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WOODY-BIOMASS PRODUCTION IN MICHIGAN: SPECIES, GENOTYPE, AND CULTURAL INVESTIGATIONS

Michigan State University

PH.D. 1984

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WOODY-BIOMASS PRODUCTION IN MICHIGAN: SPECIES, GENOTYPE, AND CULTURAL INVESTIGATIONS

By

Raymond Oyen Miller

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Forestry

1984

ABSTRACT

WOODY-BIOMASS PRODUCTION IN MICHIGAN:
SPECIES, GENOTYPE, AND CULTURAL INVESTIGATIONS

By

Raymond Oyen Miller

A stepwise approach was adopted in 1978 for developing a comprehensive woody-biomass production system for Michigan. The program consisted of four phases: 1. Identification of the most promising biomass species through trial plantings on abandoned agricultural fields and cleared forest stands, 2. Preliminary yield comparisons of several species growing in existing experimental plantations, 3. Species improvement using standard tree improvement techniques, and 4. Development of cultural techniques designed to optimize woody-biomass yield from energy plantations. This dissertation summarizes results of research in each of these areas.

Species recommendations for each of three climatic zones in Michigan are based on survival and growth of 23 species at nine old-field sites after four growing seasons. *Pinus sylvestris*, *P. banksiana*, *P. resinosa*, *P. nigra* x *P. densiflora*, *Larix leptolepis*, *Alnus glutinosa*, and *Picea abies* are recommended for use in the Upper Peninsula; *Pinus sylvestris*, *P. resinosa*, *P. nigra* x *P. densiflora*, *Larix leptolepis*, *Alnus glutinosa*, *Picea abies*, and *Quercus robur* are recommended for use in the northern Lower Peninsula; and *Pinus sylvestris*, *Alnus glutinosa*, *Larix leptolepis*, *Populus*,

Quercus robur, Fraxinus pennsylvanica, and Salix are recommended for use in the southern Lower Peninsula of Michigan.

Yield predictor equations were developed and yields analyzed for 13 species. The best yielding species in the older plantations (14- to 16-years old) were Pinus nigra x P. densiflora and Betula alleghaniensis. The best species in the group of younger plantations (five- to nine-years old) were a Populus hybrid mixture and Ailanthus altissima.

Seven provenance tests and one clonal test were evaluated to develop preliminary seed-source and clone recommendations for Acer rubrum, Betula alleghaniensis, B. papyrifera, Fraxinus americana, F. pennsylvanica, Juglans nigra, Larix laricina, and Populus hybrids. Test plantation ages corresponded to the rotation lengths of short-rotation, biomass plantations. Gains in single-tree, oven-dry biomass yield of selected over "local" sources can be as high as 37 percent with proper provenance selection. Yield losses due to improper provenance selection can be as much as 48 percent of "local" source yield.

To the memory of my brother

Erling John Miller

(1957-1978)

ACKNOWLEDGMENTS

The author thanks the members of the Guidance Committee--Drs. J. Hanover (Chairman), D. Dickmann, C. Ramm, and J. Flore--for their assistance during the course of this study.

Thanks are also due to those who assisted in the collection of data and in the editing of this work--G. Howe, A. Anderson, and M. Brady.

Special thanks are due to my family, and especially my wife Dorothy, for their patience and support during the years of this project.

Financial support for this study was provided by the Oak Ridge National Laboratory and the United States Department of Energy under subcontract number 9053.

TABLE OF CONTENTS

Chapter | Page

LIST OF TABLES

Table | Page

LIST OF FIGURES

CHAPTER 1

Woody-Biomass Production for Energy in Michigan

INTRODUCTION

The most predictable aspect of the world energy situation is that sometime early in the next century, the finite reserves of fossil fuels will inevitably shrink to insignificance (Pollard, 1976). One strategy for alleviating the repercussions of this profound development is the replacement of fossil fuels with non-fossil, non-nuclear energy sources. Several such alternatives are now available; solar, geothermal, hydroelectric, wind, and biomass. All these sources are not only renewable but are also clean from the pollution standpoint and do not disrupt the temperature-regulating carbon dioxide balance in the earth's atmosphere, as does the burning of fossil fuels.

All five of the alternate energy sources mentioned above can be used to generate electricity and/or heat, but only biomass offers the additional benefit of being an alternate carbon compound source. This fact makes biomass an extremely attractive substitute for fossil fuels in a society such as ours, which is heavily dependent on synthetic polymer products, liquid petroleum derivatives, and gaseous fuels.

Biomass, as wood fiber, contributes more than any other non-fossil fuel to the global energy budget (Deudney and Flavin, 1983). In the United States, wood energy, as firewood and mill and logging residues, currently provides two to three percent of the total energy consumption, or 1.5 to 2.4 quads[1/] (Waldrop, 1981; Yarosh, 1983). This is roughly equivalent to the energy provided from nuclear fuels.

The production of woody-biomass in "energy plantations", to supplement the more conventional production techniques now being used, has been investigated across the country since the early 1970s. Research scale plantations have been yielding an average of 5 to 9 OD $Mg \cdot ha^{-1} \cdot yr^{-1}$ [2/]. It has been estimated that the use of genetically improved materials and improved cultural practices in these plantations will ultimately result in average yields of 15 to 20 OD $Mg \cdot ha^{-1} \cdot yr^{-1}$, by the year 2030 (Cannell and Smith, 1980; Van Hook and Ranney, 1983). If "energy plantation" grown materials are combined with current supplies of woody-biomass, it may be possible for wood to contribute 8 to 15 quads, or 8 to 15 percent, of the United State's energy requirements, by the year 2030.

The state of Michigan is richly endowed with biomass and a potential for vastly increasing its production, particularly in "energy plantations." This paper will use Michigan as an example of how woody-biomass production is currently used for energy, and as a case study of the contribution of "energy plantations" to future energy production.

1/Quadrillion British Thermal Units.
2/Oven-dry Megagrams (Metric tonnes) per hectare-year.

WOOD USE IN MICHIGAN

Fifty-three percent of Michigan's land area, or about 7.8 million hectares, is forested. 7.0 million hectares are classified as commercial forest land. Because of this large forest area, there is currently an excess supply of wood in the state, and in fact Michigan is a net wood exporter (Blyth and Smith, 1980; Vodak, et al. 1981).

The timber industry in Michigan is primarily composed of seven major fiber and paper companies, and about 300 small and medium-sized sawmills (Zollner, 1980). The home firewood market accounts for a major portion of the lower quality hardwood sales, and in some portions of the state is in direct competition with pulpwood buyers. Finally, there are several new wood-electrical generating plants completed or under construction, which will also create a substantial demand for wood in this state.

At present, the demand for wood in Michigan has not exceeded the supply, except in isolated areas. This condition is not likely to persist as more woody-biomass energy production systems are introduced into the state, and as traditional forest product industries expand production. Some paper manufacturers guard against this type of supply shortage by establishing fiber plantations near their mills. From this standpoint alone, it is only logical that biomass-energy producers should do the same.

THE ADVANTAGES OF "ENERGY PLANTATIONS"

Woody-biomass presents many advantages over current energy systems: it is low in sulfur and heavy metals so it burns cleanly, it has a much smaller impact on the carbon dioxide balance in the atmosphere, it presents no hazardous waste disposal problems, it is compatible with current furnace and handling system designs, and it is renewable. Woody-biomass can be produced on sites which are unsuitable for conventional agriculture, and can be grown to ameliorate existing pollution problems.

"Energy plantations" offer the additional benefits of providing constant, reliable sources of woody-biomass with controlled physical and chemical characteristics. Plantations can be located close to the energy producer, and be managed intensively to improve the productivity of each hectare. Productivity can be optimized through the proper selection of species and genotypes for each site, and by management practices specifically designed for short, high-yielding rotations. This fact is clearly demonstrated by comparing the average productivity of commercial forest land in Michigan of 1.1 OD $Mg \cdot ha^{-1} \cdot yr^{-1}$ at age 50 (Hahn, 1982) to that obtained in research plantations of a hybrid pine at Michigan State University of about 8 OD $Mg \cdot ha^{-1} \cdot yr^{-1}$ at age 16 (Chapter 4). These high yields were obtained with cultural techniques which provided for weed control but did not use extraordinary measures such as fertilization or irrigation.

"Energy plantations" offer the only reasonable way of incorporating improved genetic materials into the available growing stock. The importance of tree improvement in the production of woody-biomass has been demonstrated repeatedly. Studies at Michigan State University have demonstrated gains of 8 to 37 percent over local seedlot yields through provenance selection (Chapter 6). Additional gains can be obtained from continued breeding programs of the more promising species.

ENVIRONMENTAL CONCERNS WITH "ENERGY PLANTATIONS"

In 1979, the United States Department of Energy assessed the environmental impacts of wood-energy. The report lists five areas of environmental concerns:

1. air pollution from particulates, hydrocarbons, and carbon monoxide emissions.
2. residential fires caused by wood stoves.
3. soil erosion and stream sedimentation from increased harvesting.
4. nutrient depletion due to increased organic matter removal.
5. ecosystem impacts associated with extensive forest harvesting.

The list of possible problems has been expanded by Pimentel, et al. in 1984 to include:

6. Wildlife habitat conversion.

7. Reduced diversity of the plant communities through monoculture and the resultant increase in pest epidemics.

8. Various economic impacts which would result from the removal of cropland from agricultural production.

The importance of the problems described above cannot be overemphasized. Protection of the forest ecosystem is of paramount importance if silviculture is to avoid the problems with which American agriculture is now faced; namely chronic resource depletion. The social and economic demands of a pluralistic society such as ours must also be considered. Past experience has shown that these needs can have a stronger impact on public policy than a body of scientific evidence. Foresters and researchers working with woody-biomass production systems must consider the implications of their actions in a broad context. It must be emphasized, however, that none of these problems are insurmountable. Prudent application of available technologies, coupled with research and education programs, will help reduce negative impacts. When the positive contributions of energy from woody-biomass are considered fully, they most certainly outweigh the negative.

PRODUCTION SYSTEMS FOR MICHIGAN

Research conducted at Michigan State University and elsewhere in the Lake States has provided the groundwork for short-rotation "energy plantation" establishment. Species have been identified for various regions of the state, inventory techniques have been developed, yields have been projected for some species at various spacings, and tree improvement programs have begun for many species. This dissertation will present the results of a major portion of the woody-biomass research which was conducted at Michigan State University over the last six years.

The research program was structured to: first, identify the better species for biomass production in Michigan; second, to screen large numbers of families of these superior species in large provenance/progeny tests; third, to identify the genotypes which respond well to short-rotation culture from among the better families in the provenance/progeny tests; and fourth, to provide demonstration plantings to encourage the application of research findings. This approach is recommended in other states as a comprehensive way of developing "energy plantation" systems. The urge to take short-cuts at various stages is strong, but incorrect decisions, based on incomplete information, can postpone the day when successful commercial "energy plantations" are the norm rather than just a theory.

