ORNL--6625

DE91 001012

ENVIRONMENTAL SCIENCES DIVISION

SHORT ROTATION WOODY CROPS PROGRAM: ANNUAL PROGRESS REPORT FOR 1989

L. L. Wright
A. R. Ehrenshaft*

*Health and Safety Research Division

Environmental Sciences Division
Publication No. 3484

Date Prepared: August 1990

Prepared for the
Office of Renewable Energy Technology
Biofuels and Municipal Waste Technology Division
EB 24 01 00 0

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

CONTENTS

CONTENTS (Cont'd.)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Cont'd.)

ABSTRACT

WRIGHT, L. L., A. R. EHRENSHAFT. 1990. Short Rotation Woody Crops Program Annual Progress Report for 1989. ORNL-6625. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 120 pp.

This report synthesizes the technical progress of research projects in the Short Rotation Woody Crops Program for the year ending September 30, 1989. The primary goal of this research program, sponsored by the U.S. Department of Energy's Biofuels and Municipal Waste Technology Division, is the development of a viable technology for producing renewable feedstocks for conversion to biofuels. One of the more significant accomplishments was the documentation that short-rotation woody crops total delivered costs could be $40/Mg or less under optimistic but attainable conditions. By taking advantage of federal subsidies such as those offered under the Conservation Reserve Program, wood energy feedstock costs could be lower. Genetic improvement studies are broadening species performance within geographic regions and under less-than-optimum site conditions. Advances in physiological research are identifying key characteristics of species productivity and response to nutrient applications. Recent developments utilizing biotechnology have achieved success in cell and tissue culture, somaclonal variation, and gene-insertion studies. Productivity gains have been realized with advanced cultural studies of spacing, coppice, and mixed-species trials.

1. INTRODUCTION

This report is a summary of the technical progress and achievements made in the Short Rotation Woody Crops Program (SRWCP) during FY 1989. The primary goal of this research program, sponsored by the Biofuels and Municipal Waste Technology Division, U.S. Department of Energy (DOE), is the development of technology for producing renewable feedstocks for energy conversion in the form of biofuels. The SRWCP completed its first decade of research activities focused on increasing wood productivity per unit of land area and evaluating cost components. The use of fast-growing short-rotation woody crops (SRWC) that have excellent coppice and cloning potential (i.e., hardwoods) has emerged as the central means for achieving program production and cost goals. Plant breeding, development of clonal propagation techniques, selection of elite clones, and improved culture techniques have brought about productivity gains beyond initial program expectations. Yields of 8 to 17 $Mg \bullet ha\text{-}1 \bullet year^{-1}$ have now become commonplace in research trials.

The SRWCP represents an integrated research program in both scientific initiatives and institutional involvement. Eighteen universities, government agencies, and private cooperators participated nationwide in SRWCP research and technology transfer activities in 1989 (Table 1 and Fig 1). The SRWCP funding level for FY 1989 necessitated cutbacks in the number of projects supported by the program (down from 23 the previous year) and in the amount of money awarded to each institution. Several of the 18 institutions cooperated under no-cost extensions or no contract for a portion or all of the year. Administration of program subcontracts and data synthesis are accomplished by management staff in the Environmental Sciences Division at the Oak Ridge National Laboratory (ORNL).

Research projects supported by the SRWCP in 1989 have progressed in describing the physiological mechanisms of high yield in poplar species and in developing genetic improvement programs for three additional SRWC species. One 10-year cultural/economic evaluation project has been completed, a "woodgrass" study has begun to produce results, and propagation techniques for two species have been greatly improved. Two out of three industry cost-shared monoculture viability/scale-up studies survived both drought and funding cuts. Additional scale-ups in the Southeast are surviving as a result of forest industry and municipal interest, but DOE-supported data

Table 1. Short Rotation Woody Crops Program projects

Institution	Investigator	Title
Amana Society[a]	D. Shoup	Monoculture viability trial of woody crops for energy production
BioEnergy Development Corporation[b]	T. B. Crabb	*Eucalyptus* plantations for energy in Hawaii
University of Georgia	B. C. Bongarten L. R. Boring R. O. Teskey	Optimizing energy yields in black locust through genetic selection
Institute of Paper Chemistry	R. J. Dinus	Review and summary of efforts to alter the composition of woody plants
Iowa State University	R. B. Hall E. Hart H. S. McNabb, Jr.	Selection and breeding of pest-resistant clones of *Populus* for biomass energy production in the North Central Region
Kansas State University[b]	W. A. Geyer	Great Plains energy forest research program
Michigan State University	D. I. Dickmann K. S. Pregitizer	Net assimilation and photosynthate allocation of *Populus* clones grown under short-rotation intensive culture: physiological and genetic responses regulating yield
Mississippi State University	S. B. Land	Early selection criteria and clonal propagation methods for increased productivity of sycamore in short-rotation energy systems
North Carolina State University[b]	D. J. Frederick R. C. Kellison	Silvicultural and harvesting systems for producing fuels from woody biomass in the Southeast
North Carolina State[c] University	R. Lea	Short-rotation sweetgum plantations: establishment and care in the southeastern United States
Oak Ridge National Laboratory	R. J. Norby	Optimum nitrogen nutrition in short-rotation sycamore plantations
Pennsylvania State University	P. R. Blankenhorn T. W. Bowersox C. H. Strauss	Economic analyses for producing *Populus* hybrids under four management strategies
Southern Illinois University	W. C. Ashby J. E. Preece P. L. Roth	Genetic Biomass and growth analyses of clonal silver maple (*Acer saccharinum* L.) in several locations

Table 1 (continued)

Institution	Investigator	Title
Tuskegee University, Carver Research Foundation	A. Weaver	Nutrient optimization research
USDA FS North Central Forest Experiment Station	E. Hansen	Short-rotation woody crops trials for energy producing in north central United States
USDA FS Pacific Northwest Forest and Range Experiment Station	D. S. DeBell M. A. Radwan	Increasing the biomass production of alder and cottonwood plantations in the Pacific Northwest
USDA FS Pacific Southwest Forest Experiment Station	C. D. Whitesell	*Eucalyptus* plantations for energy production in Hawaii
University of Washington/ Washington State University	R. F. Stettler T. M. Hinckley P. E. Heilman	Evaluate *Populus* selections for fuel wood (U.S.-India Science and Technology Initiative)

[a]Other institutions cost sharing the Amana Society contract include Iowa State University, the Iowa Department of Natural Resources (DNR) Energy and Geological Resources Division, and the Iowa DNR Forestry Division.

[b]Institutions cooperating with the SRWCP under no-cost extension or receiving funding for only a part of FY 1989.

[c]Industries cost sharing the monoculture viability trial work led by North Carolina State University include Federal Paper Board Company, Inc., and Scott Paper Company.

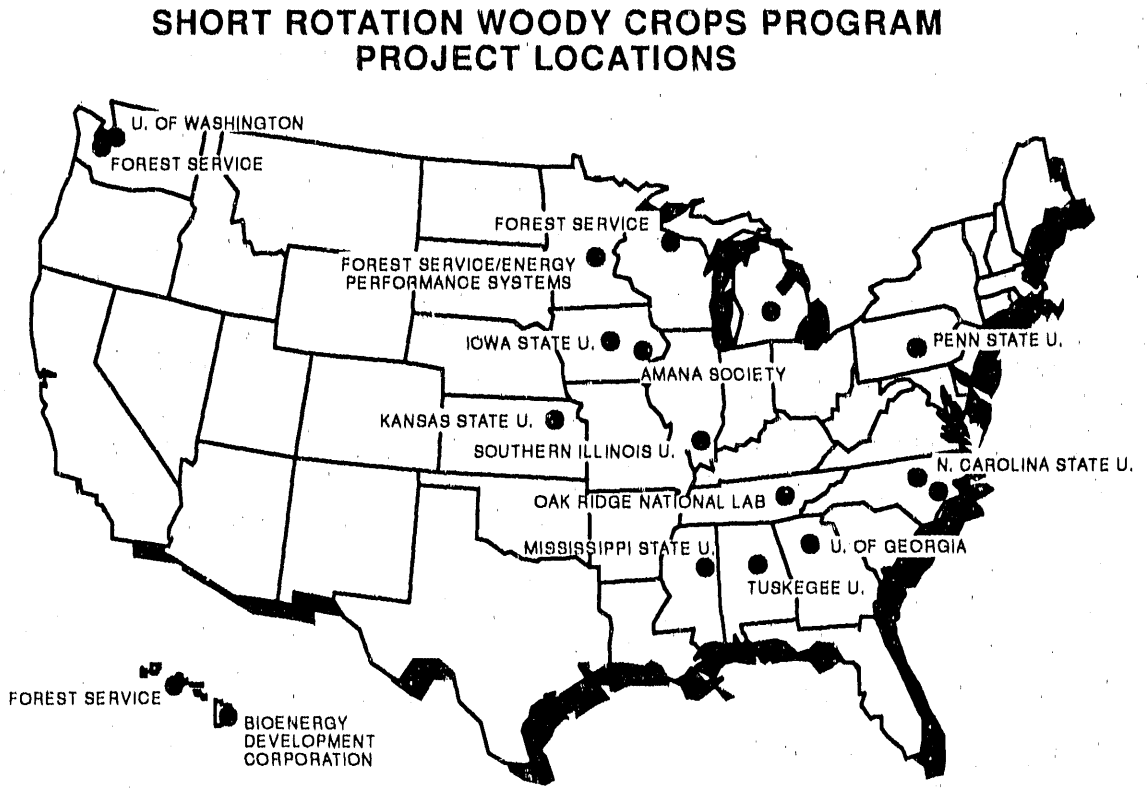

Fig. 1. Short Rotation Woody Crops Program project locations.

collection has terminated. Results of projects under active contract for at least a portion of the year are summarized by project in Sect. 5, production and cost overviews are presented in Sects. 3 and 4, and a brief discussion of progress toward program goals is presented in Sect. 2.

2. PROGRESS SUMMARY

2.1 TECHNOLOGY DEVELOPMENT

Delivery of plantation-grown wood energy feedstocks at prices that are competitive with coal, gas, and oil requires that high productivity goals be achieved. The major focus of the SRWCP during its first decade has been the development of the research base and infrastructure needed to ultimately reach such productivity rates. Significant progress has been made in both of these areas.

An example of the research base is the information that has been developed on relatively small plots, providing an estimate of operational productivity and costs. The "average" 1989 yields (Table 2) are selected values from production research results considered most representative of SRWC technology in each geographical region. The 2010 research goals (Table 2) are set at sufficiently high levels to ensure achievement of the cost goal of $1.92/GJ. They are believed to be reasonable because they are less than "record" yields that have already been observed in small plot SRWC trials. The status of SRWC production trial and exploratory trial results will be summarized in Sect. 2.

The research base also includes estimates of total delivered costs of SRWC feedstocks. The best-known cost components are those associated with establishment since SRWCP-funded scale-up trials, operational experience, and research experience have provided numerous sources of information (see Sect. 4). Annual costs of plantation tending under normal conditions can be reasonably estimated, but the cost of protecting plantations from as yet undetermined pests and diseases cannot be well defined. Harvest and handling costs vary widely, depending on assumptions regarding equipment used and degree of processing occurring in the field. The basis for the cost estimates in Table 2 was a recent synthesis of costs observed or projected for operational-scale hybrid poplar plantations, assuming production of wood chips as the final delivered product (Strauss and Wright, in press). Sensitivity analysis was used to determine the effect of regional land rental values and yield differences on costs, assuming all other inputs were the same (see discussion in Sect. 4). The results suggest SRWC costs in the range of $2.00 to $3.00/GJ anywhere in the United States where medium-to-good cropland can be converted to producing SRWC feedstocks for chips. If SRWC wood can be handled and used for

Table 2. Short Rotation Woody Crops Program 1989 research status and future research goals by region

Regions	1989 Research status			2010 Research goals			
	Yield[a] (Mg ha^{-1} year^{-1})	Cost[b] ($/GJ)	Cost ($/Mg)	Yield[c] (Mg ha^{-1} year^{-1})	Cost ($/GJ)	Cost ($/Mg)	2010 Land resource[d]
Northeast (NE)	9	2.75	54.45	15	1.90	37.62	0.5
South/Southeast (S/SE)	9	2.51	49.70	18	1.90	37.62	5.0
Midwest/Lake (MW/L)	11	2.75	54.45	20	1.90	37.62	21.0
Northwest (NW)	17	2.15	42.57	30	1.90	37.62	1.2
Subtropics	17	2.36	46.73	30	1.90	37.62	0.5

[a]Dry weight, aboveground, leafless standing yields at harvest age. Numbers are selected values from production research results considered most representative of current technology in the region. Yield after processing and storage is assumed to be 15% less than standing yields.

[b]Delivered costs of chips including production, harvest, in-field chipping, and transportation costs and regional land costs, assuming yields shown in column one and no federal subsidies. Assumed land rental rates of $100/ha in NE, $75/ha in SE, $150/ha in MW/L, $150/ha in NW, and $200/ha in subtropics.

[c]Dry weight, aboveground, leafless standing yields at harvest age. Numbers are based on projections of possible "average" yields if the best available plant materials were further improved for disease resistance and adaptability.

[d]The potential land base that is estimated to be available and capable of sustaining economically viable energy crop production by 2010, assuming average annual budgets of $10 million or more to allow development of several species. With continued research, up to 77 million ha might produce economically competitive energy crops by 2030.

energy production in essentially "whole-tree" form, as proposed by the whole-tree burner concept (described in Sect. 4), then SRWC feedstock costs could be considerably less.

A major topic of current interest is the actual amount of suitable land on which competitively priced feedstocks for energy can be produced now and in the future. Given current and predicted prices for coal, gas and oil, SRWC delivered costs would have to be $1.90/GJ or less to be competitive as an energy feedstock. Although, as Table 2 indicates, estimated 1989 costs of producing, harvesting, and delivering chipped SRWC feedstocks is higher than this amount in all regions, there are some conditions currently existing under which SRWC crops may produce net profits for landowners and provide a competitive feedstock. These conditions involve the utilization of land qualifying for federal subsidies [e.g., the Conservation Reserve Program (CRP)], particularly in the Midwest/Lake States Region, where relatively high-quality land is being enrolled. In the states of Minnesota, Wisconsin, Iowa, Illinois, and Missouri, about 1.5×10^6 ha have been enrolled in the program. Although this amount of land could not make an appreciable impact on supplying energy for the region, it could serve as a land base for demonstrating SRWC systems. The land resource estimated to be economically available by 2010 is based on distribution of cropland in the United States and current trends toward removal of cropland from food crop production. Exact quantification of the land available is impossible, because policy decisions at the federal level could have major impact.

The summary provided by Table 2 of the 1989 research status in comparison with 2010 goals indicates areas where additional investments in developing the research base are necessary. For instance, major investments in genetic research are needed to improve the yield levels of model SRWC species, and regionally oriented research will have the highest payoff in the Midwest/Lake States and the South/Southeast if the large potential land resource for those regions is to be brought into production. The table does not indicate, however, the research that is needed on harvesting and handling systems to bring down the feedstock costs in all regions. Also not identified are more subtle research needs such as work related to environmental issues that could affect the way the technology is perceived and accepted by the public or the fact that a greater variety of species may be needed to optimally utilize the available land base. Table 2 is meant to be a general guideline of milestones against which the progress of the research is measured.

There are many aspects of progress in the program that cannot be measured in terms of yield levels and cost estimates. The infrastructure that is being developed by the SRWCP is very important. Experts familiar with the concepts of short-rotation forestry and improved genetic materials of several species will be critically needed if the country chooses to increase its reliance on biomass energy resources. The value of the training provided by the SRWCP can already be seen in the fact that many SRWCP researchers are beginning to be called on to serve as consultants to municipalities and industries for assistance in establishing SRWC trials. Additionally, the SRWCP has been very successful at facilitating integrated research, both within and among institutions, particularly on the principal model species, poplars. One of the benefits of integrated research teams is that often one or more of the researchers has funding from other agencies, such as National Science Foundation (NSF) or U.S. Department of Agriculture (USDA), for work on basic problems that enhance the overall team effort. SRWCP-funded research on understanding the physiology of SRWC systems and on applying biotechnology tools to solving SRWC problems is at the forefront of forest science. The building of scientifically respected research teams is a measure of progress of the SRWCP. The continued availability of this cadre of researchers and technicians for research on energy crops is a significant national resource.

2.2 RESEARCH AND ASSESSMENT NEEDS

Although progress in development of the technology has been significant, there are many questions and concerns remaining that suggest the appropriate direction of the program's attention in the next few years. The widespread concern about the environment from all aspects is one of the issues that will drive research in the SRWCP. The increased interest in finding ways to mitigate atmospheric CO_2 provides an additional incentive for developing all aspects of biomass energy technology because production and use of biomass crops for energy results in little to no net addition of CO_2 to the atmosphere. Use of biomass energy in place of fossil fuels could play a significant role in meeting future CO_2 emission goals. However, questions are arising about what exactly is the carbon cycle in biomass energy systems, how much is stored in roots, how much is released during establishment and maintenance of the plantations, and how efficiently can biomass be converted to energy? Answering these questions will require a combination of

analysis of data already available and new research to learn more about what is happening in the soil and roots.

Although atmospheric CO_2 emission reduction is a clear environmental benefit of biomass energy use, questions are also arising about what negative environmental impacts will occur if millions of acres of land in the United States are dedicated to production of energy crops. To answer these questions, assessments are required to evaluate the land base more carefully to determine where and what type of land would likely be used. Additionally, ongoing and proposed field trials need to include evaluation of the environmental effects of various maintenance activities. To meet the need for more environmental effects research, more large-scale sites that incorporate a research component need to be established so that biological, economic, and environmental risks can be evaluated under a wider variety of conditions. Increased cooperative research and development with the private sector would seem to be the most effective way to meet this need. There is also a need for additional small-scale research trials to develop new or alternative cultural practices that can mitigate some of the environmental concerns that are being raised. For instance, some research on intercropping with legumes or other cover crops during the first couple of years of stand establishment and additional research on developing techniques for managing mixed plantings of nitrogen fixing and non-nitrogen fixing of trees would be desirable.

