8 and 9). The intersection of this line with any break-even line represents the point at which the internal rate of return is equal to the specified discount rate or at which present net worth is zero. Any solution to the left of the intersection would have a positive present net worth and an internal rate of return greater than the selected discount rate. Net income (tons) at the time of harvest is represented by the vertical distance between break-even yields (cost-) and yield- (revenue) lines.

IRRIGATION--POLLUTION ABATEMENT TRADE-OFFS

One of the interesting considerations in intensive culture is the possibility of charging the cost of irrigation against the

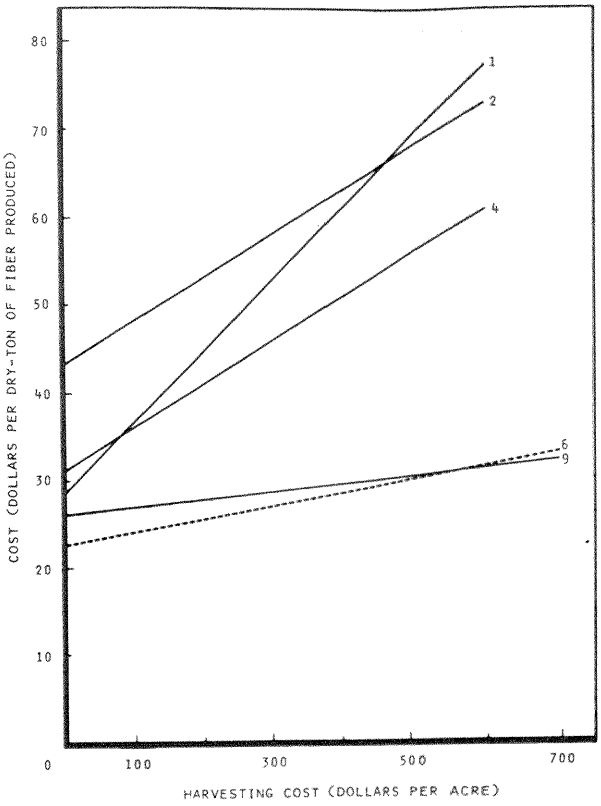

Figure 10.--*Fiber production costs for selected alternatives.*

cost of cleaning up polluted effluent. Timber industries involved in both timber production and production of pulp and paper will be faced with new and stringent standards for the quality of effluent. The Water Pollution Control Act of 1972 (PL92-500) charges industry with zero discharge by 1985 and will require strict pollution abatement standards. These legal requirements will increase production costs substantially, and the implications are especially severe if discharge even of treated effluent is not possible; i.e., discharge on land is required.

With zero-discharge interpreted literally, irrigation of crops would become a free byproduct with no cost to the forest manager. Even if the irrigation setup, maintenance, and operation costs are charged against the irrigated crop, these costs should be properly reduced by savings in operating pollution abatement systems, by savings in fertilizer costs (due to possible soil-improving characteristics and the nutrient content of the effluent), and by increases in crop yields due to irrigation. Pollution abatement costs could be reduced if irrigation is possible with effluent that has gone only through some of the cleanup stages, such as primary treatment, with savings to be realized mostly in operation of secondary and other cleanup stages. The capital facilities for all treatment stages must, however, be available in case irrigation has to be disrupted, such as during the winter in northern climates.

If effluent is used for irrigation after going through the primary clarification, the annual savings in operating biological clarification and secondary clarification could run around $225,000 for a large pulpmill (100-ton per day capacity). Biological oxidation might be necessary to eliminate offensive odors near residential areas. Savings would then be only about $50,000. At $40 per acre for maintenance and operation of an irrigation system, 1,250 acres could be irrigated without cost to the forest sector by writing these costs off against the savings in pollution abatement.

If such cost savings can be realized, break-even yields will change substantially (figs. 8 and 9, table 2). The irrigation-pollution abatement trade-off has to be large, however, before irrigation would become economically feasible and more profitable than the no-irrigation alternative.