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CHAPTER 2

Short-rotation, Biomass-species Screening on Old-field Sites in Michigan; Four-year Results

ABSTRACT

Twenty-three species were tested on nine, abandoned, agricultural fields throughout the state of Michigan to determine which were best suited to maximum woody-biomass production. Planting recommendations for each of three climatic zones in Michigan were made based on survival and growth after four growing seasons. *Pinus sylvestris*, *P. banksiana*, *P. resinosa*, *P. nigra* x *P. densiflora*, *Larix leptolepis*, *Alnus glutinosa*, and *Picea abies* are recommended for use in the Upper Peninsula; *Pinus sylvestris*, *P. resinosa*, *P. nigra* x *P. densiflora*, *Larix leptolepis*, *Alnus glutinosa*, *Picea abies*, and *Quercus robur* are recommended for use in the northern Lower Peninsula; and *Pinus sylvestris*, *Alnus glutinosa*, *Larix leptolepis*, *Populus*, *Quercus robur*, *Fraxinus pennsylvanica*, and *Salix* are recommended for use in the southern Lower Peninsula of Michigan.

INTRODUCTION

Rising costs of petroleum and increasing concern about the environmental effects of nuclear and fossil fuels have prompted a search for alternate sources of energy. Woody-biomass is one of several alternatives which has been under development as a replacement for solid, liquid, and gaseous fossil fuels (Kelsey and Shafizadeh, 1979; Inman, 1977).

Biomass used in each of these processes must meet certain chemical, structural, and economic criteria which are often dependent on the species and genotypes used and the conditions under which it is grown.

The characteristics of woody-biomass can be best controlled when trees are grown in plantations. The use of plantation culture allows the forester to control species composition and genetic make-up of the stand more closely than other regeneration systems. In addition, plantation management can improve yields, thus reducing the overall land base required to produce a fixed amount of biomass (Inman, 1977). The concept of producing pulpwood on short rotations using intensive management practices was first proposed eighteen years ago (McAlpine, et al. 1966). Since then, this type of management has been applied to the production of biomass-energy (Einspahr, 1972; Inman, 1977; Schreiner,1970).

This project was designed to provide a preliminary assessment several promising species for short-rotation "energy-plantations" on abandoned agricultural fields (old-fields). Old-fields were chosen because they are well suited to mechanized planting and maintenance practices, and because this type of land is common throughout the state.

MATERIALS AND METHODS

Nine, old-field planting sites were chosen throughout Michigan to represent a range of climates and soil types. The sites were grouped into zones of similar climatic conditions. The Upper Peninsula (U.P.) was designated Zone 1, the northern half of the Lower Peninsula (northern L.P.), was designated Zone 2, and the southern half of the Lower Peninsula (southern L.P.) was designated Zone 3. A summary of the characteristics of the sites within each zone appears in Table 2.1. In general, the shortest growing seasons and coldest average temperatures are found in the U.P. Growing seasons are longer and the temperatures are warmer at the more southerly latitudes. Soil texture varies within each zone.

Species were selected for testing on the basis of their growth habits and site requirements (Dickmann, 1975; Vail, 1979). Containerized seedlings were grown in Michigan State University greenhouses, following procedures developed by Hanover, et al. (1976). All species could not be tested at each site, but each species was planted in at least one plantation in each zone. The 23 species tested are listed in Table 2.2.

Sites were cleared of brush and debris, and strips were sprayed with Amitrol-T herbicide. Nine species were planted in the spring of 1979 (Table 2.2), and the remaining fourteen were planted in the spring of 1980. A sub-soiling, tree

Table 2.1. A summary of characteristics of the nine old-field sites chosen for species trial plantations in Michigan.

Nearest Town	North latitude (degrees.minutes)	West longitude (degrees.minutes)	Soil texture class 1/	Frost free days 2/	Mean annual temp. 3/
ZONE 1 (Upper Peninsula)					
Matchwood	46.35	89.25	Clay	120 days	40°F
Chatham	46.20	86.55	Sandy loam	100	42
Rexton	46.10	85.15	Sandy loam	120	41
Oak Ridge	46.20	84.10	Clay	140	41
ZONE 2 (northern Lower Peninsula)					
Wellston	44.10	86.00	Sand	140	45
Tawas City	44.15	83.35	Sandy clay loam	120	45
ZONE 3 (southern Lower Peninsula)					
Six Lakes	43.30	85.10	Loamy sand	140	47
East Lansing	42.30	84.30	Sandy clay loam	150	48
Augusta	42.25	85.20	Sandy loam	160	49

1/ - Texture analysis performed by Michigan State University Soil Testing Service.
2/ - Hill and Mawby, 1954.
3/ - From: Mean Temperature Maps, 1975.

Table 2.2. Species included in old-field, biomass production trials.

COMMON NAME	LATIN NAME
Norway maple*	*Acer platanoides* L.
Ailanthus	*Ailanthus altissima* (Mill.) Swingle
European alder	*Alnus glutinosa* (L.) Gaertn.
Green ash*	*Fraxinus pennsylvanica* Marsh.
European white birch	*Betula pendula* Roth.
Honeylocust	*Gleditsia triacanthos* L.
European larch*	*Larix decidua* Mill.
Japanese larch	*Larix leptolepis* (Sieb. & Zucc.) Gord.
Siberian Larch	*Larix siberica* Lebed.
Norway spruce	*Picea abies* (L.) Karst.
White spruce*	*Picea glauca* (Moench.) Voss.
Jack pine	*Pinus banksiana* Lamb.
Kellogg hybrid pine	*Pinus nigra* Arnold. x *Pinus densiflora* Sieb. & Zucc.
Red pine	*Pinus resinosa* Ait.
Eastern white pine	*Pinus strobus* L.
Scotch pine	*Pinus sylvestris* L.
Sycamore	*Platanus occidentalis* L.
Hybrid poplar	*Populus*
Bigtooth aspen*	*Populus grandidentata* Michx.
Trembling aspen*	*Populus tremuloides* Michx.
English oak	*Quercus robur* L.
Black locust*	*Robinia pseudoacacia* L.
Willow	*Salix*

* - These species were planted in the spring of 1979.
(all others were planted in the spring of 1980)

planter was used to establish the trees except at site number four where the trees were hand-planted. Trees were planted on two-meter square spacings in a randomized block design. Each plantation comprised four blocks of 23, single-species, 20-tree, rectangular plots. Post-planting weed control was accomplished by mowing between plantation rows and spraying within rows with simazine (Princep) and glyphosate (Roundup). Heights of all trees were measured (to the nearest 5 cm) and survival was recorded in the fall of 1982.

Height means were computed for all plots at each site. An analysis of variance in height growth was performed for each zone to test for differences among species and plantations. Plot mean heights were expressed as a percent of the block mean to eliminate block effects, and these adjusted heights were averaged for each plantation within a zone, then ranked to identify the species which grew best.

Plot survival was also averaged for each species within each zone. The Kruskal-Wallis non-parametric one-way analysis of variance (Steel and Torrie, 1960) was used to test for significant differences in survival among species within each zone.

In most cases, the trees in this study were too small to be considered mature for biomass production, so it was necessary to derive an estimate of productivity. Productivity is a function of survival and growth, so plot survival (in percent) times average plot height (expressed as a percent of the block mean) was computed to approximate the way each species might respond in a production plantation situation. The seven best species (top 30%) in each zone, were selected based on this "index of productivity." Changes in species ranking within each zone were noted and trends identified.

RESULTS AND DISCUSSION

Significant differences in height were found among species within each zone (Table 2.3). Significant differences in survival were also found among species within each zone (Table 2.4). A summary of average height and survival for the best seven species and the best single species in each zone is presented in Table 2.5. The performance of the single best hardwood and conifer plot is also presented for each zone. Average heights and survivals in the U.P. and northern L.P. are low (58 - 73cm height and 58 - 88% survival) but there are examples of plots which performed much better (133cm height and 100% survival). Average height growth was generally better in the southern L.P. (144 - 194cm) with individual plots growing as much as 384cm. Most species were more difficult to establish successfully in the U.P. and northern L.P. than in the southern L.P.

These investigations have identified species groups for use in the various climatic zones of Michigan. Recommendations within each zone can only be made in a general way, due to limitations of the experimental design. The seven best species in each zone, based on the "index of

Table 2.3. Analysis of variance for height growth of biomass species in three climatic zones in Michigan after 4 growing seasons.

Source of variation	Degrees of freedom	Mean square (cm)	F ratio
	Zone 1. (Upper peninsula)		
Plantation	3	4986	
Species	16	5416	4.42**
Block (plantation)	12	1832	
Species x plantation	48	1224	6.41**
Error	168	191	
Total	247		
	Zone 2. (northern Lower Peninsula)		
Plantation	1	1169	
Species	18	2874	9.39**
Block (plantation)	6	2224	
Species x plantation	18	306	3.29**
Error	83	93	
Total	126		
	Zone 3. (southern Lower Peninsula)		
Plantation	2	22780	
Species	16	26574	11.93**
Block (plantation)	9	2642	
Species x plantation	32	2228	3.53**
Error	139	631	
Total	198		

** - significance at the 0.01 level of probability.

Table 2.4. Kruskal-Wallis one-way test for differences in survival among species in each of three climatic zones in Michigan.

ZONE	NO. of CASES	CHI SQUARE VALUE
1	352	190.246**
2	180	126.749**
3	227	152.656**

** - significant at the 0.01 level of probability.

Table 2.5. Average height and survival for the best seven species and the best single species, and the best hardwood and conifer plot in each climatic zone in Michigan after 4 growing seasons.

Zone[1/]	Average zone height and survival for the best seven species		single species		Best single plot height and survival for conifers		hardwoods	
	cm	%	cm	%	cm	%	cm	%
1	61	59	71	76	92	100	133	100
2	58	58	73	88	105	100	131	45
3	144	81	194	87	213	95	384	90

1/ Zone 1 = Upper Peninsula of Michigan
Zone 2 = northern Lower Peninsula of Michigan
Zone 3 = southern Lower Peninsula of Michigan

productivity", are listed in Table 2.6. In general, conifers were the better performing species in both the U.P. and the northern L.P. while hardwoods such as hybrid poplar, green ash, and willow only ranked well in the southern L.P. plantations.

The analysis of variance showed significant species x plantation interaction within each zone (Table 2.3). This implies a degree of site specificity within the larger "zones" for some of the selected species.

Scotch pine and jack pine ranked highly throughout the U.P. The other five species which performed well in the U.P. (Table 2.6) do show some site specificity, but there seem to be no patterns which can be linked to the measured site characteristics (Table 2.1).

Scotch pine also ranked highly on both sites in the northern L.P. Jack pine, Kellogg hybrid pine, and English oak outperformed the other species on the sandy, droughty site in this zone. These species did not perform as well as Japanese larch and European alder on the other site in the zone, which had heavier and more poorly drained soils. These results are in keeping with expectations based on the silvical characteristics of the species; pines and oaks are better able to compete on dry sites while alders and larches can better compete on moist sites.

European alder, Japanese larch and English oak performed well on all three sites in the southern L.P. Scotch pine only performed well in relation to the others on the sandier

Table 2.6. Best performing species in old-field screening trials in Michigan, showing superior traits of each species.