Because the federal government, private sector utilities, and many environmental organizations are at a stage at which new policy considerations are being evaluated (e.g., the 1990 farm bill), the demand for information on biomass energy crops is almost overwhelming. To meet this need, consideration is being given to reorganizing to include a biomass information center as part of the ORNL Biomass Production Program's mission. Increased program funding would be required, however, before this could be done. In addition to simple information requests, the demand is very strong for assessments of projected energy production levels and the consequent environmental and economic effects, given various levels of research effort or varied government incentives. This demand is being met by the program management staff at ORNL with preliminary roughcut analysis, but it is anticipated that additional effort will need to be allocated to more sophisticated analysis during the next year or two.

Research and development needs are still very strong in the area of developing improved harvesting and handling systems and in developing genetically improved plant materials. The latter research is ongoing and will be detailed in Sect. 5, but harvesting research is currently at a standstill. Increasing cooperation between USDA and DOE is being facilitated through a Memorandum of Understanding recently signed at the secretarial level of the two agencies. It is expected that one productive area for cooperative research will be in the development of harvest and handling equipment.

3. SHORT-ROTATION WOODY CROPS PRODUCTIVITY

The yield data most recently collected by the SRWCP are summarized in Tables 3 and 4. Table 3 summarizes the 1988 growing season yield results from SRWCP experimental production trials by region, species, and test design. To fit into this category, the experimental treatment plots must contain 225 or more trees, with at least 100 trees within the bordered measurement plots. In several cases, reported results were obtained earlier than 1989 but represent the most recent data available for those regions. The amount of new yield data reported this year was relatively small because several of the ongoing projects are either not conducting field oriented production research (reduced funding) or they just recently established the field trials and have not yet estimated yields.

The average yields reported in Table 3 range from 5 to 24 Mg/ha, the highest yields being found in the subtropics and the Pacific Northwest. The average yields reported from the Midwest and South are currently among the lowest reported, but this may be temporary. However, growth rates being observed in the monoculture trials of hybrid poplars in the Midwest suggest that higher yields will soon be documented for the region. Operational plantings using SRWC techniques have recently been established in the South/Southeast. Age 1 and 2 growth is very good, but data are insufficient data for projecting harvesting yields.

The exploratory yields given in Table 4 point the way to the future of SRWC hardwoods. Exceptionally high yields were obtained in 1988 by second-rotation *Populus trichocarpa* x *deltoides* hybrids in the Pacific Northwest (43.5 $Mg \bullet ha^{-1} \bullet year^{-1}$) and are still the highest reported anywhere in the United States. New exploratory yield data should soon be available from physiological/genetic studies initiated in 1987 with silver maple, black locust, and sycamore. Although the high yields reported in Table 4 have been obtained only in exploratory research experiments, they suggest that we have only begun to exploit the genetic potential of hardwoods for high juvenile growth rates. These results mandate a continuing search for the physiological mechanisms responsible for such high production rates so that the knowledge can be applied to developing better SRWC hardwoods for all regions of the United States.

There are many limitations to the current research information base on SRWC yield estimates. For instance, the data that currently represent the Midwest are based on

Table 3. Most recent Short Rotation Woody Crops Program yield data (March 1989)—experimental yields based on a treatment plot with approximately 225 or more trees (including border trees)

Region	State	Species	Test type	Root age	Stem age	No. treatments	No. replicates	Yield (dry Mg•ha^{-1}•year^{-1})		
Northeast	PA	*Populus* hybrids	Culture	8	4	8	3	10.4	9.3	12.1
Lake States/ Midwest	WI	*Populus* hybrids	Clone/spacing	8	8	11	2	7.5	5.3	10.3
			Spacing	12	12	2	4	7.5	6.5	8.4
Pacific Northwest	WA	*Populus* hybrids	Woodgrass	3	1	4	3	8.2	8.0	8.9
			0.5 x 0.5 m	3	3	2	3	15.1	14.3	15.8
			1 x 1 m	3	3	2	3	14.4	10.0	18.7
			2 x 2 m	3	3	2	3	10.2	4.5	15.8
Subtropics[a]	HI[a]	*Eucalyptus saligna*	Spacing	4	4	4	4	8.9	5.4	14.4
			Spacing	8	8	4	5	12.8	11.6	14.0
	HI[a]	Mixed	Species mix	5.4	5.4	3	9	11.2	6.8	17.3
			Species mix	4	4	7	4	23.6	16.7	27.5
Southeast[a]	AL[a]	Mixed	Spacing	6	6	9	6	6.6	5.3	7.4
				6	3	9	6	5.3	4.8	6.3
	NC	*Liquidambar styraciflua*	Monoculture	2	2	1	32[b]	0.97		
			Weed free	2	2	1	8[b]	1.15		
			Monoculture	1	1	1	32[b]	0.08		
			Weed free	1	1	1	8[b]	0.09		

[a]Data are from earlier years and are most recent available for the region.
[b]Number of subplots, rather than number of replicates.

Table 4. Most recent Short Rotation Woody Crops Program yield data (March 1989)—exploratory yields based on less than 225 trees per treatment plot (including border trees)

Region	State	Species	Test type	Root age	Stem age	No. treatments	No. replicates	Yield (dry Mg•ha^{-1}•year^{-1}) Av	Min	Max
Subtropics	HI	*Eucalyptus grandis*	Spacing	5	5	4	4	22.0	19.0	27.6
			Spacing	5	5	6	4	16.9	12.7	24.2
Pacific Northwest	WA[a]	*Populus trichocarpa*	Provenance	8	4	51	3	11.3	3.13	32.6
		Populus hybrids	Clonal	8	4	3	3	32.8	21.5	43.5
		Populus/Alnus	Species mix	8	4	28	3	11.4	-	-
	WA	*Alnus rubra*	Spacing	7	7	3	2	3.6	2.0	5.0
			Fertilizer	3	3	2	3	13.0	11.6	14.3
				4	4	2	3	11.1	7.8	14.4
Southeast	FL[a]	*Pinus elliottii*	Fertilizer	8	8	3	3	14.1	13.5	14.8
			Selection	8	8	-	3	15.2	-	18.4
			Nelder	8	8	-	8	18.2	-	22.7
	GA	*Robinia pseudoacacia*	Culture	1	1	4	2	1.0	0.5	1.6
	MS	*Platanus occidentalis*	Root growth	1	1	2	5	0.34	-	0.37

[a]Data are from earlier years but are the most most recent expiatory yields reported for the region.

trials in one location (Rhinelander, Wisconsin), which is somewhat atypical for the region because it has a shorter, harsher growing period. Newly established monoculture and clone/site trials established in the Midwest will provide some excellent data in the future. In the South/Southeast, several trials were initiated at a range of sites in the early 1980s, but most were on nutrient-deficient soils and/or suffered from inadequate weed control. Those trials were discontinued, and the data are not included in Tables 3 and 4. The most recent data from the South/Southeast are from very recently established trials with trees only 1 or 2 years old. The Northeast is represented by data on one clone from one location in central Pennsylvania. The limited locations on which SRWC crops are currently being evaluated using the improved techniques developed over the past 10 years present a serious problem for estimating potential production levels over a large land base. Collection of data from several additional regions and site types is needed to provide a truly representative information base on the yield potential of SRWC in the United States.

Although yield prediction remains uncertain, considerable information has been gained on factors required to obtain acceptable yields and the research problems that remain to be addressed. For example, the benefits of weed control for survival and accelerated growth have been established in numerous trials, but specific methods for achieving good weed control in SRWC plantations, especially under operational conditions (e.g., type, quantity, and application methods for herbicides), are not well known by extension or industry people. Furthermore, labeling of potentially useful chemicals for SRWC plantations is generally inadequate. Information on how to achieve the benefits of weed control without exposing the soil to erosion during the first 2 years of plantation establishment is sorely lacking. These information gaps represent a major challenge to successful commercialization of SRWC techniques by the private sector.

4. SHORT-ROTATION WOODY CROPS ECONOMICS

The economic competitiveness of SRWC systems in the United States varies widely depending on a large number of factors such as end-product use and price, conversion technology, yields, and land costs. SRWC systems are considered to be economically viable for production of a stable, secure supply of wood for pulp under some conditions, as evidenced by the recent increase in interest in SRWC systems by several pulp and paper companies. There are also a few conditions under which production of wood for energy feedstocks could be viable today. This section will review analyses that describe conditions under which SRWC might be competitive as an energy feedstock if markets were available. The most recent data available on actual costs incurred in the initial establishment of SRWC plantings will also be summarized.

4.1 COMMERCIAL HYBRID POPLAR PLANTATIONS SYSTEM AS SOURCE OF CHIPPED FEEDSTOCKS

A paper prepared in 1989 by Dr. C. H. Strauss of Pennsylvania State University and L. L. Wright of ORNL (Strauss and Wright, in press) presents an overview of possible costs incurred in production of wood energy feedstocks for ethanol production in a commercial poplar plantation in the United States. The analysis assumed no federal subsidies with chipped biomass as the delivered material. Production costs for poplar plantations were synthesized from data available from a series of commercial-sized research plantations established with funding assistance by DOE. The plantation designs evaluated assumed establishment of hybrid poplars planted on relatively good agricultural sites at spacings of 1700 to 3500 cuttings/ha with probable rotations of 5 to 8 years. Operational requirements included a fall/spring site preparation sequence, followed by spring planting and herbicide applications. Annual charges were assessed for insecticide/fungicide applications, fertilizations, land costs, and managerial expenses. A discounted cash flow analysis developed for the SRWCP by Pennsylvania State University was applied to alternate-length rotations, with a minimum cost criterion used in selecting the optimum length.

Using an estimated growth curve for trees planted at 2100 trees/ha and a targeted yield of 16 dry Mg $ha^{-1} \cdot year^{-1}$, the discounted cash flow analysis of operating costs and

predicted yields placed the least-cost solution in the 6th year with production costs (exclusive of harvest, transportation, and chipping) of about $17.00/dry Mg under a two-rotation system. A third rotation at the same yield level would reduce the preharvest production cost to $15.45/dry Mg. The operating costs assumed are summarized in Table 5. Site preparation, fertilization, and planting represented 38% of this cost, with annual management and maintenance contributing another 20% and land rent and taxes the remaining 42% (Fig. 2).

The preharvest production of hybrid poplar wood energy feedstocks at $15 to $17/dry Mg would be within the competitive range of prices for wood from domestic U.S. forests. Additional harvesting, chipping, and transportation costs for SRWC energy feedstocks were projected to be about $20 dry/Mg, which, when combined with an 85% net delivery of plantation yields, would place the delivered costs of the feedstocks near $40/dry Mg (Fig. 3).

The analysis by Strauss and Wright (in press) incorporated a reasonable harvest/handling/transportation scenario that had emerged from previous evaluations by Strauss et al (1988) based on several trials of harvest and handling prototypes. It follows traditional thinking in assuming that chipping is part of the feedstock production cost. This idea may need to be reexamined if whole-tree burners become end-users of SRWC wood instead of or in addition to conversion processes requiring chips. Two factors stand out in this analysis: the major impact of land within the SRWC cost structure and the importance of high yields in reducing the unit cost of biomass.

4.2 SENSITIVITY ANALYSIS OF EFFECT OF LAND COST ON SRWC PLANTATIONS

The cost of land, as projected by various SRWC studies (Lothner et al. 1985, Strauss et al. 1988), is usually a direct reflection of its productivity in other agricultural pursuits. Good-quality agricultural land derives its market value from the net returns secured in various cropping enterprises (which are strongly affected by farm programs and subsidies tied to land). For SRWC plantations to compete for this resource, comparable or higher net returns must be available from the production of woody biomass. The goal is to obtain competitive net returns without federal subsidies. The option of using lower

Table 5. Establishment and maintenance costs for SRWC plantations

Operations	Cost components	$/ha
Fall Establishment:		
Total kill herbicide	Machine and labor	5
	Materials (1.5 kg/ha)	75
Mowing/brushing	Machine and labor	20
Plowing	Machine and labor	35
Liming	Machine and labor	7
	Materials (2.0 Mg/ha)	68
		210
Spring Establishment:		
Disking	Machine and labor	12
Pre-emerg. herbicide	Machine and labor	5
	Materials (1.8 kg/ha)[a]	90
Fertilization	Machine and labor	14
	Materials (60 kg/ha each N,P,K)	43
Planting	Planter and labor	22
	Material (2100 cuttings/ha)	105
		291
Summer Establishment:		5
Herbicide-year 1	Machine and labor	55
	Materials (1.1 kg/ha)[a]	
Herbicide-year 2	Machine and labor	5
	Materials (1.1 kg/ha)[a]	55
		120
Maintenance:		
Insecticide/funggicide	Machine and labor	3
(years 2,4,6)	Materials (1.6 kg•ha^{-1}•appl.$^{-1}$)[b]	22
Fertilization	Machine and labor	
(years 3,5,7)	Materials (120 kg•ha^{-1}•appl.$^{-1}$ of N)	8
		27
Land rent	(5.0% of $1700/ha)	85
Land taxes	(0.75% of $1700/ha)	13
Managerial	Labor and facilities	35
	av. annual	163

[a]Combination of linuron/glyphosate.
[b]Combination of Sevin/Dylox.

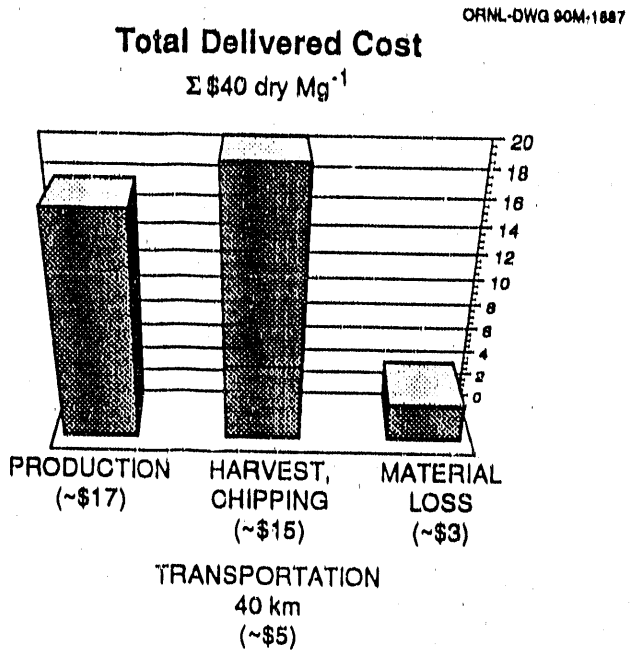

Fig. 2. Relative proportion of costs allocated to each component of SRWC preharvest production costs.

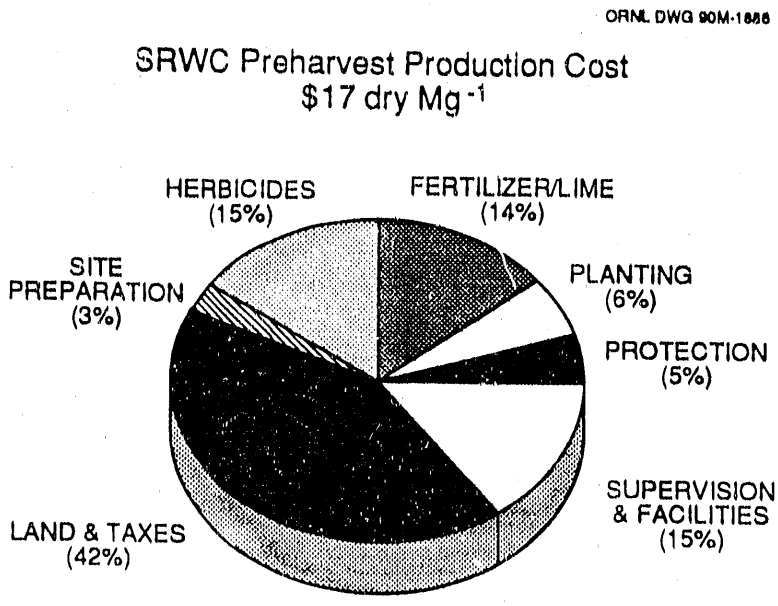

Fig. 3. Relative proportions of the total SRWC delivered cost.

priced, marginal lands would reduce the cost impact but, in all probability, would also lower the yield potential of SRWC.

The land rent with taxes assumed for the Strauss and Wright (in press) analysis ($98/ha) was slightly less than the 1988 average rental rates for farmland in the United States. However, farmland varies considerably in value over the regions in which SRWC is currently being evaluated. Examples of land rental rates are: Iowa, $237/ha; Minnesota, $148/ha; Pennsylvania, $113/ha; Georgia $82/ha; Washington (nonirrigated), $125/ha; and Alabama, $74/ha (USDA/ERS 1989).

A preliminary sensitivity analysis was conducted by J. W. Johnston of ORNL to determine how changes in land cost might affect the final delivered cost. The vehicle used for analysis was a SRWC cost accounting model developed by A. F. Turhollow (ORNL). The same operational and rotation length assumptions made by Strauss and Wright (in press) were used but applied to three rotations. No drop in yield over the three rotations; a discount rate of 5%[1]; and a aggregate harvest, handling, and transportation cost of $20.80/Mg were also assumed. Four different standing yield levels and five different land rent values were analyzed. Wood losses during handling and storage were not taken into account by the model. Input values (such as fertilization level) were not changed to accommodate higher yields. This premise should be refined in later analysis, but it is feasible to assume that yield differences could be attributed to species selection and genetic improvement. The results are plotted both in terms of dollars per megagrams and dollars per gigajoule, assuming a value of 19.805 GJ/Mg of biomass (Fig. 4). Because losses due to harvest and storage were not taken into account by the model, one should derive final feedstock cost as a function of standing yield by assuming a 15% yield reduction before interpreting the cost.