HARVESTING COSTS

One of the most difficult to estimate costs in intensive culture is the harvesting cost, because it depends on the conditions of the terrain, on the characteristics of the stand, the harvesting system, and the scale of the operation. Published harvesting costs provide, at best, only a range in harvesting costs for traditionally managed stands in a variety of locations (Zasada 1971, Anderson and Granskog 1974, Biltonen *et al.* 1974, Biltonen and Steinhilb 1975). These and other sources give information on old and new harvesting systems in the Lake States. It is not possible, however, to strictly apply such cost estimates to intensive cultures. The latter will differ greatly from traditionally managed stands in terms of stand characteristics such as volumes per unit area, tree spacing, and tree size distribution. For the longer rotations, savings might be possible with highly mechanized and properly balanced total harvesting systems.

For extremely short rotations, even fewer harvesting cost estimates are available. However, harvesting young stands

with techniques developed for older stands would probably be too costly because of the large amount of small material to be handled. Agricultural type machinery, such as forage harvesters, has been suggested and tested, however, with some success, and harvesting costs with such cheap equipment could be much lower than assumed in this study (Dutrow 1971). Our estimate from the long-run cost curve for a single-row forage harvester driven at 3 m.p.h. and operating 1,000 acres per year is $25 for the 4 by 4 spacing. Much better information based on actual field trials is necessary, however, before conclusive statements are possible. With harvesting costs as low as indicated above, the extreme short-rotation alternative would become economically feasible (fig. 8).

THE MANAGEMENT PROBLEM

One of the major problems facing large pulp and paper mills is getting a continuous supply of fiber to the production facility. Most mills depend on outside suppliers but also manage their own wood holdings for the continuous production of fiber. To match management practices to the conditions of the site through species selection, rotation determination, intensity of management, and degree of mechanization, the industry forester must know the site factors and their influence on costs and revenues.

A useful first step in identifying suitable management alternatives for a site is to classify the land according to biological, physical, and socio-economic criteria. The classification system must describe the factors that most significantly affect the biological and economic feasibility of intensive cultures. But at the same time, a compromise is required between the detail of such a classification scheme and the cost of measuring its components. The site index as a measure of growth potential must be refined to show the growth potential under various degrees of fertilization and irrigation. Climate, terrain, and soil conditions determine the potential for irrigation and mechanization. Accessibility is an important economic factor in harvest and hauling operations. Land rents will reflect the potential productivity of a site.

For areas that are similar in terms of biological productivity, soil and terrain, production costs, and markets, the second step is to design alternative management approaches and identify associated costs and revenues. An economic production equivalent value that quantifies the net return of a site for various management approaches was used by Rust and Hanson (1975) to rate crop equivalents of Minnesota soils. The third step involves ranking and comparing alternatives according to one or more management criteria. The final step involves implementing the chosen alternative. These steps are fairly standard in any investment analysis. A complicating factor is the lack of information about the growth of intensively managed forest crops.

Break-even requirements for various sites and available management options must be compared to the yield that is likely on the site for the assumed management intensity (table 7). Yield of natural stands on the site can serve as a conservative estimate of a site's growth potential for comparing with break-even yields, if better growth estimates cannot be obtained for intensive culture regimes. A good clone, however, could produce less than a natural stand if moved out of its optimal environmental conditions, especially if it has a narrow range under which it performs well. Such considerations will be essential in judging the economic feasibility of a management alternative.

Table 7.--*Comparison of required and expected mean annual growth (hypothetical)*
(In dry tons per acre)

Location					
A		B		C	
Required	Expected	Required	Expected	Required	Expected
PRICE--25 DOLLARS PER TON					
4.04	4.0	4.04	4.0	4.75	5.0
5.38	5.0	5.38	5.0	6.08	6.0
5.27	6.5	6.61	6.0	8.31	6.5
5.60	7.5	7.96	7.5	9.66	8.0
PRICE--30 DOLLARS PER TON					
3.37	5.0	3.37	4.0	3.96	5.0
4.48	5.0	4.47	5.0	5.06	6.0
4.39	6.5	5.51	6.0	6.92	6.5
4.67	7.5	6.63	7.5	8.05	8.0

Personal experience, professional consultation, and yield tables of managed and unmanaged stands must be used to obtain point or internal estimates of potential yields and to identify promising and infeasible alternatives. The hypothetical growth estimates in

table 7 are assumed to be the result of such an approach. With this information, location A would have been selected on that basis as a promising site for irrigation and fertilization, but the same management intensity would have been found infeasible on site C or B.