Species	Zone 1/	Species had Superior Performance in:	
		growth	survival
Scotch pine	1,2,3	X	X
Red pine	1		X
Jack pine	1,2	X	
Kellogg hybrid pine	1,2		X
Japanese larch	1,2,3	X	
Norway spruce	1,2		X
European alder	1,2,3	X	
English oak	2,3		X
Green ash	3		X
Hybrid poplar	3	X	
Willow	3	X	

1/ Zone 1 is the Upper Peninsula, Zone 2 is the northern Lower Peninsula, and Zone 3 is the southern Lower Peninsula of Michigan.

site in the zone. It would seem that the pines cannot outproduce the hardwoods and larches, in terms of survival and early height growth, on the more fertile areas of the southern L.P. Hybrid poplar, ailanthus, and green ash ranked best in relation to other species on the most southerly and more fertile sites, but do not perform as well on the coarse textured soils in the northern part of the zone. Honeylocust only ranked highly on the most southerly site where temperatures were warm and the growing season was longest. This is probably because honeylocust continues to grow until the terminal bud is killed by frost, and the longer growing seasons in the south allow more growth.

The species x site interactions described above are the only ones which can be clearly identified from this test. It will be necessary in future investigations to increase the number of sites on which tests are located to obtain a better cross section of the types of sites available for biomass plantations in Michigan. This test has provided a preliminary screening of many species. Subsequent testing could be restricted to the better species identified here.

This investigation, and others like it, contain several sources of experimental error. Most often these errors arise because of the large size of the test, but in some cases are due to unforeseen or uncontrollable complications. The following problems were thought to have affected this investigation:

1. Seedlings of some species were smaller than others

as a result of an attempt to grow and plant all species simultaneously. This affects seedling survival and early growth.

2. Conditions of planting and weed control varied among sites. The tree planter which was used to establish these plantations has since been deemed unsuitable for most sites in Michigan. Also the weed control applied to these plantations may have been insufficient for some of the more sensitive species.

3. Animal damage to seedlings such as deer browsing and mouse girdling varied among sites and was severe in some cases. This type of damage was generally sustained on hardwood species.

4. Planting times, and therefore weather conditions, were different for each site.

5. The seedlings which were planted were grown in greenhouses under accelerated growth conditions and may have responded differently than nursery-grown stock. In addition, seedling health varied among species and sites, to a certain extent.

All these factors tend to increase experimental error which, in turn, reduces the discriminatory ability of the tests and may adversely affect the evaluation of species performance.

High survival and fast growth are traits which all biomass species should possess. Only those species exhibiting both of these traits should be selected. The experimental error mentioned above may have caused a reduction in survival or growth for some species. Consequently, it is not possible to determine whether moderate survival or growth rate in this test is due to experimental error or inherent species characteristics. Rather than eliminate species which may have survived and grown poorly because of poor test conditions (Type II error), it was decided to include borderline species for subsequent testing and risk Type I error. Figure 2.1 shows growth strategies which were observed in this study; note that average survival may be offset by faster growth and slower growth may be offset by high survival, each resulting in superior production.

Species which exhibited average survival (such as Japanese larch) or slower growth (such as red pine) were identified among those with superior "index of productivities" and marked for further investigation. Jack pine, for example, grew well in the U.P. but had only moderate survival. This species usually survives well when planted in these areas and one is led to suspect that the depression in survival is a result of experimental error rather than inherent species characteristics. Therefore, future investigations of jack pine should concentrate on improving survival.

Future tests should concentrate on the species identified by these preliminary studies (Table 2.6). Alternate cultural techniques (especially weed control),

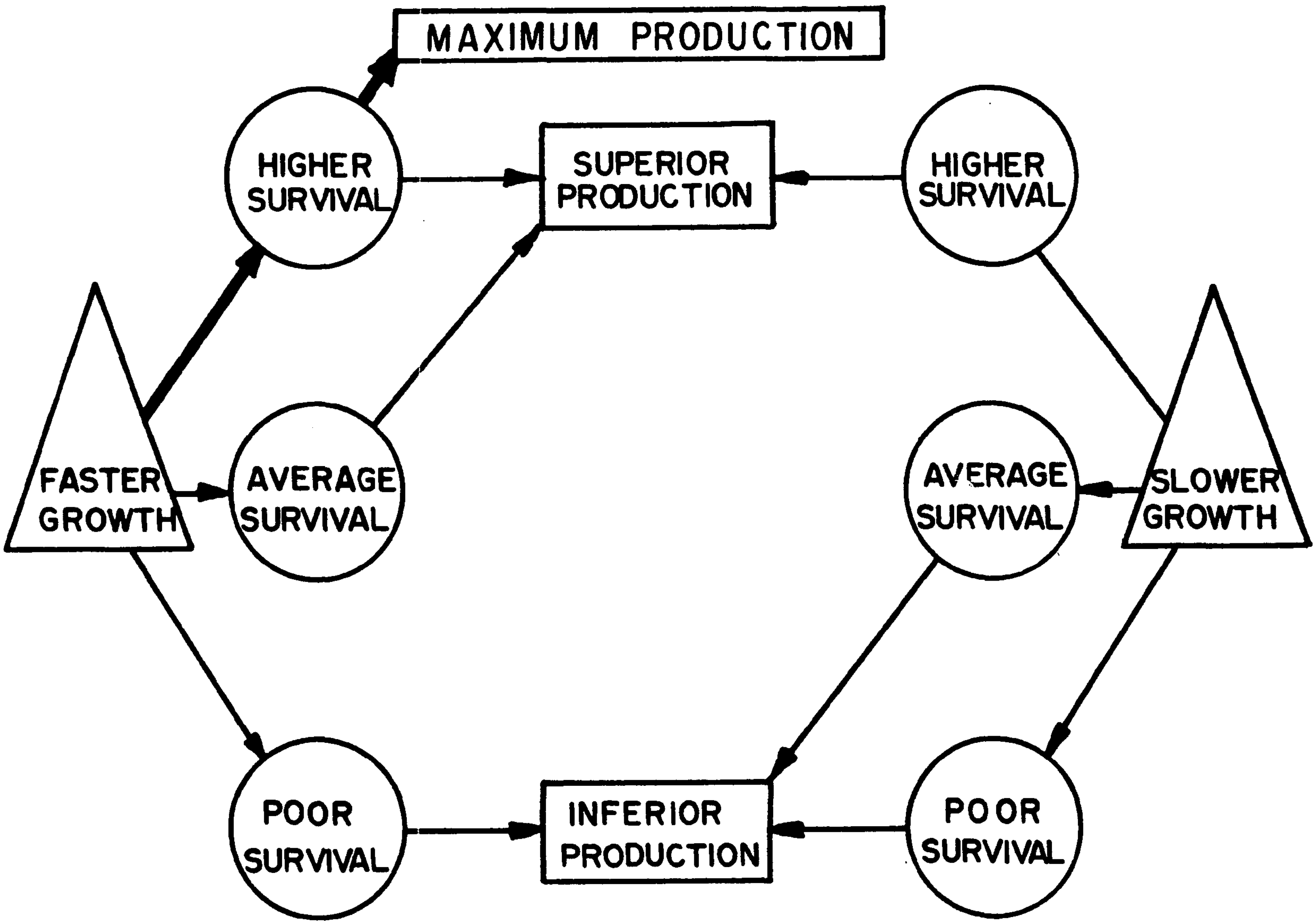

Figure 2.1. Biomass production strategies.

seedling production, handling, and planting methods should be investigated. Genotype evaluation should be carried out for all species identified as superior producers in these tests to identify the best varieties for biomass production.

The genetic base for the species in this test was limited. Most species were represented by a small number of families; sometimes by only one family. This occurred because of time constraints imposed at the outset of the study, brought on by the need to grow all 23 species simultaneously. The effect of this narrow genetic base can be most clearly observed in black locust. The survival of this species was poor throughout the test, but in the southern L.P. black locust was among the top three species in height growth. This indicates that the family of black locust used in this test was difficult to establish but was an exceptional grower. Tree improvement efforts are currently being directed to improve the survival, growth, and cold hardiness of black locust in Michigan plantations.

Tree improvement programs can lead to faster growing and better surviving varieties of all species in this study. In most cases, these efforts are already under way in the Forestry Department of Michigan State University. This area of research promises to produce substantial gains for all biomass species.

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CHAPTER 3

Biomass Predictor Equations for Eleven Short-rotation Biomass Species Growing in Southern Michigan Plantations.

ABSTRACT

Non-destructive, single-tree, above-ground, biomass yield predictor equations were developed to facilitate yield estimates and comparisons among, and within species growing in short-rotation energy plantations in southern Michigan. Yield models have been developed for eleven, promising species growing in Michigan, based on measurement of seven to eight trees within each of eleven plantations. Trees were destructively sampled to determine whole-tree, oven-dry weight and to assess the distribution of biomass within the tree. Test plantations were located in southern Michigan and ranged in age from five to sixteen years. Field data required to use these predictor equations are restricted to tree height and stem diameter (DBH in most cases), for ease of application.

INTRODUCTION

Wood-energy is becoming important, again, in the energy budget of the United States as the price of other fuels continues to increase. As wood use increases, foresters are being asked to estimate stand biomass in addition to pulpwood and timber volume. Traditional forest inventories have not been sufficient for predicting whole-tree biomass yields on a single-stem or stand basis, nor have they been sufficient for estimating residue biomass (unmerchantable tops, branches, etc.). Some investigators have been developing inventory methods specifically for biomass determinations by modifying existing stand tables or generating new stand-biomass predictor tables (Adams, 1982; Tritton, 1982). This has facilitated inventories of older, existing stands for biomass availability reports.

Biomass production in short-rotation, energy plantations is a concept which has yet to be put into wide-spread practice, but is being investigated by several research organizations (USDOE, Gas Research Institute, major universities, and others). The Department of Forestry at Michigan State University has been conducting short-rotation species and genotype suitability studies since 1978 with the U.S. Department of Energy. During these investigations it became necessary to obtain non-destructive yield estimations for a number of species. Tables or equations for small plantation-grown trees were unavailable, so investigations were designed to provide preliminary yield predictor equations for use in subsequent species and genotype screening.

MATERIALS AND METHODS

Eleven species were selected (Table 3.1), based either on their superior performance in previous tests or on their rapid juvenile growth potential, and on the availability of young test plantations. One plantation of each species was

Table 3.1. Species for which biomass predictor equations were developed.

Red maple	*Acer rubrum* L. var. *rubrum*
Ailanthus	*Ailanthus altissima* (Mill.) Swingle
Yellow birch	*Betula alleghaniensis* Britton
White birch	*Betula papyrifera* Marsh.
White ash	*Fraxinus americana* L.
Green ash	*Fraxinus pennsylvanica* Marsh.
Black walnut	*Juglans nigra* L.
Tamarack	*Larix laricina* (Du Roi)
Kellogg hybrid pine	*Pinus nigra* Arnold x *P. densiflora* Sieb. & Zucc.
Sycamore	*Platanus occidentalis* L.
Hybrid poplar	*Populus*

selected for measurement. All plantations are located in the southern Lower Peninsula of Michigan at one of two experimental forests owned by Michigan State University. The plantations had each been established on 2.4m square spacings (except for black walnut which was planted at a 3.1m square spacing) and maintained under similar management regimes, but were of different ages. The characteristics of each plantation are given in Table 3.2.