The results demonstrate that low yield situations are more sensitive to land cost increases than are high-yield situations. They further show that, given the production and harvesting/transportation cost assumptions, the cost goal of $1.90/GJ could be obtained with stand production levels of 13 Mg/ha or higher on land with annual charges of $50 to

[1]It has been recently learned that the federal government's Office of Management and Budget is now recommending a 10% discount for this type of analysis, which would result in slightly increased cost projections.

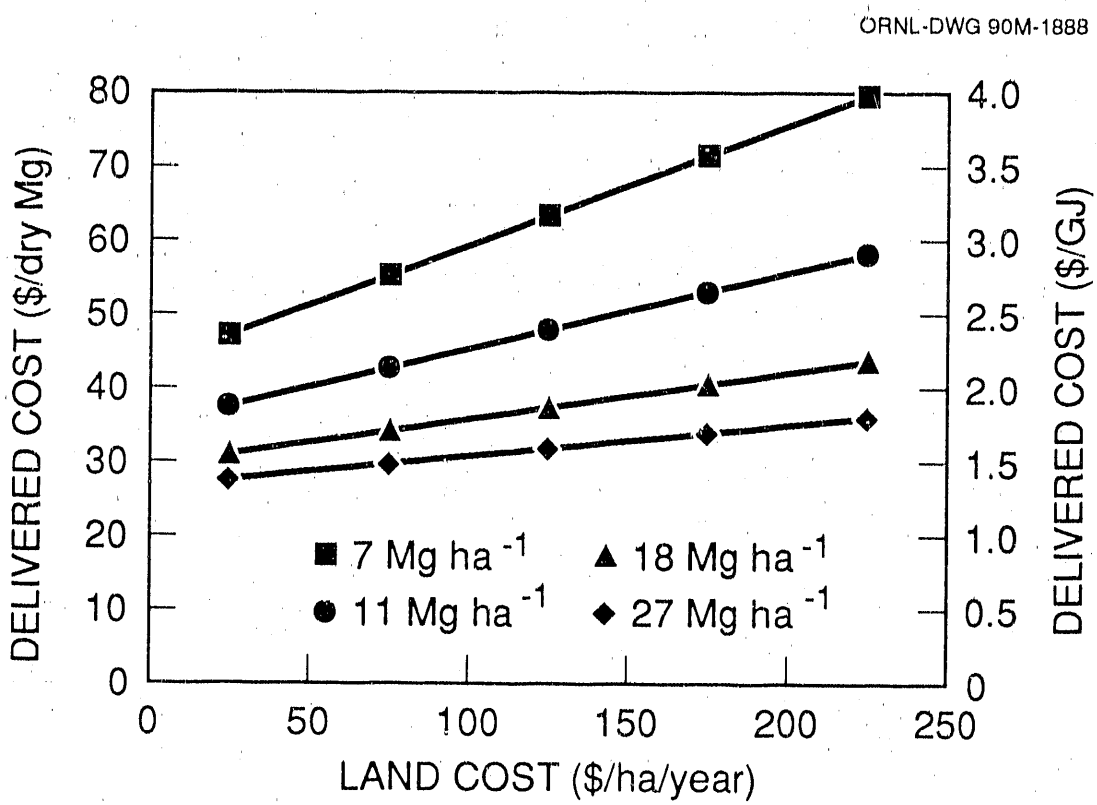

Fig. 4. SRWC delivered cost ($/dry Mg and $/GJ) for wood chips harvested on a 6-year rotation as a function of land cost and yield.

$150 ha/year. It is clear that standing SRWC yields have to be improved beyond the 11 dry Mg•ha^{-1}•year^{-1} that is generally agreed to be a good estimate of the "average" yield that might currently be obtained over a range of site types. Furthermore, it is likely that land at a rental value of $50/ha would require additional site preparation activities than were assumed in the Strauss and Wright (in press) analysis. SRWC yield potentials in the range of 20 to 30 dry Mg•ha^{-1}•year^{-1} are necessary to ensure that land with good productivity potential is allocated to production of SRWC feedstocks.

4.3 POTENTIAL SRWC FEEDSTOCK PRODUCTION COSTS IN THE NORTH CENTRAL REGION, WITH AND WITHOUT GOVERNMENT FINANCIAL INCENTIVES

A recent analysis prepared by D. C. Lothner, E. A. Hansen, and D. A. Netzer of the USDA Forest Service (Lothner et al. 1988) investigated the financial attractiveness of two woody biomass plantation alternatives for agricultural land: a basic SRWC plantation system on average agricultural land and a system on erodible agricultural land that is eligible for government financial incentives through the CRP. The methods involved in the analysis are described in Lothner et al. (1988). They differ from the Strauss and Wright (in press) analysis in that a product value is assigned and investment criteria (net current value and internal rate of return) are determined, as opposed to simply determining the costs involved.

The CRP was authorized by the Food Security Act of 1985 (i.e., the 1985 Farm Bill). The program encourages farmers through 10-year contracts and annual payments from USDA to reduce erosion on highly erodible cropland by planting a protective cover of grass or trees. If bids for enrollment are accepted, the landowners can receive annual payments to cover land rental costs and payment of up to 50% of the costs of establishing permanent vegetative cover. Eligibility is limited to "highly erodible" cropland, filter strips, certain woodland areas, and fields having evidence of scour erosion. Such land could be suitable for SRWC energy plantations.

The SRWC management assumptions used by Lothner et al. (1988) for an average agricultural site were very similar to those used by Strauss and Wright (in press) described above. The primary differences in management assumptions were (1) cultivation, in addition to herbicides, would be required in the first and second year to control weeds;

(2) liming would not be necessary; and (3) fungicide/insecticide applications would not be needed. A system utilizing a longer rotation length (11 years) was assumed because a stipulation of enrollment in the CRP is that no harvest can occur for 10 years. To accommodate the longer rotation, a slightly lower density of about 1736 trees/ha was utilized. The yield assumption used for analysis was production of 15.7 dry Mg•ha^{-1}•year^{-1}.

On the erodible sites enrolled in the CRP, site preparation assumptions differed. Because of erodibility of the site, site preparation is assumed to require band spraying and plowing of strips rather than doing so for the whole site. Later weed control management is essentially the same as for average agricultural lands, except that cultivation is only done within the strips.

The Lothner et al. (1988) cost assumptions on harvesting, handling, and transportation include some innovative new ideas that merit consideration and testing but have not been demonstrated operationally. For purposes of the comparison being made, it is only important to know that harvesting and transportation costs were the same in both cases. The market value of the biomass was placed at a low figure of $20/dry Mg, which is equivalent to the cost of coal in the region. Cost assumptions with and without CRP payments are summarized in Table 6.

Using a 4% discount rate and the production input values in Table 6, the SRWC plantation on erodible agricultural land with a CRP financial incentive resulted in a highly positive performance based on investment criteria, whereas without CRP payments investment returns were negative (Table 7). This analysis suggested that SRWC production on land enrolled in the CRP could provide feedstocks at a highly competitive cost if the management and harvesting assumptions are correct.

A sensitivity analysis by Lothner et al. (1988) showed that significant factors affecting investment performance were the product sale value and yields. If the market value of the wood were to increase to just over $28/dry Mg, SRWC plantations in the North Central Region could break even without federal incentives, as long as yields of about 16 Mg•ha^{-1}•year^{-1} could be obtained. However, yields in the range of 11 Mg•ha^{-1} year^{-1} would not break even unless market prices were at least $36/dry Mg. At a fixed yield, land rent was determined to be the most important cost factor, with transportation and harvesting costs following close behind.

Table 6. A comparison of cost components of SRWC plantations grown on average cropland without CRP payments and on erodible cropland with CRP payments at 2.4 by 2.4 m spacing and on 11-year rotation[a]

Cost component	Value for average cropland	Value for erodible cropland	Year(s) occurring
Land rent, $/ha	$99.00	$99.00	1–11
Land taxes, $/ha	$12.00	$12.00	1–11
Site preparation, $/ha	$172.00	$105.00	1
Planting, $/ha	$296.00	$296.00	1
Cultural tending, $/ha	$222.00	$259.00	1
Cultural tending, $/ha	$37.00	$37.00	2
Fertilizing, $/ha	$99.00	$99.00	2
Harvesting, $/dry Mg	$5.50	$5.50	11
Transporting, $/Mg^{-1}•km	$0.055	$0.055	11
Harvest yield, dry Mg/ha	172.7	171.7	11
Product value, $/dry Mg	$20.00	$20.00	11
CRP annual payment, $/ha		$173.00	1–10
CRP establishment cost payment, $/ha		$383.00	1

[a]From Lothner et al. 1988.

Table 7. Investment performance of two SRWC systems[a]

Management alternative	Net present value ($/ha)	Internal rate of return (%)
SRWC plantation on average agricultural land without a Conservation Reserve Program	-975	<0
SRWC plantation on erodible agricultural land with a Conservation Reserve Program	898	27

[a]From Lothner et al. 1988.

A critical consideration not directly addressed by the Lothner et al. (1988) analysis was whether the erodible cropland being enrolled in the CRP program can produce the same yields as agricultural land that might not be as highly erodible. This question is currently being evaluated by SRWCP-funded hybrid poplar clonal test plots established over a range of sites in the North Central Region and by large plantings of hybrid poplars actually being established on land enrolled in the CRP in the region.

Although there is a considerable amount of land already enrolled in the CRP, it is still not reasonable to use the CRP case as a standard for defining SRWC costs. It is unlikely, for instance, that conditions would exist in which large amounts of land enrolled in the CRP would exist close to a power plant facility. Thus, to obtain an adequate supply, a power plant facility would have to persuade landowners to use whatever land is available. Furthermore the CRP is making commitments for only 10 years, and the last sign-up period will occur soon unless the program is extended. Nevertheless, the comparison of the advantages provided by the CRP does demonstrate how federal policy could affect landowner attitudes towards wood energy crops. Such programs may be needed to begin to get wood energy feedstocks established, which in turn might provide the incentive needed to consider wood as a serious energy feedstock.

4.4 SUMMARY OF CURRENT ESTIMATED AND ACTUAL SRWC ESTABLISHMENT COSTS AND MANAGEMENT FUNCTIONS

The Lothner et al. (1988) analysis suggests that SRWC feedstocks produced on land enrolled in the CRP could be highly cost competitive with coal in the North Central Region, whereas without the incentives provided by the CRP, SRWC feedstocks would not currently be cost competitive. Strauss and Wright (in press) also suggest that under conditions of moderate land costs and high yields, SRWC delivered costs could come close to meeting DOE cost goals for production of feedstocks for conversion to ethanol. Although many cost assumptions are similar, there are some critical differences exist between the operations and cost assumptions in the two analyses. To provide a background for evaluation, the operations and costs associated with those two analyses are compared with other current sources of information for the North Central Region (Table 8).

Table 8. Summary of establishment operations costs for SRWC plantations in the North Central Region during the first rotation

	Strauss and Wright (in press) Cropland	Campbell (1988) Marginal cropland	Lothner, Hansen and Netzer (1988) Cropland	Lothner, Hansen, and Netzer (1988) Erodible cropland	Kroll (1989) Erodible cropland
			Establishment operations		
Fall	Herbicide Mow/brush Plow Lime	Herbicide Plow Lime	Herbicide Plow/disk	Herbicide strips Plow strips	Herbicide Plow/disk
Spring	Disk Herbicide Fertilize Plant 2100/ha	Disk Herbicide Fertilize Plant 2100/ha[a]	Disk Herbicide Plant 1735/ha	Disk strips Herbicide Plant 1735/ha	Disk/harrow Herbicide Plant 1232/ha
Summer 1	Herbicide	Herbicide and cultivate	Cultivate and herbicide	Cultivate and herbicide	Cultivate and herbicide
Summer 2	Herbicide	-	Cultivate	Cultivate	Cultivate
Costs					
ha^{-1}	621	695	727	697	699
Minus CRP payment	-0	-0	-0	-383	-494
Total	621	695	727	314	175

[a]Campbell chose 6735 trees/ha for evaluation of costs. Using his estimate of $0.17/seedling, the costs were modified to assume 2100 trees/ha and use of weed control methods for 2 years instead of 1 year.

Table 8 was developed using the two analyses previously discussed and two additional sources of information: the actual experience by the Minnesota Department of Natural Resources in planting poplars on land enrolled in the CRP Minnesota (T. Kroll, Division of Forestry, Minnesota Department of Natural Resources, Minneapolis, office memorandum, June 12, 1989) and a summary of published information on typical operations and costs of SRWC plantations (Campbell 1988). Campbell (1988) also evaluated costs under six different sets of management alternatives. The alternative used for comparison most closely corresponds to the situation described by Campbell as "marginal farm land with conventional tillage and fertilization." Campbell's costs were modified, based on information included in his paper, to reflect a planting density of 2100 trees/ha rather than the 6734 trees/ha used in his analysis.

It is evident that although the five establishment scenarios assumed for the North Central Region in Table 8 differ somewhat, the estimated (or actual) cost of establishment are relatively similar, differing by no more than $100/ha if no financial incentives are involved. The generality of the establishment cost assumptions to other parts of the country are validated by Rockwood and Dippon (1989) in which infrastructure, site preparation, fertilization, seedling costs, and planting costs were estimated to equal $696/ha for Eucalyptus and $579/ha for slash pine when calculated on the basis of 2100 trees/ha. Strauss and Wright (in press) assume a very low cost of planting materials ($0.05 per cutting) relative to other estimates for hardwood planting material. The difference lies in the assumption that cuttings can be produced at low cost by the grower, whereas the other evaluations assume purchase of cuttings or seedlings from nurseries at current prices that are not geared to high-volume production. At any cutting or seedling cost, higher-density plantings cost substantially more to establish.

With respect to annual maintenance costs, there are distinct differences in assumptions between analysts, though they would not result in major differences in total delivered costs (Table 9). Strauss and Wright (in press) include the costs of insecticides and fungicides as a standard cost because of the known susceptibility of most hybrid poplar clones to Septoria canker and to insects such as the cotton leaf beetle. Lothner et al. (1988) prefer to assume that only plant materials resistant to those pests will be planted and that fungicides and insecticides would only be used as a last resort. Both views are defendable. Only a few of the currently available clones have shown good resistance to

those pests; on the other hand, it is a goal of the SRWCP to find additional clones having resistance to those pests within the next 5 years.

All information sources summarized in Tables 8 and 9 assume conversion of recently tilled cropland to tree plantations. This is reflected in the relatively narrow range of land rents assumed. It is apparent from the land rent cost and land description provided by Campbell (1988) that he is assuming somewhat lower quality land than either Strauss and Wright (in press) or Lothner et al. (1988). Strauss and Wright (in press) include a cost for mowing and brushing in case the land has been left fallow for a year or so, but no major clearing costs are assumed. The addition of land clearing costs could increase establishment costs considerably.

4.5 SUMMARY OF CURRENT ASSUMPTIONS ON HARVEST, HANDLING, AND TRANSPORTATION STRATEGIES

There are differences of opinion about whether SRWC wood should be delivered as chips or whole trees to the plant gate and whether "feedstock costs" should incorporate "processing costs." The differences between the assumptions of analysts on how the SRWC material might be harvested, handled, and transported have a significant effect on total delivered feedstock cost. Table 10 provides a comparison of some of the variability in SRWC harvesting/handling assumptions and associated costs used in recently published and recent unpublished analyses. Ostlie (President, Energy Performance Systems, Minneapolis, Minnesota, phone calls to L. L. Wright in 1989 and 1990) has proposed use of a continuous feller buncher type harvesting machine to which a grapple hook is also attached. The grapple would take the bunches of whole trees and load them onto specially designed truck beds, which may be pulled behind the harvester or onto road-suitable vehicles that drive alongside the harvester. He assumes the whole trees (including branches) are transported no more than an average of 65 km (40 miles) to an electric power generating plant, where the trees are stored and essentially burned as whole trees in a "whole-tree" burner. This process eliminates chipping costs and skidding costs. Storage and drying costs are assumed to be the responsibility of the power plant facility.

Strauss et al. (1988) describe a harvesting-baling strategy based on research conducted by Schiess (1984) and Stuart et al. (1985). This strategy assumes that the conversion process will require chips, and thus the cost of chipping is included in the

Table 9. Summary of maintenance operations and other annual costs for SRWC plantations in the North Central Region during the first rotation

Strauss and Wright (in press) Cropland	Campbell (1988) Marginal cropland	Lothner, Hansen and Netzer (1988) Cropland	Lothner, Hansen, and Netzer (1988) Erodible cropland	Kroll (1989) Erodible cropland
Insecticide/fungicide years 2,4,6 at $25•ha^{-1}•appl^{-1}	-	-	-	-
Fertilizer applied years 3 and 5 at $35•ha^{-1}•appl$^{-1}	Fertilizer applied year 2 at $55•ha^{-1}•appl$^{-1}	Fertilizer applied year 2 at $99•ha^{-1}•appl$^{-1}	Fertilizer applied year 2 at $55•ha^{-1}•appl$^{-1}	Fertilizer recommended year 2 at $55•ha^{-1}•appl$^{-1}
Land rent at $85/ha	Land rent at $66/ha	Land rent at $99/ha	Land rent at $99/ha	Land rent $0/ha (10 yrs)
Land tax at $13/ha	Land tax at $14/ha	Land tax at $12/ha	Land tax at $12/ha	Land tax variable
Labor and facilities at $35/ha	Labor and facilities at $25/ha			

Table 10. SRWC harvesting and handling assumptions and associated costs

	Strauss et al. (1988)		Strauss et al. (1988)		Stokes et al. (1986)		Stokes et al. (1986)		Lothner et al. (1988)	
	Description	$dry Mg^{-1}	Description	$dry/Mg	Description	$dry/Mg	Description	$dry/Mg	Description	$dry/Mg
Harvesting	Severance head on tractor	4.33	Harvester/ chipper combine	15.04	Continuous feller buncher	5.41	Continuous feller buncher	5.42	Continuous feller buncher with attached loader	5.50
Field handling	Baler	3.66	Forwarder	8.61	Large skidder	8.00	Small skidder	3.68	None	
	Loader-unloader	4.21	Transfer utility	2.78	Large chipper	9.34	Small chipper	6.50	None	
Subtotal cost		12.20		26.43		22.76		15.60		5.50
Transportation	Tractor-trailer with bales for 40 km	4.87	Tractor-trailer with chips for 40 km	7.63	Not considered		Not considered		Whole-tree transport for 40 km at $0.055•Mg^{-1}•km^{-1}	2.20
Plant handling	Plant chipper	2.98	Unloader	0.64	Not considered		Not considered		Not considered	
Total cost		20.06		34.70						

feedstock cost. The chipping cost is reduced by assuming it will be performed at the plant facility, but the field handling includes crushing of the trees to reduce moisture content and the forming of bales, which are then loaded onto tractor-trailers for delivery to the plant site.