The greater the difference between estimated yields and break-even requirements, the smaller the production risk would be, assuming all yield estimates are equally reliable. The alternative with the smallest risk would not necessarily be the best in terms of other investment criteria, such as present net worth and internal rate of return. The latter can, however, only be calculated if product values, as well as fiber yields, can be estimated. Without such knowledge, a decision must be based on the economic feasibility and risk of an alternative.

If break-even yields for an alternative are higher than known or estimated potential yields, the alternative must be discarded for the area under investigation. Economic feasibility might be achieved by reducing the intensity of intensive culture management, leading to lower break-even requirements. The question then is whether the cost reduction (or break-even yield reduction) more than outweighs the potential reduction in yield. It is through a series of such steps that land management zones or classes can be identified. For each zone, management plans that are economically feasible and infeasible can be stated. Zones will be ranked by their suitability for intensive culture and opportunity for investment.

Because any given cost estimate has a rather large error, zones will share areas of overlap for which the economic feasibility of a management plan is of greater uncertainty. One procedure to quantify further the risk of an investment is, therefore, to change individual costs that show a large degree of variability and/or that are least known, so as to identify the sensitivity of break-even yields to such a change. This procedure is illustrated in table 7 for a price change from $25 per ton to $30 per ton.

SUMMARY AND CONCLUSION

The intensive culture of woody species has created widespread interest because of threats of timber shortages and the demonstrated economic and biological potential of intensively managed species. It is essential to identify the locations best suited for intensive culture and select the management intensity that is best in terms of a selected economic criterion. Because yield information is still limited, break-even analysis was suggested as an initial selection criterion. Because yield information is not used in this measure, it is a less powerful tool than other economic criteria that include yield; e.g., present net worth or internal rate of return. Future research efforts must emphasize growth and stand treatment studies and focus on some of the critical cost factors that were identified.

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UTILIZATION ADVANTAGES OF MATERIAL PRODUCED IN MAXIMUM FIBER YIELD PLANTATIONS

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The usual justification for agronomic systems of fiber production is to greatly increase yields to meet future fiber shortages. However, the material produced should have utilization advantages over typical rough wood chips by having reduced grit and deleterious bark cell contents. Efficient harvesting and processing will be possible because of great uniformity in the material derived from control over genetics, environment, and age. Efficient processing should help overcome low pulp yields and strengths characteristic of juvenile material.

The usual justification for agronomic systems of fiber production is to greatly increase yields to meet future fiber demand. However, agronomic fiber production has many other advantages from a utilization standpoint. This paper deals with those advantages.

The key to these advantages is efficiency. Recently, forest utilization has become more efficient through the adoption of whole tree utilization. Here all aboveground portions of the tree are harvested and used, sometimes doubling yields. This has been accomplished by the development of machinery that chips whole trees at the landing and the utilization of rough wood chips (those containing bark) at the mill. Moreover, under this system harvested areas are cleaner, more esthetically pleasing, and cheaper to regenerate. And trasportation and handling costs are less than for conventional harvesting practices.

However, whole tree chipping has created some new problems, particularly at the mill. Lifespans for equipment are shortened because wear and erosion are accelerated by increased amounts of dirt and grit included with whole-tree, rough wood chips. Grit becomes lodged in the bark from skidding whole trees to the chipper, especially during muddy seasons. More mill equipment, such as washers, screeners, and centricleaners, is needed to remove the increased grit load from pulp furnishes. Bark itself causes problems in pulp furnishes by reducing pulp yield, strength, and cleanliness. Often additional digestor capacity, used liquor recovery capacity, and centricleaners are needed to handle the bark. Nevertheless, the additional yields from whole tree chipping offset mill disadvantages, and when crisis shortages occur, as is already happening in many areas, mills would rather run on less than desirable furnish than not run at all.

Maximum fiber yield systems can reduce or circumvent most of the major mill problems associated with typical rough wood chips and still retain and enhance most of the advantages of whole tree utilization.

Let's examine the grit problem. Wood procurers dream of some huge machine that would travel over the land and cut and chip trees as it moves. An extremely complex and expensive piece of machinery would be needed to handle trees of all sizes over

rough terrain. Also, chip mixtures arriving at the mill would vary with the compositions of the harvested stands. Varying chip mixtures complicates pulping because pulping conditions must be changed to accept them.