Tree diameters were measured at 137 cm (4.5 feet) above the ground if the smallest trees in the plantation were larger than 13 mm (0.5 inches) at this point, otherwise they were measured at 61 cm (2 feet) from the ground. The range of diameters within each plantation was determined to establish diameter classes; 2.5 cm (1 inch) classes were used if the range of diameters was 12 cm (5 inches) or less, and 5 cm (2 inch) classes were used if the range was greater than 12 cm. A seven- or eight-tree random sample, stratified by diameter class, was harvested from each plantation for destructive analysis before leaf fall in 1982. Each tree was divided into four components: twig, branch, bark, and bole. Oven-dry, whole-tree weights for the sample trees were determined by obtaining and summing the weight of each component. Regressions using total height and diameter were then used to predict whole-tree weight for each species.

Single-tree oven-dry weight determinations

Sample trees were removed from the plantations after

Table 3.2. Characteristics of plantations from which trees were sampled to develop yield predictor equations.

Species	No. Trees Sampled	Plantation Age	Type Of Test 1/
	5 - 9 Year Old		
Red maple	7	9	G
Ailanthus	7	5	S
White birch	8	7	G
White ash	8	6	G
Green ash	8	5	G
Sycamore	8	5	S
Hybrid poplar	8	8	C
	15 & 16 Year Old		
Yellow birch	8	15	G
Black walnut	8	16	G
Tamarack	7	16	G
Kellogg hybrid pine	7	16	H

1/ G = genetic provenance and/or progeny test.
S = spacing study.
C = hybrid clonal trial.
H = bulk hybrid seedling trial.

height and diameter were recorded. Branches and upper stem portion of the tree (bole diameter less than 2.5 cm or 1 inch) were removed and set aside. The bole was then sectioned into 61 cm (2 foot) lengths. The diameter at the top and bottom of each section was determined both inside and outside the bark. Inside and outside bark bole volume was determined using the Smalian Log Rule. The Smalian rule was chosen to eliminate the need for mid-section diameter measurements. Disks were removed from the bottom of each section and used to make specific gravity determinations of the wood in that section. Average specific gravity for the bark was determined by sampling bark from each disc. All specific gravity determinations were based on the oven-dry weight of the wood or bark and its volume at fiber saturation point.

The oven-dry mass of each section of bole within a tree was determined as the product of the section volume based on DIB (diameter inside bark) and it's corresponding specific gravity. Total bole mass was computed as the sum of the section masses. Bark volume was determined as the difference of bole volume based on DOB (diameter outside bark) and volume based on DIB. Bark oven-dry mass was then computed as the product of bark volume and bark specific gravity.

Branches removed from the main stem of each tree were further separated in two components; twigs (current year's growth including leaves), and branches previous years' growth. Tamarack and the Kellogg hybrid pine were too large to be handled expediently using these procedures, so branches and twigs were treated as a single component (branches).

The fresh-weight of each component was recorded in the field. Samples were oven-dried to a constant weight at 105^{o}C, and the moisture content was determined. The oven-dry weight of each component was computed as the product of fresh-weight and one minus the moisture content.

Whole-tree biomass was calculated as the sum of all component biomass. A summary of the distribution of biomass within the tree was developed by averaging the component masses of each sampled tree for each species.

Model development

Several regression models which had been used by other investigators were chosen for testing (Baskerville, 1972; Lavigne and Van Nostrand, 1982; et al.). These models were linear, non-linear, natural log-transformed, constrained, and unconstrained models using functions of diameter and/or height as independent variables to predict whole-tree, above-ground, oven-dry biomass. The individual-tree data were used to solve for the regression coefficients of each model using a least squares regression approach. Correction factors for the log-transformed regressions were calculated as described by Sprugel (1982), and incorporated into the "Y intercept" term of each model. Models were evaluated based on the five criteria listed in Table 3.3. The model which had the best overall goodness-of-fit using these test criteria was selected for each species. Pearson's product-moment

Table 3.3. Parameters used for comparing regression performance of yield predictor equations.

S	(generalized coefficient of determination) 1/
	$1-(\Sigma(y-\hat{y})^2/\Sigma(y-\bar{y})^2)$
RMSE	(root mean square error) 2/
	$\sqrt{\Sigma(y-\hat{y})^2/n}$
MAE	(mean absolute error) 2/
	$\lvert y-\hat{y}\rvert/n$
MPE	(mean percent error)
	$\Sigma((y-\hat{y})/y)/n$
D	(index of agreement) 2/
	$1-\Sigma(y-\hat{y})^2/\Sigma(\lvert\hat{y}-\bar{y}\rvert+\lvert y-\bar{y}\rvert)^2$

Where: y = observed yield in kg.
$\hat{y}$ = predicted yield in kg.
$\bar{y}$ = average observed yield in kg.
n = number of observations.

1/ Payandeh (1981).
2/ Willmott (1982).

correlation coefficient (r) and the coefficient of determination (r^2) were not used in comparing models because of deficiencies in their ability to adequately predict model accuracy especially for log-transformed and constrained models (Payandeh, 1981; Willmott, 1982).

RESULTS AND DISCUSSION

The regression models which were selected for use are presented in Table 3.4. Single-tree biomass yield models have been shown to be relatively independent of site, age, and spacing (Alban and Laidly, 1982; Crow, 1983; and Jacobs and Monteith, 1981). This suggests that the models developed in this study may have utility elsewhere in the Lake States. Eight of the sampled plantations were genetic test and, therefore, contained a diversity of genetic material. This may act to reduce the applicability of these models in plantations composed of different or less diverse genetic material.

The sample size used to develop these yield predictor equations was limited to seven or eight trees for each species. Although this sample size has been used by others (Albrektson, 1980), there is general agreement that larger samples should be used for better confidence in the predictive accuracy of the models (Grove, et al. 1982). Models presented here should, therefore, be considered as preliminary and used with caution until further sampling can refine or confirm these results.

Table 3.4. Regression models chosen for predicting whole-tree, oven-dry biomass of eleven short rotation species growing in southern Michigan test plantations.

Species	n	Regression Model 1/	S	Residual Analysis RMSE	MAE	MPE	D
		5 to 9-Year-Old					
Red maple	7	$Y = -2.70445 + 0.485D^2 + 0.56793H - 0.03604D^2H$	.985	.480	.324	.170	.996
Ailanthus	7	$Y = 0.25567D^{2.01803} - 0.17879H$	.911	2.810	1.985	.260	.976
Paper birch	8	$Y = -2.34234 - 0.17524D^2 + 1.01637H + 0.0515D^2H$	.951	1.482	1.19	.185	.987
White ash	8	$Y = -0.02285D^2 - 0.00642H + 0.05130D^2H$	.991	.156	.117	.103	.998
Green ash	8	$LnY = -0.83160 + 1.93642LnD - 0.30172LnH$	.919	.453	.307	.119	.979
Sycamore	8	$Y = 0.2777D^{2.03504} - 0.18999H$	.973	.576	.467	.417	.993
Hybrid poplar	8	$Y = 0.17783D^2$	.962	1.698	1.426	.183	.990
		15 and 16-Year-Old					
Yellow birch	8	$LnY = 0.09617 + 2.83563LnD - 1.40931LnH$	.972	5.337	3.332	.096	.993
Black walnut	8	$LnY = -3.70277 + 0.78726LnD + 2.40604LnH$	.944	5.340	3.759	.192	.985
Tamarack	7	$Y = 0.57058D^2 - 0.8363H - 0.02128D^2H$	.978	3.646	2.578	.080	.994
Kellogg hybrid pine	7	$LnY = -2.23651 + 2.05503LnD + 0.39002LnH$	.990	4.128	2.660	.036	.997

1/ Where: Y = Yield in Kg (oven-dry).
H = Total tree height in meters.
D = Diameter in cm. measured at 1.4m (4.5') above ground - except for white ash which was measured at 0.67m (2') above the ground.

Accurate prediction of tree components' biomass using conventional mensurational data, such as DBH and height, has been shown to be difficult (Alban and Laidly, 1982; Alemdag, 1981; Alemdag and Horton, 1981). For this reason, and due to a limited sample size, which would further compromise the estimates, no attempt was made to develop regressions to predict bole, branch, bark, or twig and leaf biomass individually. A summary of the average proportion of these components was developed, instead, to provide an understanding of biomass distribution for the eleven species in these plantations (Table 3.5).

For most species, the biomass of the bole is approximately half of the tree's total biomass. This suggests that efforts should be made to harvest more than just the bole. Nutrient-rich leaves and twigs make up a small percent of the total biomass of older trees, but in some of the younger plantations they represent as much as 33 percent. Harvesting systems may need to be designed to accommodate the amount of fine materials (twigs and leaves) for each species. Further, if nutrient removal from the site by harvesting is to be minimized, species which have large portions of their biomass in leaves and twigs may be less desirable.

Further investigations will be required to develop better component estimates for these and other species at various ages. Such estimates are needed to make management decisions regarding the type of harvesting system necessary

Table 3.5. Relative distribution of biomass within sampled trees of eleven promising species.

Species	Relative proportion of total biomass: Twig	Branch	Bark	Bole	Wood specific gravity
5- to 9-Year old Age Group (% of whole-tree mass, oven-dry)					
Red maple	7%	29%	10%	54%	0.33
Ailanthus	20	22	5	53	0.42
Paper birch	18	32	4	46	0.36
White ash	33	33	3	31	0.43
Green ash	9	40	4	47	0.47
Sycamore	20	25	2	53	0.42
Hybrid poplar	7	29	10	54	0.33
15 & 16 Year Old Age Group					
Yellow birch	5	43	4	48	0.49
Black walnut	4	35	12	49	0.47
Tamarack	--	38	8	54	0.35
Kellogg hybrid pine	--	58	7	35	0.32

to maximize biomass harvested and minimize nutrient removal from the site (Kimmins, 1977).

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CHAPTER 4

Biomass Yield Comparisons of Eleven Promising Short-rotation Species in Southern Michigan

ABSTRACT

Plantation yield information has traditionally been available for mature (30- to 80-year-old) coniferous trees of pulp and timber species. Increased interest in short-rotation energy-plantations has created a need for yield data on young trees (five to fifteen years old) of species with rapid juvenile growth. Eleven, single-species plantations, from among the genetic and cultural tests at Michigan State University, were selected for measurement and yield assessment. Average, single-tree, above-ground, oven-dry biomass yield, expressed as a mean annual increment was determined for each plantation and projections were made to approximate the areal yield which could be expected from large-scale, biomass plantations.

The best yield in the older plantations (fourteen to sixteen years old) was from the hybrid, *Pinus nigra* x *P. densiflora* (4.64 OD $Kg \cdot tree^{-1} \cdot year^{-1}$). The best species in the group of younger plantations (five to nine years old) was a *Populus* hybrid mixture (1.13 OD $Kg \cdot tree^{-1} \cdot year^{-1}$). Other species which also yielded well included *Betula alleghaniensis* and *Ailanthus altissima*.