Stokes et al. (1986) evaluated harvest and handling systems similar to those currently used for obtaining pulp chips, the main difference being equipment size. The system with the smaller skidder and chipper offered a definite cost advantage when harvesting trees in the size ranges projected for most SRWC stands. Transportation costs were not considered in the Stokes et al. (1986) analysis; therefore, the numbers do not provide a total estimate of harvest and handling systems.

4.6 REFERENCES FOR SRWC ECONOMICS

Campbell, G. E. 1988. The economics of short-rotation intensive culture in Illinois and the central states. Forestry Research Report No. 88-12. University of Illinois, Agricultural Experiment Station, Urbana, Ill.

Lothner, D. C., E. E. Hansen, and D. A. Netzer. 1988. Growing and utilizing intensively cultured woody crops for energy: some recent evidence from the north central United States. pp. 92-102 IN Lonner G. and A. Tornquist (eds.), Proceedings IEA Bioenergy, Task III, Activity 4, workshop "Economic Evaluations of Biomass Oriented Systems for Fuel." Swedish University of Agricultural Sciences, Uppsala, Sweden.

Ostlie, L. D. 1988. The whole tree burner: a new technology in power generation. Biologue 5(3):7-9.

Rockwood, D. L., and D. R. Dippon. 1989. Biological and economic potentials of *Eucalyptus grandis* and slash pine as biomass energy crops. Biomass 20:155-165.

Schiess, P. 1984. Evaluation of the whole tree baler and its potential for use in biomass plantations in the Pacific Northwest. pp. 617-681. IN Cultural Treatment of Selected Species for Woody Biomass Fuel Production in the Pacific Northwest (2 Vols). College of Forestry Research, University of Washington, Seattle.

Stokes, B. J., D. J. Frederick, and D. T. Curtin. 1986. Field trials of a short-rotation biomass feller buncher and selected harvesting systems. Biomass 11: 185-204.

Strauss, C. H., S. C. Grado, P. R. Blankenhorn, and T. W. Bowersox. 1988. First and second rotation cost evaluations of biomass from SRIC *Populus* plantations. pp. 66-84. IN Klass D.L. (ed.), Energy from Biomass and Wastes XII, Institute of Gas Technology, Chicago.

Strauss, C. H., and L. L. Wright. Woody biomass production costs in the United States: an economic summary of commercial *Populus* plantations systems. IN Klass D.L. (ed)., Energy from Biomass and Wastes XIV. Institute of Gas Technology, Chicago (in press).

Stuart, W. B., D. S. Markey, and J. B. Teel. 1985. A prototype short rotation harvester. pp. 167-174. IN The Seventh International FPRS Industrial Wood Energy Forum 1983, Proc. 47337, Vol. 1, Forest Prod. Res. Soc., Madison, Wis. 167-174.

USDA/ERS. 1989. Agricultural resources: agricultural land values and markets–situation and outlook report. AR-14. U.S. Government Printing Office, Washington, D.C.

5. PROJECT SUMMARIES

The following summaries were contributed by the principal investigators on each project specifically for incorporation into the SRWCP annual report for 1989.

5.1 AMANA SOCIETY-A MONOCULTURE VIABILITY TRIAL OF WOODY CROPS FOR ENERGY PRODUCTION

Purpose and Background

Objectives are to improve the productivity and cost efficiency of growing woody plants for energy, to provide the support in terms of technical expertise, materials, and assessment to establish and maintain a silver maple energy plantation, and to research questions of risk, of expanded and different cultural treatments, of tree and plantation growth and yield, and of cost and production efficiency through a commercial-scale monoculture viability trial of silver maple (*Acer saccharinum*).

Accurate cost estimates of growing woody crops for energy on a commercial scale in short-rotation plantations are difficult to obtain under research conditions. Information is essential to ascertain the economic feasibility of future contributions of biomass to the U.S. energy supply.

Accomplishments

Preparation for spring 1990 planting on the 6.2 ha in work unit 3 has included the removal of all honeylocust (*Gleditsia triacanthos*) stumps. Burning and disking of the unit will be done in the fall to complete site preparation work.

Planting of unit 1, unit 2, and research sites were completed by April 30 with 30,000 trees selected for planting based on the criteria developed by Iowa State University. Grading criteria were (1) healthy/nondamaged seedling, (2) number of first order lateral roots, and (3) total height from soil line to base of main stem terminal bud. An additional criteria set (total height and number of lateral roots) was applied to select for "super seedlings" to be used for research work. A time study of the sorting process indicated that the regular Department of Natural Resources sorting averaged 3000 seedlings per hour while selection for the "superior" seedlings averaged 600 seedlings per

hour. This clearly indicates that tougher grading criteria is a more costly and time consuming process.

The time and motion study conducted during spring planting observed a delay time of approximately 45%, which is considerably less than the 70% observed during fall planting. An estimated 25% of the delay time was attributed to operational delays where planting production was delayed by (1) other planters, (2) moving to a new row or area, (3) changing personnel on the equipment, and (4) time required to supply planting crews with seedlings. The balance of delays was mostly attributed to personal delays (lunch, breaks) with the remainder coming from mechanical delays.

With the addition of 16 permanent inventory plots established this year, the total number of plots in both units 1 and 2 is 24. After planting, measurements were taken on these plots to determine average tree spacing. Average spacing in unit 1 was 1.4 x 2.4 m (4.7 x 8.0 ft) or 21% more area/tree than planned. Average spacing for unit 2 was 1.3 x 2.5 m (4.2 x 8.1 ft) or 10% more area/tree than planned. Average survival rate as measured in the 24 inventory plots as of August 8 was 86%. Individual rates were:

Spring 1989 Unit #2 = 89%

Spring 1989 Unit #1 = 91%

Fall 1988 Unit #1 = 82%

The maintenance program included both mowing and herbicide applications. After both units were planted, 1.1 kg per ha active ingredient of Goal (oxyfluorfen) and 2.2 kg per ha active ingredient of Surflan (Oryzalin) were applied for weed control. At the time of application, Princep (Simazine), an excellent herbicide for the control of both common ragweed (*Ambrosia artemisiifolia*) and giant ragweed (*Ambrosia trifida*), was not labeled for forestry use in Iowa. The impact of not having this herbicide available was the establishment of an aggressive population of ragweed, over-topping tree seedlings within the rows. However, this problem did not appear to reduce growth or survival of the trees as indicated by the 86% survival rate found on the inventory plots. Maintenance of the research plots involved a spring application of Goal and Surflan, hand mowing and an application of Round-Up (glyphosate) to invading vegetation.

Twenty more groundwater monitoring wells were installed completing all well installation work. Each well elevation was surveyed to determine groundwater gradient within each working unit. Water table depths measured during June and July throughout

the plantation continued to drop due to the lack of recharge events. Water quality results for samples taken during these months are not yet available. In August, a rain simulation chemical tracer percolation study was conducted to determine the potential for nitrate and pesticide movement within the unsaturated zone of the fluvent soil type. Experimental results are being analyzed.

A weather monitoring station was installed in the center of unit 2 and a portable computer was purchased for the downloading of data collected from the station. Data will be collected from the station when computer memory is nearing capacity. These data will then be stored on magnetic disks for future reference.

Insect and pathogen monitoring is done on a monthly basis. Several pest problems have been discovered at the plantation; however, none are critical at the moment. There has been an infestation of nymph grasshoppers and a few small beetles that appear to be eating some silver maple leaves much like the nymph grasshoppers. Perhaps the more important pest find relates to a cambium miner (*Phytobia setosa*, Loew), which typically bores "serpentine mines" in the cambium of sugar and red maples. The miner may pose a major problem and is monitored closely. I.S.U insect/pathogen team of Sandy McNabb and Woody Hart have formulated a general plan in the event of a pest outbreak.

Cost and hours spent on each activity associated with the project are being monitored and documented. Along with the cost accounting/record keeping tasks, an in-depth economic analysis is being formulated for the plantation. The analysis will provide information regarding different investment criteria such as soil expectation value, net present value, and internal rate of return. Other parameters are also being calculated that include the elasticities of input, mean required yield for energy production, the marginal rates of technical substitution, and a breakeven analysis. The data are being input into a Lotus 1-2-3 program to aid the Amana Society and other groups interested in short-rotation woody crops production.

Statistical measurements were taken on the nelder plots, and baseline measurements were taken on all experimental trees. The final statistical summary is not yet available.

A methodology for collecting data on wildlife has been developed with interest focused on white tail deer and turkey, with the possibility of surveying and assessing other

nongame species. These plots will allow us to generate initial estimates of the frequency of use of the wildlife.

During the past year, the transfer of technology has been enhanced by the slide presentation and poster put together for the annual subcontractors' workshop in Washington, D.C., in July. Since then, the poster has been used on several occasions by I.S.U. and the slides have been presented to the Iowa Woodland Owners Association's annual meeting in Amana.

5.2 THE UNIVERSITY OF GEORGIA–OPTIMIZING ENERGY YIELDS IN BLACK LOCUST THROUGH GENETIC SELECTION

Purpose and Background

Objectives are to determine efficient strategies for selecting and breeding black locust (*Robinia pseudoacacia*) for increased energy yield and to estimate the increase in energy yield resulting from the implementation of such programs.

Black locust is one of the most promising species for short-rotation woody crops. On sites throughout the eastern United States, it has outyielded other tested species including sycamore, sweetgum, and European black alder. In addition, it is capable of symbiotic nitrogen fixation, a property that may reduce the need for supplemental nitrogen fertilization and its attendant economic and energy costs.

Economic analysis has shown that the efficacy of biomass plantations is largely dependent on increasing biomass production. Genetic improvement offers the potential for such increases without the large annual outlays required of most silvicultural improvement options. The opportunities for improvement by genetic selection are particularly great in black locust, previous work having shown that black locust harbors an unusually large pool of genetic variation.

However, of the many possible genetic improvement strategies that could be employed, it is not clear which will be most efficient, most rapid or most effective. To select the most desirable improvement strategy, knowledge of propagation systems, mating systems, and genetic architecture must be obtained. Furthermore, correlations among traits of interest and opportunities for juvenile and other forms of indirect selection must be determined. The objectives of this project are to obtain this information and to project the gains possible from effective selective breeding programs.

The project plan calls for the establishment of progeny and clonal field trials to determine genetic parameters applicable to field conditions. Moderate size (24-tree) plots will be used to derive estimates of growth on an area basis. Trees from the same families and clones will be grown under nursery, greenhouse, and laboratory conditions to determine if an effective basis for juvenile selection can be found. The physiology of growth will be examined in field trees and seedlings to suggest additional criteria which may serve as a basis for juvenile or indirect selection. In particular, the physiology of nitrogen fixation and assimilation will be examined to determine optimum strategies for joint selection of nitrogen fixation and biomass production. Inbreeding and other mating system parameters will be determined from analysis of electrophoretic enzymes. Allozyme analysis will also be used in conjunction with previously established progeny tests to determine the structure of genetic variation in the native population of black locust.

Accomplishments

The establishment of the field progeny test was completed. The progeny test includes 24 open-pollinated families treated with two levels of irrigation (irrigated vs. nonirrigated) and two levels of nitrogen fertilization (100 vs. 0 kg ha^{-1}). Each family is represented in each treatment combination, in each of four blocks, by a 24-tree plot. The progeny test covers nearly 4 ha.

Measurements were collected on progeny test trees which were growing in the field for one season. First, volume and biomass equations were developed from border trees. One hundred trees were measured, harvested, their volumes determined by displacement in water, and weights determined after oven-drying. Diameter at 15 cm for the base accounted from 85% of the variation in volume and weight. The product of diameter and height accounted for 97% of the variation. Other seedling measures, such as number and diameter of first order branches and cross-sectional areas at greater tree heights, did not substantially improve the prediction equations for individual volume or dry weight.

Black locusts which had been in the field one growing season averaged 2.00 $m^3 \bullet ha^{-1}$ in volume and 0.92 $Mg \bullet ha^{-1}$ in dry weight. Greater yields might be expected in most years, when drought and frost are not as severe as they were during the 1988

growing season. Nevertheless, volumes and dry weights attained during 1988 exceed those for hybrid poplars grown in the Pacific Northwest for one year.

In 1988, when rainfall was 50% of normal, irrigation, at the rate of 5 cm per month, resulted in a threefold increase in biomass production of 1-year-old seedlings. Nitrogen fertilization had little effect on biomass yields. Families exhibited a fourfold variation in biomass production. The top 10% of families exceeded the test mean by 50%. In general, the same families excelled in each of the four irrigation-nitrogen treatments. These results confirm previous observations that genetic variation in biomass productivity are substantial, and the opportunity for increasing biomass production through genetic selection are great.

Overall survival in the progeny tests was 93%. Despite the previously mentioned drought, which began in spring, no differences in survival were observed between irrigation treatments. However, a significant difference in survival was evident between blocks. Survival in Block A, which was planted with larger seedlings, was 97%, whereas survival in Block B, planted with smaller seedlings, was 88%. This demonstrates the importance of establishing biomass plantations with large, healthy stock.

While the progeny plantings have been installed as planned with little difficulty, the clonal plantings have been delayed by funding shortages and propagation difficulties. Many clones which were easily propagated by root cuttings last year proved problematic this year, and clones which were recalcitrant last year were compliant this year. Storage conditions and sanitation may influence propagation success, and we are taking measures to improve both. Despite these difficulties, approximately 20,000 cuttings were harvested in the spring. Cuttings from surplus clones were distributed to cooperators at Michigan State University and Westvaco Company.

Investigation of the physiology of growth of black locust was initiated by examination of the gas exchange properties of four clones. Net photosynthesis, leaf conductance, and transpiration rates were measured at three soil water potentials (0.0, -0.5 and -1.0 MPa) and three absolute humidity deficits (6.9, 11.5, and 16.1 $g \bullet m^{-3}$) on previously well-watered and previously droughted plants. Compared to other broad-leafed deciduous tree species, black locust had high mean and maximum rates of net photosynthesis. Decreasing soil water potentials and increasing absolute humidity deficits had only a small effect on net photosynthesis and transpiration rates. During a dry-down

period, previously well-watered plants tended to close stomata when leaf pre-dawn xylem pressure potential reached -1.0 to -1.5 MPa, while stomata in previously droughted plants remained open until leaf pre-dawn xylem pressure potential reached -2.0 MPa. Thus, under moderate water deficits black locust was able to photosynthesize at near maximum rates. This may account, in part, for the rapid growth rate of juvenile black locust.

Examination of nitrogen fixation proceeded along two avenues of research. In the first, methods for labeling soil nitrogen with ^{15}N were explored. By labeling soil nitrogen with ^{15}N the relative contributions of atmospheric and soil sources of plant nitrogen can be determined. In a greenhouse study, seedlings of black locust and honeylocust (used as a reference plant) were treated with ^{15}N enriched ammonium sulfate or potassium nitrate. Both salts provided similar estimates of nitrogen-fixed plant nitrogen (approximately 70% in 10-week-old seedlings) when applied in small amounts with high enrichment levels. Estimates obtained with these supplements were similar to those obtained from natural abundance measures. Applying larger amounts of ammonium sulfate with low enrichment levels resulted in a significant fertilizer effect confounding the results. (Fixed nitrogen decreased to 30% of the total plant nitrogen.) For field work, it may be desirable to apply salts with intermediate levels of enrichment. High enrichment levels may be prohibitively costly, whereas low levels introduce fertilization effects. Natural abundance methodology is probably unworkable because of variation in soils under field conditions. Field trials were established this year to test these assumptions.

In a second line of work, the effects of soil nitrate concentration on nitrogen accretion mechanisms in black locust was examined. Nitrogen fixation was measured by acetylene reduction on 15-week-old black locust seedlings, watered daily with solutions of 0.0, 0.5, 5.0 or 15.0 mM nitrate. In general, increasing nitrate concentrations reduced total acetylene reduction (TAR). The decrease in TAR with increasing nitrate predominately reflected a decrease in acetylene reduction per gram nodule dry mass rather than a decrease in nodule dry mass. Increasing nitrate concentrations also increased nitrate reductase activity. Unlike soybeans, nitrate reductase activity was much higher in leaves than roots of black locust. Nitrate reduction in leaves is more energy efficient than reduction in roots. Family differences in acetylene reduction and nitrate reductase activity were also observed. One of the three families examined showed significantly lower acetylene reduction rates and higher nitrate reductase activity suggesting that it might be

more responsive to nitrate fertilizer than the other two. A greenhouse experiment designed to examine the effects of soil nitrate on nitrogen accretion from soil and atmospheric sources and the energy costs attendant with each has now been conducted, but the data have not been analyzed. Cursory examination of the data suggests that increases in soil nitrate decrease nitrogen fixation by decreasing root nodulation and the specific activity of the nodules. Furthermore, it appears that nitrogen obtained from soil nitrate has lower energy costs than nitrogen obtained from nitrogen fixation, but these conclusions must be regarded as preliminary.