Plantations of trees grown in maximum fiber yield systems are ideal for moving harvester-processors. The plantations will be on good sites that are nearly level, precluding problems with rough terrain. Furthermore, the trees will be nearly uniform in size and grown at regular spacings. These factors allow for efficient machine design. Trees less than 3 years old can be harvested with beefed-up forage harvesters, but specialized harvesting equipment will be required as trees grow larger. The new moving harvester-processor may incorporate the helical head chipper developed at the North Central Station's Forest Engineering Laboratory.

Why all the discussion of moving harvester-processors? If trees can be cut and chipped without ever hitting the ground, skidding would be eliminated and hence grit picked up during skidding would no longer be a problem at the mill. Until such machines are developed, grit problems can be reduced by cutting and skidding only when the ground is dry or snow covered.

Other advantages derived from maximum fiber yield plantations and harvester-processors include improved logistics of mill supply and better chip quality. Greater yields in maximum fiber yield plantations require less land to supply a mill. This land could be close to the mill and the harvester-processors would be able to operate nearly all year. Then mill yard inventory can be greatly reduced. When furnish is needed, it can be readily cut and quickly transported. Less mill yard inventory requires less capital and chips will be of higher quality because they have had less time to be degraded by pathogens during storage.

How about problems associated with bark? Bark is an extremely heterogeneous mixture of many cell types and shapes--much more complex than wood. Yet most cells in bark are not extremely detrimental to pulp and paper making. The most troublesome cells are commonly called stone cells, a small fraction of bark, yet their presence has given all bark a bad reputation. Stone cells are blamed for plugging paper machine wires, causing poor drainage and sheet formation. Their presence on paper surfaces can also cause difficulty in sizing, calendering, and printing.

We have found that young material in some clones does not have stone cells. We don't know at what age these clones start forming stone cells. But if clones can be selected that do not form stone cells until after harvest age, then the problem will disappear. Even if selection does not totally eliminate stone cells, young material should have fewer of them than old material because their formation is part of aging.

Although fiber production by maximum yield systems can alleviate the major problems, some new problems, unique to this young material, must be confronted.

One of these problems is bark content. As mentioned earlier we can reduce the deleterious cellular elements found within bark, but total bark content still appears large. Pulp yields and strengths are adversely affected by the predominance of thin-walled cells in bark. Bark comprises 10 percent of conventional pulpwood from many species, but approximately 25 percent of total aerial portions of very young material. The latter figure includes bark on branches and tops as well as on stems while conventional pulpwood figures are only for stem portions.

Bark content can be reduced. As trees become larger, bark contents become proportionately smaller. Growth models of maximum fiber yield plantations indicate an optimum rotation age of 10 to 15 years, and with rapid growth, these trees will be rather large, so the bark percentage should be less than for the small, very young material we have studied. Bark content can also be reduced by plant selection. Anatonical studies of many clones show bark percentage to be variable. Low bark percentage has been a major criterion in our plant selection.

Plant selection will also be extremely helpful in reducing other problems associated with young, rapidly grown material. Reaction wood and branch fiber can cause processing problems. The branch content and incidence of reaction wood appears to be larger in younger trees, and also varies with clones. Again we will make plant selections that diminish these problems. Cultural practices,

such as spacing, can also affect branch content within a clone and spacings will be chosen to achieve the best compromise between branch content and yield.

The major objection to material grown in maximum fiber yield systems is that the wood is juvenile. Juvenile wood characteristically has lower cellulose content and shorter fibers than mature wood, which results in lower pulp yield and strength. However, in our studies we are seeking clones that have anatonical, chemical, and physical characteristics more like those of mature wood.

Yet juvenile wood cannot be all bad--all trees contain some juvenile wood! An eminent forestry researcher made the following analogy in explaining problems with pulping juvenile wood: *you can't cook a steak from an old bull with one from a young bull and expect both to be cooked to a "T".* True. But you can cook each individually, under conditions proper for each, and expect both to be better than when cooked together under compromise conditions.