INTRODUCTION

The ability of a site to produce biomass remains fairly constant over time, assuming a lack of catastrophic disturbance. Forest management attempts to shift a site's biomass production to organisms, such as trees, capable of producing usable products, such as timber or wood fiber (Smith, 1962).

Cannell and Smith (1980) conducted an extensive review of "short-rotation" plantation yield investigations, and concluded that northern temperate sites of good fertility were capable of producing a maximum of 10-15 oven-dry, metric tonnes per hectare-year (OD $Mg \cdot ha^{-1} \cdot yr^{-1}$) of usable biomass at age five years, without extraordinary cultural treatments. These yields were obtained only if the sites were fully stocked throughout the rotation.

In contrast to the maximum yield postulated by Cannell and Smith, the average production of commercial forest land in the United States has been estimated to be only 1.3 OD $Mg \cdot ha^{-1} \cdot yr^{-1}$ (Howlett and Gamache, 1977). Michigan's forests are yielding an average of 1.1 OD $Mg \cdot ha^{-1} \cdot yr^{-1}$ (Bradley, et. al., 1980; Hahn, 1982; Jakes, 1982; Smith, 1982; and Spencer, 1982). In addition, plantations managed to maximize pulpwood yield in Michigan only produce approximately 3.8 OD $Mg \cdot ha^{-1} \cdot yr^{-1}$ (Lundgren, 1982).

Research is needed in Michigan to determine ways to better capture the potential of forest sites so that woody-biomass yields might begin to approach the maximum proposed by Cannell and Smith. Michigan State University's Department of Forestry has been working with the United States Department of Energy and the Michigan Cooperative Tree Improvement Program to screen potential biomass species and identify the more promising ones for further investigation. Part of the screening process was to examine and compare the yields of several species to determine which had the highest biomass productivity rate. The purpose of these investigations was to make comparisons among species based on single-tree, whole-tree biomass expressed as mean annual increment (MAI). These single-tree yields were also expanded to an areal basis for comparison to yields reported by other authors, and to serve as preliminary estimates of yields from short-rotation energy-plantations in Michigan.

MATERIALS AND METHODS

Energy-plantations should produce high yields on relatively short rotations. It is therefore necessary that the trees used in these plantations grow rapidly during their early years (Dickmann, 1975). Eleven, single-species plantations were selected from among the cultural and genetic test plantations established by Michigan State University for measurement and analysis of juvenile growth. All eleven species were known to have rapid juvenile growth, and four are prodigious sprouters. Use of species that coppice would eliminate the need for re-planting after harvesting.

The plantations used in these studies were located on one of two Michigan State University Experimental Forests,

Table 4.1. Species for which yield projections were made.

Common name	Latin name
Red maple	*Acer rubrum* L.
Ailanthus	*Ailanthus altissima* (Mill.) Swingle
Yellow birch	*Betula alleghaniensis* Britton
White birch	*Betula papyrifera* Marsh.
White ash	*Fraxinus americana* L.
Green ash	*Fraxinus pennsylvanica* Marsh.
Black walnut	*Juglans nigra* L.
Tamarack	*Larix laricina* (Du Roi)
Kellogg hybrid pine	*Pinus nigra* Arnold x *P. densiflora* Sieb. & Zucc.
Sycamore	*Platanus occidentalis* L.
Hybrid poplar	*Populus*

located in southern Michigan (Table 4.2). All plantations were established and maintained using similar procedures. Trees were planted on 2.4 x 2.4m spacings (except for black walnut, which was established on 3 x 3m centers).

Eight of the eleven plantations were genetic tests which were planted in randomized-block designs with multiple-tree plots. In genetic test plantations, only those plots containing seedlots which could be considered "local" were included in the analysis, to minimize the effect of genetic variability on yield comparisons. The analysis of genetic variability was performed separately and is reported in Chapter 6.

Heights and diameters of all "local-source" trees were measured in the fall of 1982. Whole-tree, above-ground, oven-dry biomass was computed using the yield predictor equations (Table 3.4), developed for each plantation in Chapter 3. Single-tree yield for each species was computed by averaging the yields of each "local-source" tree. Species were ranked within each of two age groups according to calculated single-tree yield. Grouping by age was done in an attempt to minimize growth phase and between-tree competition differences among plantations. It was not possible to eliminate yield differences due to site.

Areal yields were derived from the average, single-tree yields calculated above to provide preliminary comparisons of these species with yields reported by other investigators. Estimates were derived for two spacings (2.3 x 2.3m and 1.8 x

Table 4.2. Plantations used to develop yield projections for eleven promising biomass-species in southern Michigan.

Species	Location of planting	Age (yrs)	Type of test	No. Seedlots	Spacing (m)
Red maple	Kellogg Forest	9	Provenance test	94	2.4
Ailanthus	Russ Forest	5	Spacing trial	bulk	various
Yellow birch	Kellogg Forest	15	Provenance test	35	2.4
White birch	Russ Forest	7	Progeny test	224	2.4
White ash	Kellogg Forest	6	Provenance test	35	2.4
Green ash	Russ Forest	5	Provenance test	43	2.4
Black walnut	Kellogg Forest	16	Provenance test	19	3.1
Tamarack	Kellogg Forest	14	Provenance test	33	2.4
Kellogg hybrid pine	Kellogg Forest	16	Hybrid trial	bulk	2.4
Sycamore	Kellogg Forest	5	Spacing/ interplanting	bulk	various
Hybrid poplar	Russ Forest	8	Clonal trial	40	2.4

1.8m) at two survival rates (80 and 90 percent). It was assumed that all trees would grow at the same rate as the average-tree of the test plantation.

RESULTS AND DISCUSSION

Single-tree and areal yields computed for each species are presented in Table 4.3. Kellogg hybrid pine and yellow birch are the two better yielding species in the older plantation age group. It may be possible to obtain between 6.9-12.2 and 4.1-8.2 OD $Mg \cdot ha^{-1} \cdot yr^{-1}$, respectively, in energy-plantations of these species on 16-year rotations. That is equivalent to 65.5 to 195.2 dry Mg per hectare or 29.2 to 87.1 dry tons per acre, at a rotation age of 16 years, under non-intensive management practices.

Ailanthus and hybrid poplar were the two species which had the highest yields of the younger plantations. It may be possible to obtain between 1.4-2.9 and 1.5-3.0 OD $Mg \cdot ha^{-1} \cdot yr^{-1}$, respectively, in energy-plantations with these species on six-year rotations. These yields are equivalent to 8.4 to 18.0 dry Mg per hectare or 3.7 to 8.0 dry tons per acre, at a rotation age of six years, under non-intensive management practices. All plantations in this younger age group had not yet fully occupied the planting sites. Planting densities might be increased to improve yields on rotations of five to nine years.

A summary of yields reported by other investigators is compared to yields estimated here in Table 4.4. Higher yields have been obtained by some, but often the conditions

Table 4.3. Whole-tree, oven-dry biomass yields and areal projections for eleven biomass species growing in southern Michigan plantations.

Species	Age (yrs)	No. Trees Sampled	Mean Tree Yield	Projections Of Areal Yields -Spacing- 1.8 x 1.8m -Survival- 80%	1.8 x 1.8m 90%	2.4 x 2.4m 80%	2.4 x 2.4m 90%
14 to 16-year-old group							
			($Kg \cdot tree^{-1} \cdot yr^{-1}$)	(Oven-Dry $Mg \cdot ha^{-1} \cdot yr^{-1}$)			
Kellogg hybrid pine	16	280	4.64	11.1	12.5	6.2	7.0
Yellow birch	15	44	3.05	7.3	8.2	4.1	4.6
Tamarack	14	92	2.31	5.5	6.2	3.1	3.5
Black walnut	16	32	1.62	3.9	4.4	2.2	2.5
5 to 9-year-old group							
Hybrid poplar	7	1065	1.13	2.7	3.0	1.5	1.7
Ailanthus	5	309	1.06	2.5	2.9	1.4	1.6
White birch	7	649	0.70	1.7	1.9	0.9	1.1
Sycamore	5	142	0.68	1.6	1.8	0.9	1.0
Red maple	9	80	0.67	1.6	1.8	0.9	1.0
Green ash	5	40	0.34	0.8	0.9	0.5	0.5
White ash	6	100	0.15	0.4	0.4	0.2	0.2

Table 4.4. Summary of yields reported by various authors for biomass-species grown in north temperate latitudes under low-intensity plantation culture.

Species	Age (yr)	Yield ($Mg \cdot ha^{-1} \cdot yr^{-1}$)	Site	Citation[1/]
Kellogg hybrid pine	16	12.5	Michigan	5
European black alder	6	10.3	Indiana	2
Cottonwood	6	8.8	Kansas	4
Black locust	6	8.7	Kansas	4
Yellow birch	15	8.2	Michigan	5
Silver maple	6	7.5	Kansas	4
Aspen	7	4.3	Maine	3
European white birch	6	3.9	Norway	1
Red pine	60	3.8	Michigan	7
Sycamore	5	3.5	Indiana	2
Hybrid poplar	7	3.0	Michigan	5
Ailanthus	5	2.9	Michigan	5
Jack pine	13	2.6	Michigan	6

1/ 1- Frivold and Borchgrevink, 1981.
2- Callahan and Toth, 1978.
3- Howlett and Gamache, 1977.
4- Geyer and Naughton, 1981.
5- Taken from this paper.
6- Howe, 1983.
7- Lundgren, 1982.

under which these yields were obtained are extraordinary. For example, fertilizers and irrigation schedules are often used to ensure non-limiting nutrient and water conditions on test sites. Plantations are commonly established on "prime" agricultural land or are afforded the type of cultural treatments one would expect of an agricultural crop. Comparisons have been limited to trees grown under non-intensive management strategies similar to those applied to the test plantations of this study. The assumption is that lower management costs of non-intensive systems will be more attractive to managers than the higher yields which result from the more expensive, intensive systems.

It is obvious from data in Table 4.4 that further cultural and genetic work is needed to improve the yields of species such as ailanthus, hybrid poplar, aspen and others, so that they will approach the theoretical maximum of 10-15 OD $Mg \cdot ha^{-1} \cdot yr^{-1}$ proposed by Cannell and Smith (1980).

The plantations measured in this study ranged in age from 5- to 16-years, so that each species was at a different point along its "Grand Period of Growth" curve (Baker, 1950). Interspecies comparisons have been restricted to plantations of similar ages (7 +/- 2 years and 15 +/- 1 year) in an attempt to minimize these differences. This approach is reasonable if one assumes that rotation length will be set by economic or operational factors and selections must be based on biological efficiency at a common age and spacing.

The next step, for the better species identified in these investigations, will be to measure MAI on different spacings for several years, to determine the yields of different combinations of spacings and rotation lengths. These data will provide the basis for management prescriptions for each species.

Yield information reported here is highly specific to the ages, stocking levels, and sites of the test plantations and therefore should be used only as preliminary guidelines for species selection. Extreme caution should be used when projecting the yields reported here to other sites and other management systems.