A final activity was the calculation of genetic correlations between members of open-pollinated families. Calculation was accomplished by means of an algorithm which employs allozyme data. The algorithm calculates the expected number of alleles in common for half-sib and full-sib cases, then determines the degree of relatedness by interpolation (or extrapolation) from the observed number of alleles in common. The average genetic correlation in open-pollinated collections from 23 populations within the natural range of black locust was 0.35, or about half way between half-sibs (genetic correlation of 0.25) and full-sibs (genetic correlation of 0.50). Individual families ranged from near half-sibs to near full-sibs. Thus, it is erroneous to treat open-pollinated families as half-sibs, as is often done, or to consider open-pollinated families to have similar genetic structures.

Technical Information Dissemination

Bongarten, B. C. 1989. Selection of black locust for biomass production. Paper presented at Terrestrial Energy Crops Program 1989 Conference and Workshop, July 18-21, 1989, Washington, D.C.

Boring, L. R., W. T. Swank, J. B. Waide and G. S. Henderson. 1988. Sources, fates and impacts of nitrogen inputs to terrestrial ecosystems: review and synthesis. Biogeochemistry 6:119-159.

Johnsen, K. H., B. C. Bongarten, L. R. Boring and R. O. Teskey. 1989. Short-term effects of nitrate on nitrogen metabolism of black locust seedlings. Paper presented at Ecological Society of America conference, August 6-10, 1989, Toronto.

Surles, S. E., J. L. Hamrick, and B. C. Bongarten. 1989. Allozyme variation in black locust (*Robinia pseudoacacia*). Can. J. For. Research. 19:471-479.

Surles, S. E., J. L. Hamrick, and B. C. Bongarten. 1989. Mating systems in wind-pollinated families of black locust (*Robinia pseudoacacia*). Silvae Genetica (in press).

Surles, S. E., D. K. Apsley, R. O. Teskey, and L. R. Boring. 1989. Physiological responses of black locust (*Robinia pseudoacacia*) to moisture stress. Can. J. For. Research (submitted).

Surles, S. E., J. Arnold, A. Schnabel, J. L. Hamrick and B. C. Bongarten. 1989. Genetic relatedness in open-pollinated families of two leguminous tree species. Theor. Appl. Genet. (in preparation).

Surles, S. E., D. K. Apsley, L. R. Boring and R. O. Teskey. 1989. Physiological responses of *Robinia pseudoacacia* to varying soil moisture conditions. Paper presented at Ecological Society of America conference, August 6-10, 1989, Toronto.

5.3 IOWA STATE UNIVERSITY--SELECTION AND BREEDING OF PEST-RESISTANT CLONES OF *POPULUS* FOR BIOMASS ENERGY PRODUCTION IN THE NORTH CENTRAL REGION

Purpose and Background

The project's objective is to develop new clones of *Populus* for use in the production of biomass energy in the North Central Region of the United States.

Emphasis has been placed on selection and breeding for pest resistance, dry weight yield potential, and ease of propagation. Screening for pest resistance in hybrid *Populus* populations is a major component of this project.

Accomplishments

This year, 67 clones and 9 new families were added to the nursery screening trials. Counting the material that was repropagated from material used last year in the nursery screening, 141 clones, 4 provenances, and 120 families are under test. A *Populus* breeding specialist has been hired to greatly expand the number of families produced during the 1990 breeding season. A planting of the Belgium/ISU clones was established at the Rhodes research area this spring. Rejuvenation studies were started with four trees

ranging in age from about 10 to over 50. Both grafts and rooted cuttings were established this spring and these trees are being serially repropagated in the greenhouse.

Overwintered leaves from existing plantations were again spread over the screening beds in early May. Septoria leaf spot symptoms did appear on the lower leaves of a few trees during the first week in June. During the second week of June, *Marssonina* leaf disease appeared on the lower leaves of some of the families. By the end of June, *Marssonina* leaf spot was spreading to leaves higher on the trees. In July, both *Marssonina* and Septoria leaf spots continued to increase, especially on lower leaves of susceptible trees. The Belgian clones appeared to be quite susceptible to Septoria leaf spot with several showing more resistance than the overall group. Septoria canker also appeared in some of these clones. A collection of rusted leaves was obtained from Rhinelander, Wisconsin, and spread over the screening beds in mid-August. This brought rust symptoms and signs about a week earlier than the natural infections at Rhodes Farm. Differences in rust incidence were noticed during the readings taken in late August, September, and October. The most striking observation was the resistance to rust exhibited by the Illinois cottonwood clones. This confirms the value of phenotypic selection for rust resistance in the field. Preliminary disease ratings for the Belgian clones in the nursery and field tests are presented in Tables 11 and 12.

Laboratory screening for cottonwood leaf beetle (CLB) susceptibility was completed for 14 clones and tests of another 1 clones are in progress. These first analyses indicate that there were significant clonal effects upon development time, leaf area consumed, and pupal weight; there were no significant effects of wounding upon CLB development or mortality.

Collapsible screen cages for field testing of individual trees were designed and fifty cages constructed in July. Cuttings of eight clones previously tested in the laboratory were potted and moved to these field cages in late July. However, this preliminary test had to be canceled because of CLB contamination of the test trees before the experiment started; extremely heavy natural populations of CLB were evident in all test areas this year.

Three clones, IS-31, a *P. maximowiczii*, and a Belgian clone, were propagated for a preliminary examination of the effects of leaf-wounding on larval biology in a whole-tree environment. This work was carried out in early August with the assistance of a visiting

Table 11. Preliminary disease scores for Belgian clones at the DNR Nursery, Ames, Iowa. Data taken 9/15/89.

Clone	/	ISU #	Parents	*Septoria* leaf spot score	*Septoria* canker no.	*Melampsora* rust score	*Marssonina* score[a]
Unal	/	4	t x (d xd)	3-	2	2	0+
Boelare	/	5	t x (d xd)	3	1	0+	0+
Raspallje	/	6	t x (d xd)	3	0	1-	0+
Beaupre	/	7	t x (d xd)	3	0	2-	1-
Hunnegem	/	8	t x d	2+	0	1	0+
Primo	/	9	(d xd) x n	2-	0	2	0
Ghoy	/	10	(d xd) x n	3	3	2+	0
Claver	/	11	(d xd) x n	2	0	0+	0
Gibecq	/	12	(d xd) x n	2-	0	1+	0+
Ogy	/	13	(d xd) x n	2+	0	1+	1-
Isieres	/	14	d x n	1	0	1	0+
Trichobel	/	15	t x t	2-	0	0+	0+
76.028/5	/	17	[t x (d x d)] x (d x d)	3-	3	1	0+
69.038/6	/	18	t x d	2	1	3	0+
72.029/4	/	20	t x (d x d)	2	1	2-	1+
70.045/1	/	21	t x d	3	8	3	0+
		23	n x t	3	1	0+	0+
		24	t x m	3-	0	0+	1
		25	d x m	2+	0	0+	0+
		26	d x (t x m)	3	1	0+	0+
		28	t x l	3-	0	0+	2+

[a]Septoria may mask this rating. Disease ratings are: 0 = slight; 2 = moderate; 3 = heavy. Parent codes are t = *P. trichocarpa*; d = *P. deltoides*; n = *P. nigra*; m = *P. maximowiczii*; l = *P. lasiocarpa*.

Table 12. Preliminary rust and dormancy scores for Belgian clones at the Rhodes Experimental Area. Data taken 9/19/89.

Clone	/	ISU #	Parents	Melampsora rust score	No. of trees present	No. of trees with budset
Boelare	/	5	t x (d xd)	1	4	1
Beaupre	/	7	t x (d xd)	2-	4	3
Hunnegem	/	8	t x d	1-	4	3
Choy	/	10	(d xd) x n	1-	4	3
Claver	/	11	(d xd) x n	0	4	0
Clbeeq	/	12	(d xd) x n	1+	4	1
Ogy	/	13	(d xd) x n	0+	7	5
Isleres	/	14	d x n	1-	7	4
Trichobel	/	15	t x t	0	4	0
76.028/5	/	17	[t x (d x d)] x (d x d)	2-	4	2
69.038/6	/	18	t x d	3-	4	1
72.029/4	/	20	t x (d x d)	2-	4	1
70.045/1	/	21	t x d	2-	4	1
		23	n x t	0+	8	1
		25	d x m	0	4	1

See Table 5 for explanation of codes.

student from France. CLB larvae were introduced into each cage and data taken on larval survival, leaf area consumed, and larval movement relative to the wounded leaf for each clone. Only larval survival was significant. A great deal of information was accrued for material and technique modifications for the standard field tests to begin in 1990.

In related work, Kurt Allen, a graduate student in Forestry and Entomology working with the biotechnology program, has performed a preliminary examination of beetle susceptibility on genetically transformed *Populus*. He is using *Plagiodera versicolora* (Laicharting), the imported willow leaf beetle, because of its more polyphagous habits within *Populus*. Several changes in laboratory techniques from those used with the CLB were necessitated for this species. He will be starting a full test before November 1 of the first four of fifteen clones transformed with the PIN-II proteinase inhibitor gene.

Major Constraints

A major biological constraint was that rust diseases developed late again this year throughout the North Central Region. This means that fewer entries in the trials could be positively eliminated on the basis of their rust scores; more entries will have to be carried over into next year's testing.

Technical Information Dissemination

Chun, Y. W., N. B. Klopfenstein, H. S. McNabb, Jr. and R. B. Hall. 1988. Biotechnological applications in *Populus* species. J. Korean Forestry Society 77:467-483.

Hall, R.B., J.P. Colletti, R.C. Schultz, R.R. Faltonson, S.H. Kollson, Jr., R.D. Hanna, T.D. Hillson, and J.W. Morrison. 1989. Commercial-scale vegetative propagation of aspens. Paper presented at the Aspen Symposium, July 25-27, 1989, Duluth, MN.

Hart, E. R., H. S. McNabb, Jr., R. B. Hall and R. D. Hanna. 1989. Pest evaluations in joint testing designs. Paper presented at joint meeting of the International Energy Agency Task 5 Activity Groups on Exchange of Genetic Material and Joint Trials of *Alnus*, *Populus* and *Salix*, September 25-28, 1989, Toronto.

Klopfenstein, N. B., S. A. Heuchelin, H. S. McNabb, Jr., R. W. Thornburg, R. B. Hall and E. R. Hart. 1989. Transformation of hybrid *Populus* with the proteinase inhibitor II gene. (Abstr.) Phytopathology 79:(in press).

Klopfenstein, N. B., H. S. McNabb, Jr., R. W. Thornburg, R. B. Hall and E. R. Hart. 1989. Foreign gene expression in poplar hybrids. (Abstr.) IN Abstract booklet, Second Annual Iowa State University Life Sciences Mini-Symposium, March 10-11, 1989, Ames, Iowa.

Klopfenstein, N. B., H. S. McNabb, Jr., R. W. Thornburg, R. B. Hall and E. R. Hart. 1989. Insertion and expression of foreign genes in aspen hybrids. (Abstr.) No. 8 IN Abstract booklet, Aspen Symposium '89, July 25-27, 1989 in Duluth, Minnesota.

Klopfenstein, N. B., R. W. Thornburg, H. S. McNabb, R. B. Hall, E. R. Hart, Y. W. Chun, A. Kernan and N. Q. Shi. 1989. Transformation of *Populus* - from system development to field plantings. (Abstr.) Poster and paper presented at NATO Advanced Research Workshop/IUFRO Working Party S2.04.07, Somatic Cell Genetics, 2nd International Workshop: Woody Plant Biotechnology, October 15-19, 1989, USDA Forest Service Institute of Forest Genetics, Placerville, California.

Luley, C. J. and H. S. McNabb, Jr. 1989. Ascospore production, release, germination, and infection of *Populus* by *Mycosphaerella populorum*. Phytopathology 79:(in press).

McNabb, H. S., Jr. 1989. Research in the United States of America on resistance to disease and insect injury in *Populus*. Paper presented at European Community research project meeting on Breeding for Resistance to Fungal and Bacterial Pathogens of *Populus*, April 11-13, 1989, Geraardsbergen, Belgium.

McNabb, H. S., Jr. and E. R. Hart 1989. Preliminary results of screening for diseases and insect injuries of the Belgian hybrid poplar clones imported by *in vitro* culture in 1985. Paper presented at joint meeting of the International Energy Agency Task 5 Activity Groups on Exchange of Genetic Material and Joint Trials of *Alnus*, *Populus* and *Salix*, September 25-28, 1989, Toronto.

McNabb, H. S., Jr., R. B. Hall and E. R. Hart. 1989. Poplars, Pests, and Progeny. Poster presented at the Terrestrial Energy Crops 1989 Conference and Workshop, July 18-21, 1989, Washington, D.C.

McNabb, H. S., Jr., R. B. Hall , R. C. Schultz and J. P. Colletti. 1989. Management of Poplar Systems. Poster presented at the Terrestrial Energy Crops 1989 Conference and Workshop, July 18-21, 1989, Washington, D.C.

McNabb, H. S., Jr., N. B. Klopfenstein, R. W. Thornburg, R. B. Hall and E. R. Hart. 1989. Biotechnology: Genetically Engineering Poplar. Poster presented at the Terrestrial Energy Crops 1989 Conference and Workshop, July 18-21, 1989, Washington, D.C.

McNabb, H. S., Jr. 1989. *In vitro* selection against harmful agents in woody plants - A critical review. NATO Advanced Research Workshop/IUFRO Working Party S2.04.07, Somatic Cell Genetics, 2nd International Workshop: Woody Plant Biotechnology, October 15-19, 1989, USDA Forest Service Institute of Forest Genetics, Placerville, California.

Ostry, M. E., L. F. Wilson, H. S. McNabb, Jr. and L. M. Moore. 1989. A guide to insect, disease, and animal pests of poplars. Agriculture Handbook No. 677. U.S. Dept. of Agriculture Forest Service. Washington, D. C. 118 pp.

Ostry, M. E., L. F. Wilson and H. S. McNabb, Jr. 1989. Impact and control of *Septoria musiva* on hybrid poplars in intensively managed plantations in central Michigan. USDA Forest Service North Central Forest Experiment Station General Technical Report NC-133. St. Paul, MN. 5 pp.

Sillick, J. M., H. S. McNabb, Jr. and R. W. Thornburg. 1989. Extracellular proteinases of *Septoria musiva*. (Abstr.) Phytopathology 79:(in press).

Son, S.H. and R.B. Hall. 1989. Multiple shoot regeneration from root organ cultures of *Populus alba* X *P. grandidentata*. Plant Cell, Tissue and Organ Culture (in press).

5.4 MICHIGAN STATE UNIVERSITY–NET ASSIMILATION AND PHOTOSYNTHATE ALLOCATION OF *POPULUS* CLONES GROWN UNDER SHORT-ROTATION INTENSIVE CULTURE–PHYSIOLOGICAL AND GENETIC RESPONSES REGULATING YIELD

Purpose and Background

Objectives are to quantify the differences in net assimilation and photosynthate allocation among *Populus* clones and determine why differences in assimilation and carbon allocation occur, to determine if differences in assimilation and carbon allocation among *Populus* clones before coppicing remain unchanged following coppicing, and (3) to develop breeding strategies and modify silvicultural prescriptions for increasing biomass productivity of SRWC *Populus* plantations.

The experimental approach has been field-oriented, with two major experiments nearing completion. Although follow-up and spin-off studies are presently underway, the major accomplishments have come out the following two studies.

Experiment 1, "Physiological Responses of Two *Populus* Clones Grown Under Two Levels of Irrigation," was designed to determine (1) how moisture affects net assimilation, whole-tree carbon allocation, water relations, and root growth in two poplar clones (*Populus tristis* x *P. balsamifera* cv. Tristis No. 1 and *P.* x *euramericana* cv. Eugenei) with contrasting morphology and phenology and (2) how coppicing influences established patterns of net assimilation, whole-tree carbon allocation, water relations, and root growth in the two clones. The phenology, distribution, and morphology of the fine root system has been studied with minirhizotrons.

Experiment 2, "Pot Culture to Evaluate the Effects of Genotype, Nitrogen and Water on Whole-tree Growth and Carbon and Nitrogen Partitioning," was designed to determine how availability of water and nitrogen affects photosynthesis, net assimilation, and the whole-tree economies of carbon, nitrogen, starch and sugar. The same two *Populus* genotypes as in Experiment 1 were grown in the field in large plastic pots to facilitate root recovery and provide more uniform edaphic environments. Trees were sequentially harvested over the course of two growing seasons. Although analysis of the experiment is not complete, the results to date represent a significant gain in understanding of the whole-tree physiology of *Populus*. Specific background details and design of Experiments 1 and 2 were given in the previous three annual reports submitted to the Short Rotation Woody Crops Program.

Accomplishments

The 4-year-old trees in Experiment 1 were harvested during early March 1988. Individual aboveground tree biomass of Eugenei far exceeded that of Tristis, reflecting the differences in height and diameter presented in the 1988 annual report. Branch dry weight in Tristis was equal to that of the stem, whereas in Eugenei it was about half. Biomass of Eugenei trees was more than doubled by irrigation and sylleptic branching was promoted; Tristis biomass and branching were unaffected by watering.

Coppice regrowth was vigorous, despite a record drought. First-year coppice sprouts reached ca. 3.5 m in height on irrigated Eugenei stumps, and 2.5 m on

nonirrigated stumps, with most of the growth differential occurring in late season. Tristis sprouts reached nearly 2 m in height, almost their height after 4 year's growth from cuttings. Irrigation, again, did not affect the growth of Tristis. The sum of the cross-sectional area of 1-year-old sprouts exceeded that of the stump that produced them by 68% in Tristis, but in Eugenei sprout cross-sectional areas were about 2/3 that of the stump. The interpretation of these data, using the Pipe Model Theory as a basis, shows how quickly a large leaf area is regained by poplar coppice sprouts. Photosynthesis was unaffected, but stomatal conductances increased in irrigated sprouts. By the end of the first growing season, leaves on coppice sprouts were physiologically similar to those on uncoppiced stems.