Within the analogy and rebuttal lie the problem and solution of pulping juvenile wood. Juvenile wood is more "tender" than mature wood. When it is cooked under the severe conditions necessary for mature wood, pulp yield and strength must suffer. Yet when cooked alone, under conditions tailored for it, the pulp yield and strength from juvenile wood should improve.

In the future we will see pulp lines and possibly whole plants run solely on rough, juvenile material. We are now mixing rough wood or juvenile chips with clean chips up to proportions at which acceptable products can still be manufactured using existing equipment. The compromises necessary to handle these mixtures hurt efficiency. When proper equipment and conditions are available to handle a uniform raw material, then efficiency should increase.

The greatest attribute of material produced in maximum fiber yield systems is uniformity. Uniformity is gained by minimizing sources of variation within woody materials: genetics, environment, and age.

In maximum fiber yield plantations, we will be planting only a few clones. By definition, all members of a clone are genetically identical; therefore genetic variation is eliminated. The plantations will be fertilized to ensure ample nutrients. They will also be irrigated to provide all the water needed day after day, week after week, and growing season after growing season. Through fertilization and irrigation, the environment will be modified to make it more constant, thereby reducing this source of variation. The anatomical, chemical, and physical characteristics of a tree vary with age. However, the young trees will be harvested before large within-tree variations due to age show up. In addition, all trees within a plantation will be the same age.

In summary, reduced grit and troublesome bark cells along with great uniformity make material produced in maximum fiber yield systems extremely attractive. Once specific machinery and operating conditions are established for this uniform material, maybe the mill employees can then take an extended coffee break. As the chronic fiber shortage becomes more severe, the medicine we offer to cure this illness will be very palatable, and probably habit forming.

PULP AND PAPER CHARACTERISTICS OF POPULUS HYBRIDS

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Intensively cultured Populus *hybrids show promise as future pulpwood species for the pulp and paper industry in the Lake States. Harvesting and processing will be geared to the concept of whole-tree utilization. Research is underway to evaluate the pulp quality of these hybrid species.* Populus *hybrids will be selected for specific end product uses. Such pulps may have unique properties not available in "naturally" growing hardwoods.*

The use of hardwoods by the pulp and paper industry in the Lake States over the past 25 years has increased tremendously; *Populus* species, primarily quaking aspen (*P. tremuloides*) and bigtooth aspen (*P. grandidentata*), now constitute about 48 percent of the total pulpwood production (Blyth 1975). The demand for paper and board will certainly double, and may triple, by the year 2000 (USDA Forest Service 1973). Serious fiber shortages, however, are predicted to occur as early as 1980. Several paper mills in the Lake States already are having problems procuring pulpwood, especially softwood species. So interest in utilizing hardwood continues to increase.

Whole-tree utilization is one means of increasing and extending the available fiber supply. The harvesting of all aboveground components--tops and branches--in addition to the merchantable bole of northern hardwoods doubles the tonnage obtainable per acre compared with conventional harvesting methods (Keays 1975). Whole-tree utilization, however, is but one part of the solution.

Intensively cultured hybrid *Populus* species seem ideally suited for growing the maximum amount of wood fiber per acre per year in the Lake States (Dawson and Hutchinson 1972). Planting short rotation (10 to 15 years) northern plantations on harvested forest land and marginal agricultural land not only will help meet future fiber demands but will also utilize our natural resources more efficiently.

But will these fibers be suitable for manufacturing the various pulp and paper products on the market today? Basic data on the pulp and paper characteristics of these young, fast-growing hybrids are needed so that hybrid species can be selected, improved genetically, or cultured differently to produce fiber "engineered" for a specific end product use.

HARVESTING OPERATIONS

Whole-tree chipping of these *Populus* plantations appears to be the most efficient harvesting method. Whole-tree chipping, as presently practiced, involves feller bunchers, skidders, and mobile chippers. The development of an off-ground chipping method would eliminate much of the sand and grit entering the chip supply. Chip screening, including perhaps some partial

screening in the woods along with additional screening and washing operations at the mill, would upgrade the quality of chips entering the processing system. Further separation to remove the foliage would permit the production of valuable byproducts such as muka, an animal-feed vitamin supplement, and chemicals for the pharmaceutical, cosmetic, and food industries (Keays and Barton 1975).