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CHAPTER 5

Spacing Effects on Biomass Yield of Young Plantations of *Ailanthus altissima* and *Platanus occidentalis* in Southern Michigan

ABSTRACT

Ailanthus altissima was planted at three spacings (1.2 x 1.2m, 1.8 x 1.8m, and 2.4 x 2.4m) and *Platanus occidentalis* was planted at two spacings (2.4 x 2.4m and 2.4 x 4.9m) to determine the effect of planting density on biomass yield. Both species showed increased areal yields at higher planting densities at age 5. *Ailanthus* produced 6 $Mg \cdot ha^{-1} \cdot yr^{-1}$ at the 1.2 x 1.2m spacing and *Platanus* yielded 0.8 $Mg \cdot ha^{-1} \cdot yr^{-1}$ at the 2.4 x 2.4m spacing at age five. Neither species showed significant reduction in single-stem biomass yields at the higher densities, indicating that upper density thresholds had not yet been reached and that maximum yields at age five may be obtained at higher densities than those tested in this study.

INTRODUCTION

Rising petroleum prices have been responsible for a gradual but dramatic increase in the use of wood for fuel in recent years. As the demand on the wood resource grows, forest managers will be required to modify existing silvicultural practices to increase yields of biomass-fuel. An important consideration in the production of biomass-fuel will be to maximize areal yields and thus reduce land-base requirements. This will involve using selected species and genotypes in short-rotation, high density plantations.

Each species has an optimum range of planting densities for a particular site for which biomass production is maximized. The "law of constant final yield" (Hozumi, et al. 1956) states that: Tree biomass yields of fully-stocked stands are independent of the numbers of stems per hectare over a wide range of spacings. Thus, the productive potential of the site is distributed among the individuals which are present (Cannell, 1980; Ek and Dawson, 1976; Lloyd and Jones, 1982). The stocking levels common to current forestry practice are designed to maximize production of traditional forest products such as pulpwood and sawlogs, and not to maximize biomass productivity. Spacings much closer than those now used are necessary to maximize biomass-yield on short rotations.

Mean annual increment of biomass (MAI) tends to increase with increasing planting density in young stands until optimum stocking is reached (Alemdag and Stiell, 1982; Geyer, 1978). In general there is no appreciable reduction in the heat content of the wood produced in high density plantations (Holt and Murphey, 1978; Maeglin, 1967). It is possible, however, for stand densities to become too high resulting in stand stagnation and a reduction in MAI (Howlett and Gamache, 1977). High densities could also lead to a higher incidence of disease in the plantation, which ultimately reduces MAI (Schipper, 1976).

Economic factors also affect the density at which plantations will be established. Seedling and planting costs rise dramatically with increasing density. Increased yields from high-density plantations may not offset the high establishment costs (Harms, 1982).

Density/yield relationships need to be determined for each biomass species to identify the procedures and problems that will be associated with large-scale plantations. Forest managers may then apply their own economic constraints to define the optimum system for their needs.

Two plantations were established to determine the effects of spacing on dry-matter yield of young *Ailanthus altissima* (Mill.) Swingle (ailanthus) and *Platanus occidentalis* L. (sycamore) at experimental forests of Michigan State University. Five years after the plantations were successfully established, yields were measured and summarized to provide guidelines for future stocking studies of these species.

MATERIALS AND METHODS

Ailanthus

The ailanthus plantation was established in 1976 on the Russ Experimental Forest of Michigan State University. Trees were planted in three blocks (or replicates) at densities of 6719, 2986 and 1680 trees per hectare. The young stems were killed by frost during the winter of 1977-1978 but the stand re-established itself by sprouting. This resulted in increased densities of 8317, 4564 and 3237 trees per hectare by 1982 (Table 5.1).

Heights and diameters at 1.37m above the ground of all trees in the plantation were measured in the fall of 1982. Whole-tree, above-ground, oven-dry biomass was computed for each tree using yield predictor equations specifically developed for each spacing, using techniques described in Chapter 3.

For 1.2 m spacing:

$$\text{Mass} = 0.03944 \cdot \text{DBH}^{2.92637} + 0.14737 \cdot \text{Ht}$$

For both wider spacings:

$$\text{Mass} = 0.25567 \cdot \text{DBH}^{2.01803} - 0.17379 \cdot \text{Ht}$$

Where:

Mass = Oven-dry biomass yield in $\text{kg} \cdot \text{tree}^{-1} \cdot \text{yr}^{-1}$

DBH = Diameter at 1.37m above ground

Ht = Total tree height in meters

Areal estimates of biomass yields were established by summing the individual-tree yields for each plot and expanding these totals. Analysis of variance was used to detect spacing effects on average individual-tree yields and on areal yields.

Platanus

The sycamore plantation was planted in 1978 as part of a long-term cultural research program of Michigan State University. It is located on the Kellogg Experimental Forest near Battle Creek, Michigan. The trees were planted at two different fiber-production densities (1667 and 840 trees per hectare); there was no replication of densities. This

Table 5.1. Experimental design of ailanthus spacing trial at Russ Forest, Decatur, Michigan. The change in density from 1976 to 1982 is due to sprouting after frost damage in 1978.

Conditions at planting (1976)		Plot size	Conditions at measurement (1982)		Average number of Sprouts for each original seedling
spacing (m)	trees per hectare	(hectares)	spacing (m)	trees per hectare	
1.22 x 1.22	6719	0.0156	1.10 x 1.10	8317	1.2
1.83 x 1.83	2986	0.0234	1.48 x 1.48	4564	1.5
2.44 x 2.44	1680	0.0327	1.76 x 1.76	3237	1.9

plantation was selected for analysis even though spacings were much wider than those common to biomass plantations. The mean survival for the plantation was 84 percent.

Trees were measured in the fall of 1982 and these data were summarized in the same manner as ailanthus, above. The yield predictor equation used for sycamore was developed in Chapter 3:

$$\text{Mass} = 0.05731 \cdot \text{DBH}^{2.77994} + 0.18707 \cdot \text{Ht}$$

Where: Mass = OD biomass in $\text{kg} \cdot \text{tree}^{-1} \cdot \text{year}^{-1}$

DBH = Diameter at 1.37m above the ground

Ht = Total tree height in meters

RESULTS

Ailanthus

The analysis of variance (Table 5.2) showed no significant effect of spacing on individual stem biomass production. Variability within a plot (sampling) is low, indicating uniformity of yield among stems. Yield on an areal basis was significantly affected by spacing; the highest yield was realized at the closest spacing, but there was no significant difference between the two wider spacings. Yields of ailanthus at each of the spacings tested are summarized in Table 5.3. The highest areal yields found for ailanthus averaged 6 OD $\text{Mg} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ and ranged from 4.1 to 8.1 OD $\text{Mg} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ over all blocks with 8317 stems per hectare.

Table 5.2. Analysis of variance of spacing effects on single-tree and areal biomass yields of ailanthus five years after establishment in southern Michigan.

<u>Single-tree yields</u> (yield in oven-dry $Kg \cdot tree^{-1} \cdot year^{-1}$)

Source of variance	d.f.	Mean square	F ratio
Spacing	2	1.231	0.26 NS
Blocks	2	78.149	
Error	4	4.668	
Sampling	1021	0.785	
Total	1029		

<u>Areal yields</u> (yield in oven-dry $Mg \cdot ha^{-1} \cdot year^{-1}$)

Source of variance	d.f.	Mean square	F ratio
Spacing	2	10.814	13.58 *
Block	2	6.483	
Error	4	0.796	
Total	8		

* - significant at the 95 percent level of confidence

Table 5.3. Mean annual increment yields of ailanthus planted at three spacings on Russ Forest, Decatur, Michigan, at age five.

Spacing (meters)	No. trees sampled	Whole-tree, oven-dry weight[1/] Single-tree ($Kg \cdot tree^{-1} \cdot year^{-1}$)	Whole-tree, oven-dry weight[1/] Areal ($Mg \cdot ha^{-1} \cdot year^{-1}$)
1.1 x 1.1	390	0.72 a	5.97 b
1.5 x 1.5	321	0.63 a	2.86 c
1.8 x 1.8	309	0.78 a	2.54 c

[1/] Treatment means not followed by the same letter are significantly different at the 0.05 level of probability according to the LSD criterion.

Table 5.4. Mean annual increment yields of sycamore planted at two spacings at Kellogg Forest, Battle Creek, Michigan, at age five.

Spacing (meters)	plot size (ha)	No. trees sampled	Whole-tree, oven-dry weight Single-tree ($Kg \cdot tree^{-1} \cdot yr^{-1}$)	Whole-tree, oven-dry weight Areal ($Mg \cdot ha^{-1} \cdot yr^{-1}$)
2.4 x 2.4	0.0857	101	0.68	0.82
2.4 x 4.9	0.0785	66	0.65	0.55

Platanus

The lack of replication of spacings makes it impossible to separate environmental from spacing effects. Since previous investigations have shown that environmental effects can be as large, or larger than those of spacing, doubts about the finality of the conclusions drawn from these data are raised. Nevertheless, it is of interest to examine the trends in these data to identify directions for future tests (Table 5.4).

There appear to be no differences in single-tree yields between the two spacings. Each tree yields, on average, 0.66 OD $kg \cdot tree^{-1} \cdot year^{-1}$. The areal yield of trees planted at 1667 trees per hectare is 0.82 OD $Mg \cdot ha^{-1} \cdot year^{-1}$. Trees planted at 840 trees per hectare yielded 0.55 OD $Mg \cdot ha^{-1} \cdot year^{-1}$, which is exactly two thirds of the yield found at the higher density.

DISCUSSION

Neither ailanthus nor sycamore showed reduced single-tree yields at the higher densities tested in these plantations, which indicates that the optimum planting densities for these species, at this age, on these sites has not yet been reached. Single-tree yield would be expected to decrease with increasing density when maximum MAI is being produced (Cannell, 1980). Future tests should concentrate on examining spacings closer than 2.44 x 2.44m (1667 trees per hectare) for sycamore and 1.10 x 1.10m (8317 trees per hectare) for ailanthus.

Since there were equivalent single-tree yields over all spacings for both species, increased areal yields with increasing densities was expected. The yield of sycamore, for example, increased in direct proportion to the number of stems. Yields of the two species at various spacings are compared in Table 5.5. Projections have been made beyond the limits of the test plantations by making several assumptions: 1. The single-tree yield remained constant at each spacing. This yield was equal to that of the average tree in the test plantations. 2. Survival at age five in all plantings would be eighty percent of the number of trees planted. 3. The yields of the test plantations are representative of other similar plantings. The purpose of these projections was to demonstrate what the maximum theoretical yield of these species might be in closely-spaced, short-rotation, biomass plantations. They are only projections and should be used with caution.

Sycamore and ailanthus planted at spacings tested by these investigations do not produce biomass at acceptable rates. Individual-tree yields are encouraging though, and further tests should be conducted at closer spacings and on other sites to determine if the estimates presented in Table 5.5 are reasonable. These yields seem to be in keeping with a theoretical maximum rate of 10 to 15 OD $Mg \cdot ha^{-1} \cdot yr^{-1}$ reported by Cannel and Smith (1980).