Spring fine-root growth was unaffected by coppicing in clone Eugenei; both fine-root numbers and lengths increased significantly from March (preharvest) to May (postharvest). A calibration study, which compared data taken from minirhizotrons and soil cores, indicated that minirhizotrons were unsuitable for estimating actual root length densities or biomass. The primary value of minirhizotrons, then, is for determinations of fine root dynamics and morphology.

Results from Experiment 2 indicate that the pattern of allocation of carbon on a whole-tree basis was not influenced by moisture and nitrogen during the first year. Tristis allocated more photosynthate to root production than Eugenei, regardless of environmental conditions. Carbon allocation is a highly deterministic process in the two genotypes studied and appears to be under strong genetic control. Fine roots never accounted for more than 4% of the standing crop of year-old *Populus*. They are not a major carbon sink in these young trees as was initially expected. On a whole-tree basis, more than 70% of the total nitrogen was found in the leaves during the peak of the growing season. Young *Populus* are amazingly efficient at nitrogen conservation; Eugenei went into the dormant season with at least 80% of its September total N content in storage. Large, structural roots were the major site of nitrogen storage during the dormant season. This finding has potentially important silvicultural ramifications, similar to those already known for horticultural species like peach and apple.

Patterns of whole-tree allocation to starch and sugar were not influenced by water and nitrogen the first year, although quantities of reserves were. Large roots were far-and-away the major site of carbohydrate storage during the dormant season. Large

roots were "loaded" with reserves in a very dramatic and dynamic way at the very end of the growing season, especially in Eugenei. Studies of the mobilization and utilization of belowground reserves following winter coppicing should be a high priority for additional research. Fine roots (< 0.5-mm diameter) were also loaded with starch and sugar at the end of the first growing season; concentrations increased more than 60 times in less than four weeks. These reserves may be used to fuel new production (lateral root branches) the following spring.

Second-year growth by potted trees was positively related to watering and nitrogen fertilizer treatments, especially in terms of leaf area. Eugenei outgrew Tristis and showed a greater response to water. Both seasonal and diurnal stomatal conductance and net photosynthesis were reduced by moisture stress in potted trees. These effects were most pronounced at the end of the early-season drought which developed in 1988. Both clones seemed to adapt to water stress by closing their stomata, but Tristis leaves were less affected by water deficits than Eugenei. Dark respiration rates during midsummer were not affected by water or nitrogen. Comparing high and low water treatments, respiration rates were 33 and 50% of maximum photosynthesis rates in Eugenei, and 20 and 28% in Tristis.

Microcomputer-based, image analysis software (ROOTS) to extract root measurements from video minirhizotron images was developed. The software, which requires a digitizing board, is operational and can be adapted for other uses. The analysis of video images has been a persistent research bottleneck which has plagued everyone attempting to use the minirhizotron technology. The ROOTS program represents a major step forward in the practical application of the minirhizotron technique. The program is being made available for purchase.

Technical Information Dissemination

Dickmann, D., C. Firkowski, R. Hendrick, J. Warbach, P. Nguyen, and K. Pregitzer. 1989. The effect of irrigation and harvest on fine root dynamics of two hybrid poplars. Paper presented at the Minirhizotron Workshop, April 11, 1989, Michigan State University.

Dickmann, D. I. 1989. The popular poplar: what makes it run? Paper presented at the Crop and Soil Science Department Seminar Series, May 23, 1989, Michigan State University.

Dickmann, D. I., K. S. Pregitzer, and P. V. Nguyen. 1989. Whole tree carbon assimilation in poplars. Paper presented at Terrestrial Energy Crops Program 1989 Conference and Workshop, July 18-21, 1989, Washington, D.C.

Dickmann, D. I., K. S. Pregitzer, and P. V. Nguyen. 1989. Poplar plantations for energy: the physiological basis for growth. Poster presented at the Terrestrial Energy Crops Program 1989 Conference and Workshop, July 18-21, 1989, Washington, D.C.

Dickmann, D. I. 1989. Light interception and carbon fixation in tree canopies: contrasting patterns in two-year-old *Populus* clones Eugenei and Tristis. Paper presented at IUFRO International Workshop on Dynamics of Ecophysiological Processes in Tree Crowns and Forest Canopies, September 24-29, 1989, Rhinelander, WI.

Pregitzer, K. S. and D. I. Dickmann. 1989. Acquisition of limiting soil resources: linking the root and shoot. Paper presented at IUFRO International Workshop on Dynamics of Ecophysiological Processes in Tree Crowns and Forest Canopies, September 24-29,1989, Rhinelander, WI.

5.5 MISSISSIPPI STATE UNIVERSITY: EARLY SELECTION CRITERIA AND CLONAL PROPAGATION METHODS FOR INCREASED PRODUCTIVITY OF SYCAMORE IN SHORT-ROTATION ENERGY SYSTEMS

Purpose and Background

Objectives are to provide basic descriptive information on characteristics of sycamore (*Platanus occidentalis* L.) reproductive materials (seeds, seedlings, and rooted cuttings), to determine magnitudes of genetic and common-environmental (maternal) effects, to estimate sizes of juvenile-"mature" genetic correlations, and to develop "hedging" techniques for production of rooted cuttings.

Seed and seedling characteristics should affect the performance of sycamore in short-rotation plantations, and these characteristics are subject to genetic and environmental effects that can be managed to increase productivity. The use of vegetative

propagules rather than seedlings can allow greater utilization of genetic improvement in productivity.

Accomplishments

A paper on juvenile-"mature" correlations from germinator, nursery, greenhouse, and 1-year field tests of 12 open-pollinated families was presented at the 20th Southern Forest Tree Improvement Conference in Charleston, South Carolina, on June 27-29, 1989. Rate of germination ("peak value") and root growth potential (on 1-year-old seedlings from the nursery) had significant family-mean and genetic correlations with first year growth in the field (Tables 13 and 14).

A total of 91 outcrossed seed balls, 20 selfed seed balls, and 19 non-pollinated seed balls were harvested from 222 female flowers bagged in March, 1988. Bagging was effective in preventing open pollination, as the non-pollinated seed balls produced only 2% full seeds. Sycamore was self incompatible, since selfed seed balls produced 9% full seeds and control-outcrossed seed balls (also open-pollinated balls) produced 30% full seeds. Six pairs of reciprocal crosses (12 crosses) provided full seeds for subsequent studies.

X-ray radiographs were used to separate full from empty seeds. Maternal effects (differences among reciprocal crosses for the same pair of parents) were more important than family effects (differences among pairs) for number of seeds per seed ball, seed length, weight per full seed, weight per empty seed, and embryo weight. Eleven of the 12 control crosses had sufficient seeds for germinator and nursery tests. These control crosses differed significantly for rates of germination (peak values) and germination values in the germinator and nursery and for rates of hypocotyl growth and hypocotyl length in the germinator (Table 15). Much of this variation among crosses for germination (and to some degree for hypocotyl growth) was due to common environmental effects (among crosses within pairs) rather than nuclear genetic effects (among pairs) (Table 16). Hypocotyl growth rate in the germinator (but not germination) had a high family-rank correlation with germination and early growth in the nursery (Table 17). Monthly measurements of seedling heights and diameters and bi-weekly measurements of numbers and diameters of living leaves were taken throughout the summer and fall. A graduate

Table 13. Significant product-moment correlations between germination, nursery, greenhouse, and field traits for 12 open-pollinated sycamore families

Field trait	Germination trait	Greenhouse RCP traits no. of new roots			Nursery
	Peak value	Long	Medium	Short	Medium lateral roots
Stem dry weight	0.596*	-0.96	0.035	-0.008	0.032
Root dry weight	0.738**	-0.26	0.125	0.099	0.279
Total dry weight	0.683**	-0.071	0.075	0.037	0.137
Growth secondary buds (3 months)	0.805**	0.590*	0.818**	0.821**	0.678**
No. secondary buds (1 year)	0.586*	0.529	0.711**	0.805**	0.641*
Length of topmost sprout (3 months)	-0.741**	-0.219	-0.454	-0.333	-0.514
No. total apical buds/tree (1 year)	0.560*	0.527	0.717**	0.817**	0.614*
Growth all buds/tree (1 year)	0.778**	0.543	0.700**	0.702**	0.489
Root volume (1 year)	0.624*	-0.120	0.002	0.019	0.112

* = Significant at the 0.05 level.
** = Significant at the 0.01 level.

Table 14. Genetic correlations for measures of root growth potential (RGP) and taproot length with first-year field performance of 12 open-pollinated sycamore families

Field trait by greenhouse trait	Genetic correlation
No. sprouts/tree (after 3 months) by	
Taproot length (day 264)	-0.764
No. of long (>5 cm) new roots (day 21)	0.990
No. of medium (2.5-5.0 cm) new roots (day 21)	0.966
No. of short (1.0-2.5 cm) new roots (day 21)	1.138
Growth all sprouts/tree (after 3 months) by	
No. of long (>5 cm) new roots (day 21)	0.953
No. of medium (2.5-5.0 cm) new roots (day 21)	0.970
No. of short (1.0-2.5 cm) new roots (day 21)	1.093
Total no. apical buds/tree (after 1 year) by	
No. of long (>5 cm) new roots (day 21)	0.852
No. of medium (2.5-5.0 cm) new roots (day 21)	1.002
No. of short (1.0-2.5 cm) new roots (day 21)	1.374
No. secondary apical buds/tree (after 1 year) by	
No. of long (>5 cm) new roots (day 21)	0.834
No. of medium (2.5-5.0 cm) new roots (day 21)	0.976
No. of short (1.0-2.5 cm) new roots (day 21)	1.339

Table 15. Study means for sycamore germination tests and early nursery measurement

Seed and seedling traits		Study mean	Probability of larger F-test in ANOVA[a] All crosses (pooled)	Crosses w/i pairs	Among pairs
I. Germinator					
(1) % Full-seed normal gemination	Day 5	27.9			
(2) "	Day 6	68.2			
(3) "	Day 7	81.0			
(4) "	Day 8	86.9			
(5) "	Day 9	89.9			
(6) "	Day 10	90.1			
(7) "	Day 11	90.8			
(8) "	Day 12	91.1			
(9) "	Day 13	91.1			
(10) "	Day 14	91.1			
(11) Mean % daily germination	Day 14	6.5	.3894	.4577	.3888
(12) Peak value (%/day)		12.7	.0001	.0001	.1470
(13) Germination value [=(11)x(12)]		82.7	.0001	.0097	.1524
(14) % abnormal germination	Day 14	6.4	.4326	.2624	.7539
(15) % full, nongerminated seed	Day 14	2.1	.0483	.0117	.9393
(16) Hypocotyl length (mm)	Day 5	1.5			
(17) "	Day 6	5.3			
(18) "	Day 7	8.6			
(19) "	Day 8	11.6			
(20) "	Day 9	14.3			
(21) "	Day 10	15.5			
(22) "	Day 12	16.7			
(23) "	Day 14	17.2			
(24) Hypocotyl growth (mm/day)	Day 14	1.23	.0001	.0001	.1494
(25) Peak value hypocotyl growth (mm/day)		1.71	.0001	.0001	.1713
(26) Hypocotyl length (mm) of nonfungus seedlings	Day 14	17.8	.0001	.0001	.1746
II. Nursery					
(1) % germination	Day 7	0.0			
(2) "	Day 14	7.2			
(3) "	Day 22	15.1			
(4) "	Day 28	14.3			
(5) % surviving germination	Day 56	11.9	.0001	.0001	.7670
(6) Mean % daily germination	Day 14	0.51			
(7) "	Day 56	0.21			
(8) Nursery peak value (%/day)		0.81	.0001	.0001	.8115
(9) Nursery germination value [=(7)x(8)]		0.27	.0001	.0001	.7033
(10 Seedling ht. (mm)	Day 14	1.9			
(11) "	Day 22	3.4			
(12) "	Day 28	5.2			
(13) "	Day 56	40.3			

[a]Probability values of 0.0500 to 0.0101 are considered significant (=*), values of 0.0100 to 0.0011 are considered highly significant (=**), and values of 0.0010 or smaller are very highly significant (=***).

Table 16. Relative sizes of variance components among and within six sets of reciprocal crosses for sycamore germination tests and early nursery measurements

Seed and seedling traits	Variance components[a]		
	All crosses $[V_t = V_{C(P)} + V_P]$	Pairs $[V_{C(P)}]$ (% of V_T)	Crosses w/l pairs $[V_P]$ (% of V_T)
I. Germinator			
14-day germination:			
(1) Germination value	137**	43%	57%
(2) Peak value	3.29**	47%	53%
(3) %full; non-germinated seed-day 14	2.51*	82%	18%
14-day hypocotyl growth:			
(1) Hypocotyl growth (mm/day)-day 14	0.071**	48%	52%
(2) Peak value hypocotyl growth	0.145**	53%	47%
(3) Hypocotyl length; non-fungus-day 14	13.9*	53%	47%
II. Nursery			
56-day germination:			
(1) Nursery germination value	0.087**	100%	0%
(2) Nursery peak value	0.200**	100%	0%
(3) % surv. germination-day 56	66.8*	100%	0%

[a]Variance components or percentages followed by "**" indicate significant F-tests at the 0.01 probability level for that source of variation, while those followed by "ns" are not significant at the 0.05 probability level.

Table 17. Rank correlations of cross means for germinator and nursery traits

Germinator traits	Nursery traits: Germination value	Peak value	Day 56 % germ.	Day 56 Ht. (mm)
	Family rank correlations[a]			
Germination:				
Germination value	-0.46^{ns}	-0.35^{ns}	-0.35^{ns}	-0.15^{ns}
Peak value	-0.34^{ns}	-0.30^{ns}	-0.36^{ns}	-0.24^{ns}
Hypocotyl growth:				
Peak value	0.85***	0.79**	0.89***	0.76**
Hypocotyl ht. (mm)--day 14	0.84**	0.77**	0.88***	0.70*

[a]ns = the rank correlation is not significantly different from zero; * = significantly different from zero at the 0.05 probability level; ** = significant at the 0.01 probability level; and *** = significant at the 0.001 level.

student has determined that leaf area can be accurately determined from leaf width by the equation

$$\ln Y = 1.798 \ln W \qquad (R^2 = 0.9988)$$

where Y = leaf area in square cm and W = leaf width in cm.

Rates of growth in nursery height, diameter, and leaf surface area will be tested for genetic correlations with field performance in 1990-91.

A Master of Science Thesis on development of "hedging" techniques for production of rooted cuttings was completed in June, 1989. Rooting success of hardwood cuttings from sprouts on top-pruned ("hedged") trees was enhanced significantly by (1) spraying the trees with 1000 ppm Pro-Shear (N-phenylmethyl-1H-purine-6-amine) one year prior to collection of cuttings, (2) dipping the base of the cuttings in 5% Captan (fungicide), and (3) using cuttings of at least 14-mm diameter with a node within one cm of the base and at least two nodes below ground. Sprouts collected in the early spring from a non-sprayed 1988 hedging test indicated that trees cut at a lower height (where the stem diameter was larger) produced more large-diameter sprouts (greater than 19-mm diameter) than those hedged near the top. Cuttings from the sprouts were used in planting a nursery steckling test to study clonal differences in rooting ability. However, a late frost when the first leaves were emerging from the buds caused a complete failure of the test. The same clones were "rehedged" and sprayed with Pro-Shear in March, for a 1990 study of clonal effects on rooting.

The 1988 nursery steckling test used for the Master of Science Thesis was outplanted to a field site in December, 1988. These stecklings are currently being measured for numbers and cumulative growth of terminal, first-order lateral, and second-order lateral buds. Some of the stecklings will be dug up in late October, root washed, and measured for root traits and for dry weight.

Technical Information Dissemination

Khan, M. 1989. Rooting of American sycamore shoot cuttings for short rotation energy forestry. M.S. Thesis. Mississippi State University, School of Forest Resources.

Schultz, E. B., and S. B. Land, Jr. 1989. Sycamore seed and seedling traits--Early selection criteria? IN Proc. 20th Southern Forest Tree Improvement Conference. June 27-29, 1989, Charleston, SC (in press).

Land, S. B., Jr. 1989. Rooted sycamore cuttings for energy plantations. Poster presented at the Terrestrial Energy Crops Program 1989 Conference and Workshop, July 18-21, 1989, Washington, D.C.

Land, S. B., Jr. 1989. Early selection criteria and control-pollination methods for American sycamore. Paper presented at the Terrestrial Energy Crops Program 1989 Conference and Workshop, July 18-21, 1989, Washington, D.C.

5.6 OAK RIDGE NATIONAL LABORATORY–OPTIMUM NITROGEN NUTRITION IN SHORT-ROTATION SYCAMORE PLANTATIONS

Purpose and Background

Objectives are to evaluate the optimum nitrogen fertilization regime in a short-rotation American sycamore (*Platanus occidentalis*) plantation, with optimum defined in various ways depending on management objectives and to determine the physiological basis of the primary growth responses of sycamore to nitrogen fertilization and develop biochemical indicators of the response.

The competing definitions of the optimum regime include maximum fertilizer recovery, maximum biomass production, or maximum gain in production relative to the costs. The costs of nitrogen fertilization that are considered include environmental costs (nitrate leaching into groundwater) and biological costs (altered stress resistance).

Urea fertilization was applied to triplicate 625-m^2 plots of a sycamore plantation in various timing regimes: one-time only, annual ballooning, annual even, and periodic (three times per year) applications, all providing 450 kg N ha^{-1} over 3 years. Data are collected periodically on tree growth characteristics (including relative growth rate, aboveground biomass, and leaf area), physiological responses (including photosynthesis, water relations, pigment concentrations, and carbohydrate accumulation), and nitrogen metabolism (including nitrogen concentration, nitrate reductase activity, and amino acid pools). The plant data are combined with soil measurements (including soil solution chemistry, nitrification potential) to assess the optimum fertilization regime. The results will help to define the proper fertilization protocol for sycamore in short-rotation plantations, identify

the important economic and environmental consequences of fertilization, and describe the mechanisms of response such that the results can be applied to other systems.