PROCESSING OPERATIONS

The young trees of short-rotation plantings contain greater percentages of bark due to the higher proportion of tops, branches, and twigs. The bark adheres strongly to these small-diameter components and is difficult to separate from the wood. In the kraft pulping process it is possible to pulp (cook) the bark along with the wood in order to utilize the long-fiber components of the bark. However, the presence of the bark, tops, and branches (and juvenile wood) leads to reduced pulp yields, higher black liquor solids, and greater consumption of pulping chemicals (Wawer 1975). Any decrease in the pulp yield, however, will be more than offset by the increased fiber yield gained from the forest land. Burning the bark, along with the other wood constituents and inorganic pulping chemicals in the black liquor, allows some energy recovery from this resource. If the pulp is bleached, slightly lower yields and somewhat greater consumption of bleaching chemicals also are expected (Ringley 1975). Other pulping processes, such as mechanical pulping, may require bark-chip separation by one of the many methods under development (Fuller 1974).

Existing or future mills should have sufficient digester, recovery boiler, and bleach plant capacity to process these whole-tree chips. But if it does not take as long to cook this juvenile material, pulpmill productivity may be maintained with the existing digester capacity. There have been some reports of effluent problems associated with the use of whole-tree chips. Closed-cycle kraft mills (Rapson 1967), which eliminate external effluent treatments, are one approach to such problems.

PULP QUALITY

Juvenile wood is generally believed to result in weaker pulps. As such, will our young, rapidly grown trees present a problem? We do not believe so because kraft pulp prepared from young (6 year) *Populus* species has been reported to be as strong as that from more mature trees (Hunt and Keays 1973b). Furthermore, the strength properties of some short rotation (10 years) *Populus hybrids* appear to be even superior to those of the mature *Populus* species found in our forests (Einspahr *et al.* 1970). Even though whole-tree chips may contain bark, tops, and branch-wood, which reduce the strength of pulps (Hunt and Keays 1973a), it is not unreasonable to expect that some *Populus* hybrids will produce kraft pulps having competitive (or even superior) strength properties.

PROGRESS TO DATE

The specific objectives of the study underway in our laboratory are (1) to evaluate the potential of the juvenile wood, both with and without bark, from intensively cultured hybrid *Populus* species for use in the manufacture of fine papers and newsprint by the kraft and refiner-mechanical pulping processes, and (2) to determine those changes in the processing variables necessary for producing acceptable fiber products. Unfortunately, the amount of hybrid material available for pulping studies is limited. So, mature quaking aspen is being used not only as a control against which to compare the pulp and paper characteristics of the *Populus* hybrids but also for perfecting techniques and for preliminary pulping studies.

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"AGRICULTURAL" POPLARS AS A RAW MATERIAL FOR STRUCTURAL PARTICLEBOARD

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The bulk harvesting and handling methods associated with agriculture-grown wood may make this raw material an economic reality to the reconstituted board and fiber industries. Research indicates the technical feasibility of using 5- and 6-year-old Populus *hybrids in structural particleboard. With the exception of internal bond retention following an accelerated aging treatment, physical properties were acceptable. Limited data suggest that board properties do respond to changes in anatomical aspects of the raw material.*

By definition, "agriculture wood" can be machine harvested in bulk form using methods similar to those employed in today's typical farming. This differs from the mechanical methods presently used to harvest pulpwood either in natural or plantation stands of timber. The bulk handling of wood chips, flakes, or fiber is of primary economic importance in agriculture-grown wood, and the harvesting machine capabilities well may set the upper limit of the cutting cycle.

Economical production of particleboard has traditionally demanded inexpensive wood as a raw material. In competition with plywood, the higher resin consumption required for particleboard has been offset by cheaper wood and greater manufacuring automation. The relative economic importance of cheap wood can be appreciated by reviewing the history of two particleboard mills here in the Lake States. Both mills, one in Wisconsin and the other in Michigan, were originally designed to use roundwood as a primary source of raw material. Both plants have revised their operations to utilize residues from area mills and now include "whole tree" chipped material in their product.

The utilization of chips has not been without problems. Compromises in homogeneity of furnish, manufacturing methods, and final board properties have been made to take advantage of the cheaper raw material. Although the use of agriculture-grown wood for particleboard has several advantages over wood from natural stands, depending on the final product manufactured, the issue governing the use of such wood for particleboard will be cost.