It is interesting to note that the rate of resprouting

Table 5.5. Estimated yields of sycamore and ailanthus at various spacings assuming; 1. constant single-tree yields and 2. 80% survival at age five.

		Estimated yield		
		--- stems per hectare -----		
Species	Single-tree yield 1/	1344	5375	22222
	($Kg \cdot tree^{-1} \cdot year^{-1}$)	---- ($Mg \cdot ha^{-1} \cdot year^{-1}$) -----		
Ailanthus	0.72	1.0	3.9	16.0
Sycamore	0.68	0.9	3.7	15.1

1/ Single-tree yields were derived from field measurements.

of ailanthus following frost-killing, seems to be related to planting density (Table 5.1). The number of sprouts per seedling decreases with increasing density. The result is to make the stocking more uniform among the treatments once resprouting has occurred. This is an example of the mechanism by which natural stands attempt to fully occupy a site; that is, a stand which is under-stocked sprouts back more vigorously than one which is more nearly fully-stocked.

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CHAPTER 6

Provenance and Clonal Performance of Eight Short-rotation Biomass species in Southern Michigan

ABSTRACT

Seven provenance test plantations and one clonal test plantation in Michigan were evaluated to develop preliminary seed source and clone recommendations for eight, promising biomass species: *Acer rubrum* (red maple), *Betula alleghaniensis* (yellow birch), *B. papyrifera* (white birch), *Fraxinus americana* (white ash), *F. pennsylvanica* (green ash), *Juglans nigra* (black walnut), *Larix laricina* (tamarack), and *Populus* hybrids. Test plantations ranged in age from five to sixteen years, which correspond to the rotation lengths of short-rotation, biomass plantations. Provenance or clone performance was analyzed based on single-tree, oven-dry, above-ground biomass yield, expressed as a mean annual increment.

Gains in biomass yield over "local" sources can be as high as 37 percent with proper provenance selection. Yield losses due to improper provenance selection can be as much as 48 percent of "local" source yield.

INTRODUCTION

Efforts to reduce the cost of energy and to increase the "energy-independence" of the United States began in earnest in the early 1970's. Many alternatives to fossil fuels have been, and are being investigated. In 1978, the U.S.

Department of Energy and Michigan State University began a long-term project to define an effective system for producing substantial quantities of woody-biomass for fuel on forest sites and abandoned agricultural fields in Michigan.

A stepwise approach similar to that proposed by Inman (1977) was adopted for developing a comprehensive woody-biomass production system for Michigan. The program consists of four phases: 1. Identification of the most promising biomass species through trial plantings on abandoned agricultural fields and cleared forest stands, 2. Preliminary yield comparisons of several species growing in existing experimental plantations, 3. Species improvement using standard tree improvement techniques, and 4. Development of cultural techniques designed to optimize woody-biomass yield from energy plantations. Investigations have been conducted in each phase of the program since 1978. This paper will summarize the results of the preliminary genetic screening which has been conducted on eight of the biomass species under investigation.

Forest tree improvement and biomass-tree improvement have three common goals: 1. To maximize yield by selecting genotypes with superior growth rates and wood qualities, 2. To increase the site-adaptability of a species by selecting less site-specific genotypes, and 3. To reduce the adverse effect of insect and disease pests on stands by selecting resistant genotypes. The gain which can be achieved in each of these three areas depends on the species itself, and the intensity and type of tree improvement technique being used (e.g. provenance selection, family selection, or individual-tree selection). Examples of the gains in height which might be achieved for white spruce and jack pine under different selection strategies have been provided by Nienstaedt and Jeffers (1976) (Table 6.1). Variability within white spruce provenances and families is greater than for jack pine. As a result, gains from family and within family selection of white spruce are higher than for jack pine. If the species being investigated in this study respond as white spruce does, the gains from provenance selection, which are reported here, represent the minimum gains which may be achieved by breeding.

The selection of genotypes for biomass production can be based on a range of characteristics which include: individual-tree growth rate, tolerance of competition in densely planted stands, wood quality (e.g. specific gravity, extractive content, or heat content), insect and disease resistance, and cultural treatment or site adaptability. Each of these characteristics is important in determining the quantity and quality of the biomass produced, but the consensus among biomass researchers is to concentrate on maximizing growth rates. Genotypes with other desirable characteristics may be selected from among this faster growing group in a later phase (Ezell, et al. 1983; Frampton and Rockwood, 1983; Giordano, 1969). With this in mind, selections in this study were based on single-tree, total

Table 6.1. Estimated gains which may be achieved through provenance, family, and individual-tree selection of white spruce and jack pine in the Lake States. (Nienstaedt and Jeffers; 1976)

Type of selection	Comparison of superior seedlots to control seedlots for: white spruce	jack pine
Provenance[1/]	20 - 30 %	10 - 20 %
Half-sib Progeny	14 - 25 %	2 - 10 %
Tested Clonal	10 - 100 %	10 - 50 %

[1/] These figures represent gains in height from collection within the better provenances.

above-ground, oven-dry biomass yield. Subsequent testing in higher density plantations is planned to identify genotypes within the better yielding provenances for inclusion in biomass-species seed orchards.

The forest tree improvement program at Michigan State University began in the mid-1950's. The approach taken for most species has involved provenance testing to identify racial trends, followed by progeny testing within the better provenances to identify the better families, and subsequent sexual or asexual propagation of proven superior individuals when practical. More than 45 species are currently being tested in over 400 plantations throughout Michigan. Eight of the younger provenance and clonal test plantations were selected for analysis in this study, based on the desirability of the represented species for the production of biomass on a short rotation basis.

MATERIALS AND METHODS

Species represented in test plantations are listed in Table 6.2. The plantations were located on either one of two Experimental Forests owned by Michigan State University in southern Michigan. Each test was established with bare-root seedlings, planted by machine between 1967 and 1978, and maintained under similar low-intensity management regimes. Trees were arranged in one to five-tree row plots in a randomized block design. A summary of the characteristics and experimental design of each plantation is presented in

Table 6.2. Species for which provenance recommendations were made.

Common name	Latin name
Red maple	*Acer rubrum* L.
Yellow birch	*Betula alleghaniensis* Britton
White birch	*Betula papyrifera* Marsh.
White ash	*Fraxinus americana* L.
Green ash	*Fraxinus pennsylvanica* Marsh.
Black walnut	*Juglans nigra* L.
Tamarack	*Larix laricina* (Du Roi)
Hybrid poplar	*Populus*

Table 6.3.

All trees were measured for total height and diameter in the fall of 1982. Total, above-ground, single-tree biomass was computed using predictor equations developed for each plantation in Chapter 3 (Table 3.4). Plot means for biomass were computed and an analysis of variance was performed to detect differences among seedlots and to estimate the variance components needed to compute heritability. The plot means were expressed as a percent of the block mean to minimize block effects on performance. Yield for each seedlot within a provenance was then averaged over all blocks to provide an overall estimate of performance at each plantation. The average of all Michigan seedlots was computed and used as a baseline (the "local" source). The gain or loss in biomass yield from provenance selection was computed by applying the heritability to the difference in performance of the best and worst provenances to the "local" source performance.

Heritabilility and gain were not computed for hybrid poplar because an adequate base-line was lacking in this plantation, i.e. there is no valid "local" source of hybrid poplar with which to compare other clones. Therefore, yields reported in this study represent the mean performance of the best and worst clones over all blocks in the plantation.

RESULTS AND DISCUSSION

Significant differences in yield were found among provenances for all species. High variability indicates that

Table 6.3. Plantations used for genotype evaluation of biomass production of eight promising biomass-species in southern Michigan.

Species	Nearest town	Age (Yrs from planting)	Type of test	No. seedlots (provenances)	No. of trees per plot (No. blocks)
Red maple	Augusta, MI	9	1/2-sib progeny-provenance test	94 (23)	2 (6)
Yellow birch	Augusta, MI	15	Provenance test	35 (20)	4 (5)
White birch	Decatur, MI	7	1/2-sib progeny-provenance test	224 (26)	1 (4)
White ash	Augusta, MI	6	1/2-sib progeny-provenance test	35 (23)	5 (5)
Green ash	Decatur, MI	5	1/2-sib progeny-provenance test	43 (20)	4 (5)
Black walnut	Augusta, MI	16	Provenance test	19 (13)	4 (6)
Tamarack	Augusta, MI	14	Provenance test	33 (12)	4 (3)
Hybrid poplar	Decatur, MI	8	Clonal trial	40 --	4 (8)

ample opportunities exist for biomass breeding in all species considered. The gains and yields which can be expected from plantations established with sources from the recommended provenances are presented in Table 6.4 and a summary of recommended provenances appears in Table 6.5. Losses in yield which would be expected to result from improper provenance selection are also shown. In all cases, the advantages of selecting the better provenances and the disadvantages of selecting the worst provenances are substantial when compared to the "local" source average.

It is important to note that, for each species, these data were collected in a single plantation at a single age. Heritability and gain are overestimated because of unknown genotype x environment interaction variance. All conclusions are preliminary in nature and further testing on a range of sites will be necessary to provide confirmation.

Red maple

Red maple families collected from the south-central portion of Michigan yielded 15 percent better than the "local" source in the test plantation. The reduction in yield, if the worst provenance was selected, is estimated to be 33 percent. The differences among provenances is highly significant and heritabilities are correspondingly high (0.69), indicating substantial opportunities exist for obtaining gains in yield through breeding. Townsend and Harvey (1983) examined height and diameter growth of this and

Table 6.4. Biomass yields of selected provenances and clones as compared to "local" sources in genetic test plantations of eight species in Michigan.

Species 1/	h^2	Effect of selection of the best or poorest provenances or clones			
		Best	Poorest	Best	Poorest
		Gain ------- % -------		Yield -- $Kg \cdot tree^{-1} \cdot yr^{-1}$ --	
Black walnut	0.66	+37	-26	2.22	1.20
Yellow birch	0.29	+17	-15	3.57	2.59
Tamarack	0.68	+30	-48	3.00	1.20
Red maple	0.69	+15	-33	0.77	0.45
Hybrid poplar 2/	0.78	---	---	1.80	0.40
White birch	0.54	+30	-40	0.91	0.42
White ash	0.25	+ 8	-14	0.16	0.13
Green ash	0.61	+29	-25	0.44	0.26

1/ - Species are listed from oldest to youngest.

2/ - The "best" selection of hybrid poplar here is based on the clone which produced the highest yield among the canker- resistant clones. Higher yields were observed for this species, but these clones were heavily cankered.

Table 6.5. A summary of seed source recommendations for the better biomass species, for use in southern Michigan.

Species	Recommended collection area
Yellow birch	Mackinac Co., MI.
White birch	Manistee, Mason, and Lake Counties, MI.
Black walnut	West Virginia
Tamarack	Alger Co., Michigan
Hybrid poplar	Northeast Clone NE-207 (*Populus deltoides* x *P. trichocarpa*)

four other plantations of this same material throughout the Lake States, and arrived at similar conclusions about the opportunities for breeding red maple. They also noted a significant genotype x environment interaction among plantations which may indicate that regional or site-specific source recommendations will be needed for this species. Yields of improved red maple are not outstanding (0.8 $kg \cdot tree^{-1} \cdot year^{-1}$). It is not, therefore, recommended for use in biomass plantations under these conditions.