Accomplishments

A new sycamore plantation, which had been established in 1988, was laid out in treatment plots and fertilized in April. Plots in the periodic treatment were also fertilized in June and August. Herbicide applications have kept weed competition under control.

Relative growth rate (RGR) of the sycamore trees was high (1%/day) and similar in all nitrogen treatments in April and May. By June the RGR of annual even (AE, 150 kg N/ha) and the heavily fertilized one-shot (01, 450 kg N/ha) were 17 to 19% greater than unfertilized controls (C), but all treatments were rapidly growing at ~3%/day. RGR peaked in July at 7%/day with AE and 01 growing 14 to 19% faster than C. Periodic fertilization (P, 50x3 kg N/ha) did not stimulate RGR above that in C until after July, when the site was drier. RGR in all treatments were below 2%/day in all treatments from late July through early September.

Gas exchange, including net photosynthetic rate and stomatal conductance to water vapor, were similar and moderate in C, P, and 01 on all sampling dates from May through August. Therefore, gas exchange variables should not be used as indicators of the growth response of sycamore to nitrogen fertilization.

Photosynthetic pigment concentrations were similar between treatments in May, but total chlorophyll concentration of AE and 01 was more than 20% greater than controls in June and July, paralleling the growth differences. In July, P had the lowest pigment concentrations and lowest RGR. Overall, chlorophyll concentration is a useful general indicator of growth response to nitrogen fertilization.

The 01 trees established ~40% more leaf area as early as one month into the growing season, which translated into higher RGR in the June sampling period. Leaf area of AE and 01 were 38 to 47% greater than C in July. Growth differences between treatments in the 1989 field season are solely attributable to differences in leaf area production.

The leaf nitrogen concentration of 01 and AE treatments in May were 28% and 21% greater than C, respectively. The nitrate reductase activity (NRA) of the 01 treatment was 88% greater than C in May, 2.6 times greater in June, 68% greater in July,

and 2.1 times greater in August. The changes in NRA and foliar nitrogen concentrations preceded differences in RGR, whereas differences in photosynthetic pigments paralleled differences in RGR. These physiological variables are continuing to be useful indicators of sycamore growth response to nitrogen fertilization.

Biochemical analysis of leaf tissues collected in 1987 has shown that glutamic acid and aspartic acid are the amino acids present in the highest concentrations in sycamore. Fertilized trees have higher levels of glutamic acid and aspartic acid early in the season, which suggest their potential use as predictors of nitrogen deficiency. The concentration of glutamine and the ratio of glutamine/glutamic acid (product/substrate) are good indicators of growth response to fertilization.

A solution of $^{15}NH_4Cl$ was applied around two trees per plot (C, P, and 01 treatments) in August. Leaf samples were collected periodically in order to determine the timing and distribution of the uptake of N from the soil. Soil samples were collected to determine the rate of loss of nitrogen from soil. These samples have not yet been analyzed.

Pretreatment soil mineralization and nitrification potential was determined through aerobic laboratory incubation over a 30-week period. Soil subsamples were extracted monthly and final extractions are still being analyzed for inorganic N. A cursory scanning of the mineralization curves indicates comparable (pretreatment) soil mineralization potential between the different treatment plots.

The effect of the different fertilization regimes on soil N transformations under field conditions was evaluated through monthly sampling of the soil and soil water (with lysimeters) in each treatment plot. Posttreatment solution samples taken in spring and summer (April through July) indicated accelerated nitrification with fertilizer addition especially with the higher application rates. Increases in solution NO_3 concentrations were least pronounced following the periodic fertilization. Results from the soil extractions are still being analyzed, but the available data indicate a similar but even more pronounced fertilization effect.

Technical Information Dissemination

Norby, R. J. 1989. Direct responses of forest trees to rising atmospheric carbon dioxide. Paper presented Terrestrial Energy Crops Program 1989 Conference and Workshop, July 17-21, 1989, Washington, D.C.

Tschaplinski, T. J., and T. J. Blake. 1989. Water relations, photosynthetic capacity, and root/shoot partitioning of photosynthate as determinants of productivity in hybrid poplar. Can. J. Bot. 67:1689-1697.

Tschaplinski, T. J., and T. J. Blake. 1989. Correlation between early root production, carbohydrate metabolism, and biomass production in hybrid poplar. Can. J. Bot. 67:2168-2174.

Tschaplinski, T. J., and T. J. Blake. 1989. Water stress tolerance and late-season organic solute accumulation in hybrid poplar. Can. J. Bot. 67:1681-1688.

Tschaplinski, T. J., and T. J. Blake. 1989. Photosynthetic reinvigoration following shoot decapitation, and accelerated growth of coppice shoots. Physiol. Plant. 75:157-165.

Tschaplinski, T. J., and T. J. Blake. 1989. The role of sink demand in carbon partitioning and photosynthetic reinvigoration following shoot decapitation. Physiol. Plant. 75:166-173.

Tschaplinski, T. J. 1989. Ecophysiological studies of the Biomass Program. Paper presented at International Energy Agency Task V - Activity 2 Meeting, Energy Forestry - Ecophysiology. September 20-22, 1989, Ivy Lea, Ontario.

Tschaplinski, T. J., and R. J. Norby. 1989. Optimum nitrogen nutrition in short rotation sycamore plantations. Paper presented at Annual Meeting of the American Society of Plant Physiologists. July 29 - August 1, 1989, Toronto, Ontario.

Tschaplinski, T. J., and R. J. Norby. 1989. Foliar indicators of optimum nitrogen nutrition in short rotation sycamore plantations. Paper presented at Terrestrial Energy Crops Program 1989 Conference and Workshop, July 17-21, 1989, Washington, D.C.

Tschaplinski, T. J., and R. J. Norby. 1989. Water stress tolerance of trees: Implications for biomass plantations growing under increased drought and elevated CO_2. Paper presented at Terrestrial Energy Crops Program 1989 Conference and Workshop, July 17-21, 1989, Washington, D.C.

5.7 THE PENNSYLVANIA STATE UNIVERSITY-ECONOMIC ANALYSIS FOR PRODUCING *POPULUS* HYBRID UNDER FOUR MANAGEMENT STRATEGIES

Purpose and Background

Objectives are to establish and analyze: (1) biomass yields for two rotations as a function of management strategy, site, and age; (2) financial and energy measures of key inputs for producing short-rotation hybrid poplar using four management strategies (control, irrigation, fertilization, and fertilization/irrigation) for two rotations; (3) wood properties related to use as a source of fuel as a function of management strategy and site; (4) sensitivity analyses of the selected management strategies to inputs for two rotations; (5) a comparison of the financial and energy analyses for selected management strategies for two rotations; and (6) recommendation of the most advantageous management and conversion strategies for two rotations with the most favorable financial and energy considerations.

The plantation biomass production task was designed to measure and evaluate biomass yields, growth values, and properties for short rotation woody crops (SRWC) plantations under four management strategies (control, irrigation, fertilization, and fertilization/irrigation) on two sites for two rotations. In addition, SRWC financial and energy inputs needed to operate and maintain the plantations under selected management strategies are measured. The hybrid poplar SRWC plantations established in central Pennsylvania were analyzed to determine their economic optimum rotation age. The general management design for the plantations used fertilized and nonfertilized strategies and a rotation length of 4 years. A stand-level financial model analyzed the cost of production for alternate rotation lengths, using the plantation's investment and operating costs and resulting biomass yields.

Accomplishments

In the first coppice year there were essentially no site, year of planting, or treatment differences in total tree biomass yield. The 1-year-old coppice overall average was 6.3 oven dry $Mg \bullet ha^{-1}$ which ranged from 6 to 45 times greater than the 1-year-old yields of the first rotation, depending on site, planting year, and treatment. In the second coppice growing season, all trees produced 15.2 oven dry $Mg \bullet ha^{-1}$ of total tree biomass to

accumulate 21.6 oven dry Mg•ha^{-1} at age 2. Although there were suggestions of slight gains in yield due to fertilization, the total tree yields for the 2-year-old coppice were not dependent on site, year of planting, or treatment. The second rotation 2-year-old yields ranged from 1.8 to 22 times greater than the values measured after 2 years in the first rotation, depending on site, year of planting, and treatment. Total tree biomass in the third coppice year accumulated 36.7 oven dry Mg•ha^{-1}. The 1- and 2-year-old coppice yields were not influenced by treatment, but in the third coppice year fertilization increased total tree yield over no fertilization. Averaged over year of planting and site, units which were fertilized averaged 40.3 oven dry Mg•ha^{-1} of total tree biomass and units which were fertilized averaged 33.1 oven dry Mg•ha^{-1}. The second rotation 3-year coppice yields ranged from 1.2 to 2.7 times greater than were measured after 3 years in the first rotation, depending on site, planting year, and treatment. In the fourth coppice growing season, all planted trees produced 62.3 oven dry Mg•ha^{-1} of total tree biomass to accumulate 42.9 oven dry Mg•ha^{-1}. Averaged over both planting years and both sites, total tree biomass was 38.6, 39.8, 45.8, and 48.4 oven dry Mg•ha^{-1} for the control, irrigation, fertilization, and fertilization/irrigation, respectively.

By the end of the second rotation, the major difference in treatment-site specific yields between the 2 years of planting have been eliminated. Our preliminary evaluation of the total tree biomass yields that were determined from the yield equations and the entire living continuous tree data set are:

1. Coppice rotation yield advantage over establishment rotation yields were dependent on rotation length, root system mortality, and first-rotation weed control program.
2. Year of planting (weed control program) and plantation site had no effect on second rotation yields.
3. Second rotation yields from control treatment were 38.6 oven dry Mg•ha^{-1} (9.75 oven dry Mg•ha^{-1}•year^{-1}).
4. Irrigation did not increase biomass yield over control yield.
5. Fertilization second-rotation biomass yield of 45.8 oven dry Mg•ha^{-1} (11.5 oven dry Mg•ha^{-1}•year^{-1}) was about 17% greater than control yield.
6. Fertilization/irrigation second rotation yield of 48.4 oven dry Mg•ha^{-1} (12.1 oven dry Mg•ha^{-1}•year^{-1}) was 24% greater than control yield.

The second estimate of second-rotation yields was the adjusted predicted value from the entire continuous inventory data base. Adjustments to the equation predicted values were made based on actual harvest values. Total tree yields of 35, 37, 41, and 42 oven dry $Mg \bullet ha^{-1}$ for control, irrigation, fertilization, and fertilization/irrigation, respectively, will be used in conjunction with the energy and chemical values to provide inputs to the financial and energy analyses.

Fuel and chemical feedstock property evaluations were divided into the following areas: (1) analysis of the fuel and chemical properties for differences among cultural strategies within and between sites for second-rotation biomass and between first- and second-rotation values; (2) analysis of specific gravity values from 4-year-old single-stem coppice trees with a diameter of ± 2% of the average single stem diameter for differences among management strategies; and (3) analysis of the variability in 4-year-old coppice specific gravity values among single and multiple stems as a function of management strategy and site. The 1980 planted trees for these analyses have been harvested and evaluated.

Preliminary estimates of the fuel and chemical properties for the tissues from 1980 and 1981 planted 4-year-old coppice trees have been determined. Analysis of the data will continue.

Management strategy appears to have influenced the specific gravity values at both sites. While a management strategy effect appears to be present in the specific gravity data for the bark samples, the trend may be the inverse of the wood specific gravity trend.

Bark specimens had lower moisture content values than wood at the Basher site but higher moisture content values than wood at the Morrison site. Wood gross heat of combustion values at both sites were lower than bark values. In general, bark at both sites had a higher ash and extractive content but lower holocellulose content compared to wood.

Specific gravity values for wood specimens (oven dry weight/green volume) from 1980 and 1981 planted 4-year-old, second-rotation single-stem trees with a diameter of ± 2% of the average single-stem tree diameter for each plot have been obtained. Preliminary analysis of the specific gravity values for these specimens indicated that at each of the sites the fertilization and fertilization/irrigation average specific gravity values

were statistically similar and statistically different from the control and irrigation average specific gravity values.

Specimens for analyzing the variability in 4-year-old wood specific gravity values (oven dry weight/green volume) among single and multiple stems as a function of management strategy and site have been obtained. Preliminary analysis indicated that stem 1 and stem 2 were statistically similar within each management strategy at a site.

Analysis of financial and energy data for the first two rotations indicated that the minimum unit cost for fertilizer and nonfertilizer strategies was in the fourth year of the first rotation and the third year of the second rotation. Results from this study indicated a need to realign the second rotation of the plantations to facilitate gaining a greater average annual output and, at the same time, lowering production costs. The existing 4-year harvest strategy missed the optimum production and economic points in the second rotation by 1 year. Selection of a 3-year rotation would reduce production costs by 12% in the nonfertilized strategy and by 15% in the fertilized plantation.

The major sources of production costs in the nonfertilized strategy were almost uniformly distributed among three categories: (1) establishment cost–representing 36.2% of the total, (2) land and land taxes–35.2%, and (3) annual management and maintenance–28.6%. The fertilized strategies also had near uniform distributions among four categories: (1) establishment–27.8%, (2) land and land taxes–27.0%, (3) fertilization–23.3%, and (4) annual management and maintenance–21.9%. These categories would therefore have a near uniform effect or sensitivity in altering total costs within their respective strategies.

The general structure of the least cost model used in this study should prove adaptable to other SRWC systems. This particular model can also be employed in the analysis of alternate plantation designs, cultural treatments or species. The basic limit to this analytical approach is developing a sufficiently detailed data base that is representative of the plantation system under study.

Technical Information Dissemination

Blankenhorn, P. R., T. W. Bowersox, C. H. Strauss, G. L. Stimely, L. R. Stover, and M. L. DiCola. 1988. Effects of management strategy and site on selected properties of first rotation *Populus* hybrid NE-388. Wood Fiber Sci. 20(1):74-81.

Blankenhorn, P. R., T. W. Bowersox, C. H. Strauss, G. L. Stimely, L. R. Stover, and M. L. DiCola, M. L. 1988. The effects of management strategy on the physical and chemical properties of *Populus* hybrid clone NE-388. Paper presented at the Forest Products Research Society 40th Meeting, Spokane, Washington.

Blankenhorn, P. R., T. W. Bowersox, C. H. Strauss, L. R. Stover, and M. L. DiCola. 1988. A note on the effects of *Septoria* on selected properties of first rotation four year old *Populus* hybrid NE-388. Wood and Fiber Science (in review).

Grado, S. C., C. H. Strauss, P. R. Blankenhorn, and T. W. Bowersox. 1988. Short rotation woody biomass plantations: technical requirements and costs for establishment. Biomass 17:277-289.

Strauss, C. H., S. C. Grado, P. R. Blankenhorn, and T. W. Bowersox. 1989. Developing financial and energy accounting models for woody biomass systems. Solar Energy 42(5):379-386.

Strauss, C. H., S. C. Grado, P. R. Blankenhorn, and T. W. Bowersox. 1989. Economic evaluations of optimum rotation age for SRIC plantations. in Klass, D. L. (ed.) Proc., Energy from Biomass and Wastes XIII (in press). Institute of Gas Technology, Chicago.

Strauss, C. H., P. R. Blankenhorn, T. W. Bowersox, and S. C. Grado. 1988. A cost analysis of alternate biomass supply systems. For. Prod. 38(1):47-51.

Strauss, C.H., P. R. Blankenhorn, T. W. Bowersox, and S. C. Grado. 1988. Financial and energy costs of supplying biomass to conversion sites. Applied Biochemistry and Biotechnology 17(3):31-44.

Strauss, C. H., S. C. Grado, P. R. Blankenhorn, and T. W. Bowersox. 1988. Second rotation cost evaluations of biomass from short rotation intensive culture *Populus* plantations. pp. 66-84. IN D. L. Klass (ed.) Proc., Energy from Biomass and Wastes XII. Institute of Gas Technology, Chicago.

Wright, L. L., D. R. DeBell, C. H. Strauss, W. A. Geyer, L. Sennerby-Forsse, and L. Zsuffa. 1989. Panel discussion on the relative merits of woodgrass and SRIC. IN Klass, D. L. (ed.) Proc., Energy from Biomass and Waste Conference XII. International Gas Technology, Chicago.

5.8 SOUTHERN ILLINOIS UNIVERSITY-GENETIC BIOMASS AND GROWTH ANALYSIS OF CLONAL SILVER MAPLE (*ACER SACCHARINUM* L.) IN SEVERAL LOCATIONS

Purpose and Background

The project's objective is to select and test 6 outstanding clones each of silver maple (*Acer saccharinum* L.) from 13 of 23 different provenances collected throughout the eastern United States and southeast Canada during the spring and early summer of 1987.

This project utilizes genetic and physiological techniques to maximize biomass production of silver maple as a short-rotation woody crop. Seventy-eight clones will be outplanted in replicated studies in 1990 at sites in Minnesota, New Hampshire, New York, Oklahoma, and both an upland and bottomland site in Carbondale, Illinois.

Accomplishments

At least 6 clones each from 15 provenances are being multiplied *in vitro*. Explants that have been in culture for 4 months commonly have at least 60 axillary shoots that can be subcultured or excised for rooting. Only apical segments of microshoots are now being rooted *in vitro* with 1 uM NAA in Magenta GA7 vessels to increase plantlet uniformity, survival, and acclimatization. Rooted microshoots from the *in vitro* cultures are then established in RootMaster cell containers with Promix BX for field planting. The major constraint with plantlet production has been moving from *in vitro* to greenhouse conditions. Direct rooting of vertical macrocuttings has been accomplished in a nursery bed. A chilling requirement for silver maple bud break following dormancy has been determined.