A specific advantage of agriculture-grown wood over "whole tree" chips is the lower percentage of dirt. Initial particleboard production cost as well as remanufacturing cost is reduced as the silica content decreases. An additional advantage of agriculture-grown wood is that its ready availability would permit carrying a lower "in yard" inventory.

A disadvantage is the high percentage of bark, which normally impairs board physical properties and causes severe finishing problems because of local thickness swelling differentials.

To be economical the bark should be left in the product, so our research was directed towards utilizing the material in a structural board where appearance was not of primary concern. The program dovetailed nicely into our current work on producing structural board from forest residue. A method is being developed to produce "structural" flake material from chips. This involves using fingerling-type chips in a ring-type flaker. The outer drum of a ring flaker contains a series of knives that cut the flakes from chips, which are forced into the knives by a center impeller. Fingerling chips, because of their shape, tend to align themselves with the wood grain parallel to the knives, allowing the production of long flakes with a minimum of fines.

Several machines have been invented or modified to produce fingerlings. Of specific interest is a helical, screw-type shear developed at the North Central Forest Experiment Station's Forest Engineering Laboratory in Houghton, Michigan. This chipper proved to be ideally suited for making fingerlings from 5- and 6-year-old hybrid poplar clones. To gleam the maximum information from the limited supply of material, our research was directed at making several board types with little replication. So, reliability of the data is somewhat questionable.

As mentioned previously, bark generally degrades board properties, especially when used in quantities in excess of 10 percent. Reduction in average fiber length and an increase in adhesive-consuming fines are the major contributing factors. Boards made from 4- to 5-year-old hybrid poplar clones, however, had very good physical properties. Although this material contained 30 percent bark, the fines content of the furnish (that portion passing a 1/32-inch screen) was 5 to 20 percent. The juvenile bark has longer fibers than juvenile wood and therefore may contribute some to the strength of the board.

Boards made from material from which the buds and small twigs were removed had only slightly better physical properties than those boards containing all of the aboveground material except leaves. Elimination of fines (-1/32-inch screen) increased bending properties and internal bond by about 9 percent.

Planting spacing did affect board properties. The 9- by 9- and 12- by 12-inch spaced trees were combined and produced boards 9 percent stiffer and 14 percent stronger in bending than boards made from 24- by 24-inch spaced trees. This comparison was made on the 5261 "Northwest" material only, but did hold true in six different combinations of 4- and 5-year-old material. The superior properties of the closer-spaced material may be attributed to longer fibers.

Because of the replication limitations, it is difficult to accurately determine the effect of age difference on the boards made with 4- and 5-year material. Bending stiffness increased an average of 23 percent and strength an average of 14 percent with the 1 year's growth. However, these gains averaged only 7 percent in boards having the fines removed. The analysis is complicated by the fact that the 4-year-old material had 5 percent fines and the 5-year-old had 15 to 20 percent fines. Removing more fines may have increased the wood-to-bark ratio, which in turn increased strength. Analysis is further complicated by an interaction between plant spacing, removal of fines, and age.

Lineal expansion in 50 to 90 percent relative humidity averaged 0.12 percent while thickness swell was 10.8 percent. The lineal expansion is well within the 0.25 percent allowed by commercial standard 236-66 for higher grade, medium density exterior (type 2B2) particleboard. Retention of properties following accelerated aging tests was better for the 5-year-old group, averaging 71 percent for modulus of elasticity and 100 percent for modulus of rupture based on thickness before test. Springback was high and specific gravity retention averaged 72 percent. Retention of internal bond following accelerated aging was therefore low and is attributed to the high percentage of bark and/or juvenile wood. This property, as expected, responded positively to an increase of resin content.

With the exception of three boards made from 5-year-old *Tristis* 5260, all boards have been made from *Populus Northwest* 5261. We are currently testing boards made from the hybrids, *Northwest* 5261, *Tristis* 5260, *Cranden* 5339, *Populus* spp. 5351, and the *deltoides* clone 5273. Boards are being made to evaluate differences among species in specific gravity, bark versus no bark, flake thickness,

and other factors, including flake alignment pertinent to development of a structural board.