Yellow birch

Differences among yellow birch provenances were moderately significant and heritability was low (0.29). Sources collected from the southeastern portion of Michigan's Upper Peninsula were superior and represent a 17 percent gain over the "local" source tested. These gains from provenance selection are substantial, but Clausen (1973) has stated that the variation within provenances is much greater than among provenances for yellow birch. This suggests greater gains can be achieved through family and individual-tree testing. Although yellow birch produced high annual yields in this study (3.57 $kg \cdot tree^{-1} \cdot year^{-1}$), establishment problems such as animal damage and intolerance to weed competition may limit the utility of this species in managed plantations.

White birch

A 30 percent gain in yield can be expected from white birch collected in the northwestern portion of the Lower Peninsula of Michigan when compared to the state-wide average. Differences among sources were highly significant in the test plantation and heritability was fairly high (0.54). Substantial reductions in yield (40%) would result from improper provenance selection. If the individual-tree production rate demonstrated here (0.91 $kg \cdot tree^{-1} \cdot year^{-1}$) can be sustained at higher densities than those in the test plantation, white birch could be considered as a good biomass species.

White ash

Seed source differences in the test plantation were only moderately significant and heritability was low (0.25). Moderate gains (8%) could be demonstrated from selecting provenances in the Central Plains states. Yields achieved by the better sources were so low (0.16 $kg \cdot tree^{-1} \cdot year^{-1}$) that white ash should be discounted as a biomass species in Michigan.

Kung and Clausen (1983) reported on four plantations which contained materials similar to those of the plantation measured in this study. Growth in Lake States plantations was less than that at other test locations. They also noted a strong genotype x environment interaction among the plantations. The poor yields of white ash experienced in Michigan may have occurred because no provenances suited to the conditions of the test site were included. It is more likely that the juvenile growth rate of white ash is slow and therefore not suited to short-rotation plantings.

Green ash

Green ash, as with white ash, performed poorly in terms of dry-matter production in these tests; superior sources from Illinois yielded only 0.44 kg·tree^{-1}·year^{-1}. The reasons for this poor performance may be similar to those discussed above for white ash. However, there is more variability among families for green ash than for white ash, so the opportunities for genetic improvement may be greater.

Black walnut

Black walnut sources from West Virginia performed best in this test, yielding 2.22 kg·tree^{-1}·year^{-1}. The gain from using these sources was estimated to be 37 percent over the "local" source. Although black walnut is most commonly thought of as a high-value timber and veneer species, the yields demonstrated here show that it can also produce substantial quantities of biomass on short-rotations.

Clausen (1983) examined this and six other similar plantations of black walnut located throughout the Lake States to determine how source rankings change over time. He found that the sources which grew best at age ten also were the best at age 15. This means that provenance selections based on 16-year-old trees will hold for younger trees, allowing some flexibility of rotation length.

Tamarack

Differences among tamarack provenances were highly significant and heritability was very high (0.68). Gains of 30 percent over the "local" source were demonstrated for the

Alger County, Michigan provenance. Yield from this provenance was 3.0 kg·tree^{-1}·year^{-1}, which makes tamarack appear very desirable as a biomass species. Riemenschneider and Jeffers (1981) found that the correlation between 14- and 9-year-old tamarack heights and diameters were strong, which indicates that provenances which did well in this test would also be suitable on slightly shorter rotations.

Very little genetic work has been done with tamarack, but the few tests which do exist have shown strong genotype x environment interaction among plantations (Jeffers, 1975; Riemenschneider and Jeffers, 1981). This means that source recommendations may need to be specifically tailored to the site or region of planting. Future work should attempt to find less site-specific genotypes, which would make tamarack easier to establish successfully.

Hybrid poplar

Hybrid poplar has received a great deal of attention as a short-rotation biomass species. New clones have been identified which are better adapted to the conditions of the Lake States, and they have been used to augment or replace the Northeast clones planted in this test. These newer clones tend to be more resistant to the insect and disease pests which plague most clones of hybrid poplar in Michigan (Woods and Hanover, 1982). This plantation serves as an example of the range of yields and pest resistance of hybrid poplar clones, rather than a source of data for making final clonal recommendations.

Growth rates varied significantly among clones in the test plantation and ranged from 0.4 to 3.5 $kg \cdot tree^{-1} \cdot year^{-1}$ at age eight. The best yielding clone was NE-17 (*Populus nigra* x *P. deltoides*); this was also the best clone at age four when Brissette, et al. (1979) analyzed this same plantation. Some clones which had done well at age four were no longer superior at age nine, which is consistent with the experiences of other investigators (Wilkinson, 1973). This indicates that clones which yield well on very short rotations (1-4 years) may not do well on longer rotations (10-15 years), and therefore selections must be tailored to rotation length in some cases. Hybrid poplar clones have also been shown to be very site-specific, so testing of clones must be conducted on many sites to identify and characterize these interactions (Dickmann and Stuart, 1983).

Many clones of hybrid poplar have been identified as having rapid juvenile growth, but this criteria for selection in not sufficient in Michigan. Severe problems have been encountered with cankering diseases such as *Septoria musiva* and subsequent infection by secondary pathogens such as *Fusarium soloni*. The test plantation is severely cankered. Some clones had been killed completely, while others show resistance (although no clone had escaped cankering completely).

Canker resistance must be the prime consideration for selection of hybrid poplar clones in Michigan. The fastest growing clone from among the more resistant clones was NE-207 (*Populus deltoides* x *P. trichocarpa*), which yielded 1.8 $kg \cdot tree^{-1} \cdot year^{-1}$. The lower yield must be accepted if the health of the trees and subsequent sprouts is to be preserved.

CONCLUSION

The results summarized here represent the first efforts to improve eight species for biomass production in Michigan. Provenance and clonal recommendations have been made with the understanding that the heritabilities and gains are probably overestimated due to a lack of testing on multiple sites. Further research efforts must concentrate on improving yields, site adaptability, wood quality, and pest resistance of the more promising species, through progeny and clonal testing, and systematic breeding efforts. Genetic plantations are already being established at Michigan State University for promising biomass species which have not previously been tested in breeding programs. Data from these and other tests, as well as information being generated in cultural experiments, will help to refine the optimum short-rotation, woody-biomass production system for Michigan in the years to come.

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CHAPTER 7

Summary and Recommendations for Future Research

Research conducted since 1978 has provided the basic information needed to begin production of woody-biomass in short-rotation energy plantations in the Michigan, and has identified areas where future research should be concentrated. Species screening has been conducted on abandoned agricultural fields, on clearcut forest sites, and several older single-species test plantings. The data from these tests suggests that the following species are suitable for use in short-rotation energy plantations in Michigan: Scotch pine, red pine, jack pine, Kellogg hybrid pine, larches, hybrid poplar, hybrid aspens, ailanthus, and black locust. The conifers are better suited to the colder and drier sites in the region and the hardwoods to the warmer and more fertile sites. Species-site matching can only be made in a general way at present, due to the limited number of locations tested.

Tree improvement programs and improved cultural techniques promise to increase the site adaptability and growth rates of all biomass species. Many of the species listed above have been investigated, and a great deal is known regarding their genetics and their response to cultural treatments. These species are: Scotch pine, red pine, jack pine, and hybrid poplar. Much less information is available for the remaining five species: Kellogg hybrid pine, larches, hybrid aspens, ailanthus, and black locust. Future research should concentrate on this second set of species to identify the best genetic materials and cultural systems for energy production. Several research projects have begun or are scheduled to begin in the next two years at Michigan State University which are designed to provide this information for these "primary species."

Current projections of plantation yields have been based on small (<0.2 hectare) plots, which lends uncertainty to the figures. Some investigators have applied cultural treatments which resemble those used in modern American agriculture to high density (about 200,000 trees per hectare) energy plantations and have obtained yields as high as 15-20 $Mg \cdot ha^{-1} \cdot yr^{-1}$ in one to two years. It is questionable, however, that the fertilizer and irrigation inputs and the extremely high costs of establishment required to obtain these yields can be justified.

Research conducted at Michigan State University was based on the assumption that more conventional plantation management systems would be better suited to economical biomass production than the intensive cultural systems described above. Certain species, such as Kellogg hybrid pine, have produced as much as 12 $Mg \cdot ha^{-1} \cdot yr^{-1}$ by age 16 years in test plantations using less intensive cultural systems. It is therefore recommended that biomass plantations in the Lake States be established on moderately close spacings (3000 - 5000 trees per hectare) and provided with good weed control for the first two to four years, but with no fertilization or irrigation.

Comprehensive genetic testing and breeding programs have begun for each of the five primary species. This area of research has been shown to have great potential for improving biomass yields. Yield improvements are also being sought through improvements to the cultural systems outlined above. Large-scale spacing studies are planned for each of the five primary species. These investigations are designed to build on the data reported in Chapter 5, and define the optimum planting densities for each species on a range of sites. Built into these investigations is a program to further refine the biomass predictor equations developed in Chapter 3. This will improve the ability of plantation managers to inventory standing biomass and also provide accurate yield figures needed for meaningful economic analysis.

Past research has concentrated on producing large quantities of woody-biomass to be used as fuel in direct combustion or gasification processes. Another area of current research at Michigan State University is designed to look for alternative uses for the biomass which is produced in short-rotation plantations. These include: Fiber for pulp, feedstocks for chemical production processes, animal feed, and nitrogen fertilizer substitutes. All or part of the trees grown may be used to produce these products. This will help to improve the economics for short-rotation plantation systems and to reduce the national dependence on fossil fuels for some of these commodities.

Short-rotation biomass plantations are currently only a theory in the Lake States; no commercial production systems exist. This can be attributed to two major factors. First, the technology for growing and harvesting this type of material is largely experimental, especially for the species which are being recommended. Second, there is currently an excess supply of biomass available in natural stands and older plantations in the region. The second condition will not be true for much longer. Pressure on the available timber resource is already being felt in certain parts of Michigan as paper, pulp, and composition-board manufacturers compete with home and small industrial fuelwood markets. Wood utilization is increasing rapidly and new supplies will be needed soon. It is important that plans be made soon to meet rising demands, due to the long interval between plantation establishment and final harvest (8-15 years).

The first problem can be easily solved through close cooperation between industry and university researchers. Plans are currently being made to involve several industries in Michigan in commercial size plantings of the five primary biomass species listed above. These plantings will serve as proving grounds for the theories developed in the laboratory and in experimental plots, and provide a demonstration of the feasibility of short-rotation biomass production.

Progress toward defining optimal woody-biomass production systems for the Lake States has been substantial.

Species recommendations have been made, cultural systems have been defined, and genetic improvement of many species has begun. Future research should concentrate in the following areas:

1. Refining species-site adaptability.
2. Intensifying genetic screening and breeding programs in the primary species.
3. Refining cultural systems to identify the best planting densities, weed control methods, and harvesting techniques.
4. Improving the ability to predict yields on a range of sites.
5. Searching for additional uses for woody-biomass produced under short-rotation culture.
6. Establishing short-rotation systems as a viable commercial alternative to current production techniques.