The limited research done so far illustrates the technical feasibility of producing structural particleboard from agriculture-grown *Populus*, and indicates that board properties are responsive to changes in anatomical differences in the raw material. Use of this potential source of fiber for the reconstituted board industry will ultimately depend on the economic environment.

PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

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1976. Intensive plantation culture: five years research. USDA For. Serv. Gen. Tech. Rep. NC-21, 117 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

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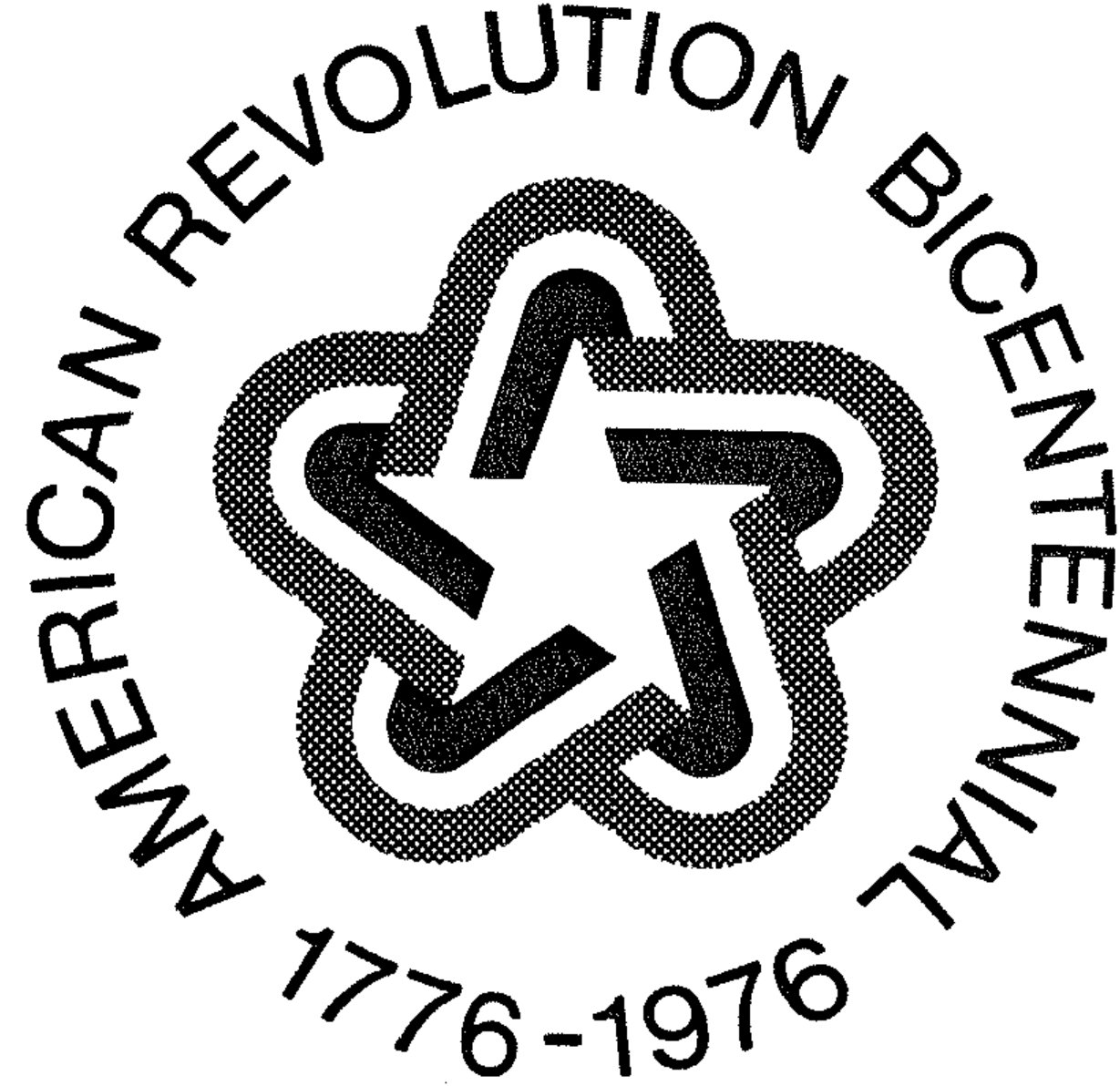
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