Trees from the provenance nursery were harvested from the four southernmost blocks after 2 years of growth during May and the stumps were allowed to coppice. The water relations of coppiced and noncoppiced trees was investigated (by Dr. Roger Kjelgren, Plant and Soil Science) to determine the effect of providing a small canopy with a large root system. Preliminary analysis of the data indicate that the coppiced trees maintained greater stomatal conductances and less negative leaf water potentials during daylight hours during three study periods. After a 3-week drying cycle, the coppiced trees had less negative predawn water potentials than the noncoppiced trees. This suggests that the coppiced trees are able to maintain greater gas exchange at lower internal water

deficits than noncoppiced trees, and despite greater water loss rates, the coppiced trees are less subject to soil water deficits, most likely due to the reduced leaf area.

The sub-sampled 1987-88 dry weights of trees from the four harvested beds in the nursery were significantly larger for several northern accessions than the Illinois and other midwestern provenances that had the lowest weights. This may be attributed to possible tree density effects in that the northern provenances had low seedling establishment and thus more growing space per tree. The density/growth relationship is being analyzed.

Wood samples of four harvested trees each from Illinois, Mississippi, and Wisconsin ranged from 15.8 - 17.5 MJ•kg (6781 -7548 Btu•lb) with a mean of 16.8 MJ•kg (7227 Btu•lb). There was no statistically evident provenance differences in energy content.

Six clones each from 15 different provenances remain *in vitro* and are all proliferating axillary shoots. Because of unexpectedly poor rooting and low survival of cuttings stuck under mist, all microshoots are now being rooted *in vitro*. To assure more uniformity and better plantlet survival, only apical segments of microshoots from culture vessels are now placed in solidified DKW medium with 1 uM NAA in Magenta GA7 cubes. When rooted *in vitro*, there was little difference in rooting between apical and nodal segments. Though the nodal segments are more numerous (a single microshoot may be cut into 2-3 segments), they acclimatized very poorly to greenhouse conditions. Thus, even though the number of available shoots for rooting has dropped, there is an increase in plantlet uniformity, survival, and acclimatization. This procedure may greatly increase the efficiency of scale-up from micropropagation research to production.

Approximately two weeks after the shoots are stuck, the rooted plantlets are transplanted into Pro-Mix BX soil-less medium in RootMasters Containers. They are placed under intermittent mist in a shaded greenhouse for the first week to begin acclimatization. The plantlets are moved to a sunlit bench while remaining under mist for 1 week, moved to a shaded bench without mist for another week and then moved to fully sunlit benches until a height of 30 cm is reached (approximately two months after being removed from the laboratory). The entire acclimatization and growing-on stages are conducted under natural photoperiods supplemented with a four hour night interruption cycle (10 p.m. to 2 a.m.) supplied by cool white fluorescent lamps.

Three hundred cuttings were taken from 2-year-old saplings of northern Illinois origin to investigate the possibility of direct sticking as a method of plantation establishment for silver maple. The cuttings were arranged factorially in two planting orientations (horizontal and vertical) with three rooting-growth regulator treatments. No horizontally-placed cuttings grew or rooted, suggesting that light was required to initiate break bud. The vertically-placed cuttings broke bud and had rooting percentages of 75, 55, and 30 % with average root numbers of 45, 25, and 10 for the Rootone, Hormodin, and the untreated cuttings, respectively, after eleven weeks.

Plantlets continue to be produced for the clonal plantations. They are growing well in the RootMaster containers with constant liquid fertilization. In previous work noted in the 1988 annual report, micropropagated silver maple trees were stored in a cooler for up to four months, during which time the trees set bud and lost their leaves. When placed into warmer growing conditions in sunlight, they broke bud and resumed growth. Trees will be "stockpiled" for field planting this spring by similar storage in coolers. Once the acclimatized plantlets are 30 cm in height, the soil is drenched with the fungicide "Banrot" and the plants are placed into a walk-in cooler at 4°C to harden off. The trees will be checked twice weekly for watering, leaf sanitation, fungal contaminants or diseases, including *Botrytis*, root problems, and presence of insects. If pest problems are noted, appropriate pesticides will be applied. The over-wintered plants can be removed after 3 months of chilling and may be either directly loaded into a truck for shipment or allowed two weeks to sprout and then culled prior to shipment.

The Minnesota plantation was partially planted on May 30-31 with 66 clones representing all 15 provenances. All trees were measured on June 1-2 and remeasured on August 11-12. The site had been disked in April and sown to orchard-grass in mid-May. Each planting spot (61-cm diameter circle) was treated with granular Princep and Dachtal immediately after planting, and the spots to be planted later were sprayed with Roundup in July. Analyses of survival and growth are being carried out by a new team member. The work so far on the Minnesota plantation has provided valuable field experience in handling plantlets from tissue culture.

The three plantation sites at Carbondale were disked and planted in early May with annual ryegrass for ground cover. Continued drought in this area led to drying up of the young ryegrass and a later invasion of weeds. The weeds were herbicided and the

sites were disked and planted to a winter cover crop in preparation for spring planting of silver maple plantlets.

The tentative planting dates are April 15, 1990, for both of the Carbondale sites and May 30 for the remaining Minnesota plantlets. The other plantations will be planted as feasible. Sufficient numbers of each clone will be available at all sites when planted so that replanting may be accomplished (with personnel on-site) in the fall to replace original mortality. If required, a follow-up planting trip will be scheduled one year after the initial planting to replace winter mortality. These plantlets should be one meter tall to approximate a one-year-old condition.

Measurement of climatic data is being carried out on a continuing basis.

Technical Information Dissemination

Preece, J. E., C. A. Huetteman, W. C. Ashby, and P. L. Roth. 1989. Site of origin affects micropropagation and rooting of cuttings of silver maple (*Acer saccharinum* L.). IN Programs and Abstracts of the 86th Annual Meeting of the American Society of Horticultural Science. Abstract and Poster Presentation.

Preece, J. E., W. C. Ashby, P. L. Roth, C. A. Huetteman, and D. F. Bresnan. 1989. Genetic biomass and growth analysis of clonal silver maple (*Acer saccharinum* L.) in several locations. Poster presented at the Terrestrial Energy Crops Program 1989 Conference and Workshop, July 17-21, 1989, Washington, D.C.

5.9 TUSKEGEE UNIVERSITY-BIOMASS RESEARCH AND TRAINING PROGRAM

Purpose and Background

A sycamore (*Platanus occidentalis*) plantation, of approximately 4000 trees, was established in spring 1987. In the spring of 1988, the trees were cut back to a uniform height of 20 cm. During April 1988, initial levels of soil fertilization were first applied to the plantation and the second application was made in April (Table 18). The plantation is kept essentially weed-free using herbicide (Roundup) or mechanical weed eating, where feasible. During the months of July to September, Tuskegee received light to moderate rainfall. The months of August to mid-September were relatively dry. However, the reduced rainfall conditions did not affect the tree growth physiology. Due to the unusual

Table 18. Soil fertilizer schedule for optimum nitrogen nutrient experimentation in the sycamore tree plantation

Type of fertilizer	Urea-N applied (kg/ha) year applied			
	1988	1989	1990	Total
Control (C)	0	0	0	0
One-shot (01)	450	0	0	450
Annual-even (AE)	150	150	150	450
Annual-balloon (AB)	50	150	250	450
Multiple (M)[a]	3 x 50	3 x 50	3 x 50	450

[a]Three applications of 150 kg/ha each will be applied during the months of April, June, and August.

conditions in July to August, the soil moisture levels were high and the trees responded with increased growth patterns during this period. Multiple applications of urea to the designated plots were made during April, June, and September. The sycamore trees were affected by fungal infection, especially anthracnose. However, the incidence of fungal infestation did not warrant the application of fungicide. The plantation was essentially weed-free as of September 30, 1989. Senescence of the sycamore trees has begun, especially in the lower canopy, and a large proportion of the trees have shed approximately 50% of their leaves.

An 800-tree green ash (*Fraxinus pennsylvanica*) plantation was planted in spring 1988 and is being maintained on a small scale for use by the students and researchers at Tuskegee University or Oak Ridge National Laboratory to determine the effects of normal and slow-release urea nitrogen applications on tree growth and biomass production.

Accomplishments

The sycamore trees are in their third year of growth. In 1988, irregular tree height measurement patterns were noted. Oak Ridge National Laboratory research staff was contacted for consultation. After consultation it was decided to coppice the trees to a uniform height of 20 cm in March 1988, and various fertilizer applications were done in April 1988. In April, June, and September, additional fertilizer applications were done.

Sycamore tree height and diameter readings on 10 trees/plot for a total of 30 trees/plot were taken monthly beginning in April. The measurement trees were selected along a diagonal transect and tagged during the spring of 1989.

Observations on leaf phenology of five replicate tree/plot were made during June and September. The number, length, and diameter of the main and secondary branches were noted. Results obtained from these measurements are being processed.

Photosynthetic pigment concentrations of chlorophyll a and b, carotenoids, and xanthophyll were measured monthly during the growing season. Data are being compiled and analyzed.

Nitrate reductase activity (NRA) in leaf samples was determined during the months of July and September. These measurements will be continued during October.

Total leaf nitrogen and -NO_3 concentrations were taken in September and are being processed.

Soil samples from control and fertilizer plots were taken during April and July for analysis of NH_4-N and NO_3-N. Results from the April analysis are presented in Table 19. The results seem to indicate that after urea application the NH_4-N levels fell below the control levels in the upper 15 cm soil depth samples except in the one-shot treatment plots. However, in the 15-30 cm soil sample depths, there were higher NH_4-N levels in all the treatment plots when compared to the controls. The NO_3-N levels in all the treatment plots were equal to the control levels at the 15-30 cm soil depths. Results from the July sampling are still being analyzed. Soil samples were taken again in October in order to detect any changes in soil nitrogen.

Destructive harvesting of selected trees was not done this summer. However, it was planned during the November/December months after complete leaf fall. It is anticipated that stem and branch samples will be processed and analyzed for NH_4-N and NO_3-N concentrations as well as macro and micro elements.

The presence of various insects and development of fungal diseases were monitored. The incidence of fungal disease infestation (sycamore anthracnose) ranged from 6.0-25% in the various treatment plots. The overall damage rating varied from 0.5-2.5 when based on a 0-5 scale (0 = no damage, 5 = serious damage). The July-September observations indicated that anthracnose and other fungal diseases became a serious problem this year due a mild winter, heavy rains (> 30 cm) during June, moderate rains during July-August (15 cm), and sustained high temperatures. All of these factors created an ideal incubation environment for sustained and elevated growth of these diseases. Data will be collected and analyzed to evaluate if there are any correlations between the N applications and other factors (i.e., leaf photosynthetic pigments).

In March 1988, the green ash trees were coppiced to a uniform 15-cm height and are in the second year of coppice growth. Plot A, which consists of approximately 400 trees, was treated with normal urea. Plot B, also consisting of approximately 400 trees, was treated with slow-release (sulfur-coated) urea. The nitrogen rates and soil application regimes are the same as those used in the sycamore plantations. The trees have regenerated well and have grown rapidly this year due to a very mild winter, increased soil moisture retention, and increased rainfall (> 40 cm) during the spring and early summer

Table 19. Soil nitrogen nutrient levels in the sycamore tree plantation during March 1989 (before fertilizer application) as determined at two soil depths

Type treatment	NH_4-N (ppm) soil depth			NO_3-N (ppm) soil depth		
	0-15 cm	15-30 cm	Mean	0-15 cm	15-30 cm	Mean
Control (C)	6.53	2.96	4.75	2.13	1.73	1.93
One-shot (01)	10.43	3.61	7.02	1.80	1.90	1.85
Annual-even (AE)	4.65	5.60	5.13	2.20	2.20	2.20
Annual-balloon (AB)	3.00	4.26	3.66	1.63	2.13	1.88
Multiple (M)	4.66	5.23	4.94	2.06	1.83	1.95

period. Growth readings of tree height and diameter are being to determine the effects of N fertilization and the unusual climatic conditions (increased rainfall) on overall biomass production.

Applications of normal and slow-release urea on the green ash plots were made during the spring, and a schedule of multiple applications of N is being followed in selected plots. Growth readings will be continued to determine the effects of N fertilization on total biomass production. The plantation is weed free, and trees have maintained a full foliage with minimal leaf loss.

Technical Information Dissemination

Weaver, A., R. S. Saini, S. Bhattacharya, A. Mauldin, D. P. Nicholson, S. Nima, M. Baiyee, and M. Randolph. 1989. Effects of various nitrogen fertilization genes on growth responses of sycamore (*Platanus occidentalis* L.) plantation. Paper presented at the Terrestrial Energy Crops Program 1989 Conference and Workshop, July 17-21, 1989, Washington, D.C.

Weaver, A., et al. 1989. Physiological responses of trees to urea nitrogen fertilization in a short-rotation sycamore (*Platanus occidentalis* L.) plantation. Paper presented at the Terrestrial Energy Crops Program 1989 Conference and Workshop, July 17-21, 1989, Washington, D.C.

5.10 USDA FOREST SERVICE, NORTH CENTRAL FOREST EXPERIMENT STATION–SHORT-ROTATION WOODY CROP TRIALS FOR ENERGY PRODUCTION IN THE NORTH CENTRAL UNITED STATES

Purpose and Background

Objectives are to obtain more accurate estimates of biomass yield and costs of wood energy (including harvesting trials) from short-rotation woody crops (SRWC) plantations through the establishment of large-size plantations, to facilitate transfer of research expertise to the private sector, identify operational problems that may require more research, and to identify hybrids best suited to the region and site.

Plantations were initially established at 12 sites across 4 states. This has since been reduced to nine due to poor soils and in one case an uncooperative landowner. There are two sites in Wisconsin, five in Minnesota, and one each in North and South Dakota. In

addition there are hybrid trials at another nine sites established cooperatively with university or experiment station personnel. The plantations consist of 8 ha (20 acres) at most of the sites. Two sites have 4-6 ha (10-15 acre)s due to partial failure from drought. A total of 53 ha (130 acres) are in plantations or hybrid trials. These plantations were established over a 2-year period that coincided with a historical record drought for the region.

The plantations are now successfully established and the major task is weed control which will continue for another 1- to 2-years until the canopies "close" for most of the clones. Other tasks include insect control and fertilization. To date three plantations have been sprayed for insect control (two with aerial application for cottonwood leaf beetle and one with ground application for forest tent caterpillar) and two plantations were fertilized (one with nitrogen and one with potassium).

Accomplishments

Growth and preliminary yields are surpassing that achieved at Rhinelander where the culture and yield data were developed for the region. Average height growth of all clones on all sites is essentially equal to the best height growth attained at Rhinelander which eventually produced 13.5-15.7 dry Mg•ha•year^{-1} (6-7 dry tons•acre•year^{-1}) of above-ground biomass from fully stocked plots. The best clones and the best sites doubled the height growth achieved at Rhinelander. However plantation survival averages only 80-90% for the better clones and less for other clones. It appears that ultimate yields of select clones on the better soils will substantially exceed those attained at Rhinelander. However, it remains to be seen by how much those yields will be exceeded. The drought induced mortality and the highly variable soils even within the 2.5-ha (1-acre) monoclonal blocks will reduce yields from that potentially achievable in small plots.

The plantations are serving their purpose as demonstration plantations and are stimulating interest in hybrid poplars as an alternative agricultural crop. On October 3, the Minnesota Department of Natural Resources (DNR) sponsored a field workshop on hybrid poplar establishment and culture for DNR foresters who work with farmers planting hybrid poplars under the Conservation Reserve Program (CRP). The workshop was held on a farm where 16 ha (40 acres) of poplars had been established during the past 2 years. About 40 DNR foresters attended along with about 10 farmers including one

who is planting 60 ha (150 acres) of hybrid poplars. In addition, hybrid trials have been established at four Agricultural Experiment stations across Minnesota. Sign-up for planting hybrid poplars on CRP lands is accelerating.

Information Needs

The establishment of this plantation network along with the acceptance of hybrid poplars by farmers as an alternative crop raises a number of research questions that require rather urgent solution. Among these are:

1. Categorize soils in the plantations so as to identify soil characteristics that produce the highest yields within the test plots. This will allow selection of future planting sites with confidence that high biomass production can be achieved. Present site selection produces variable results due to our limited knowledge.
2. Determine feasibility of midsummer weed control in 2-year and older plantations by spraying Roundup. Present control consists of grass herbicides and cultivation or disking. These herbicides are ineffective against broadleaves and the mechanical tillage requires multiply reentries and risks root damage from deep tillage. Also, if herbicides can be used in older plantations, the plantation network can be tended with a truck transported ATV with a cost savings to this program of about $20,000/year.
3. Develop a Septoria resistent clone by somaclonal methods. Septoria continues to be the major risk factor for established plantations. A group of 20 or more clones as a pool of planting stock for the region needs to be identified. Often some of the fastest growing hybrids are susceptible to Septoria and are therefor discarded. The question is, "can Septoria resistance be induced in an otherwise acceptable clone by using somaclonal techniques?"

Constraints

In January 1988, Northern States Power Company announced withdrawal from the program. It terminated its involvement 1 year later. After a lengthy search, a new sponsor, Electric Power Research Institute (EPRI) joined the program. EPRI provides the funding for land leases for a 3-year period. However, as a consequence of changing sponsors we stretched 12 months of funding over a 18-month period. This resulted in

reduced quality of operations in some cases. It also resulted in no time to conduct trials in order to improve management operations as we went along. Consequently, we have had no opportunity to develop information to improve the cultural system or to reduce costs. The examples above show some of the areas of information needed to make the cultural system economically and biologically viable.

Technical Information Dissemination

Hansen, E. A. 1988. SRIC yields: A look to the future. pp. 197-202. IN Proc., Economic Evaluations of Short-rotation Biomass Energy Systems. IEA/BA Task II Workshop. August 11-13, 1987, Duluth, MN.

Hansen, E. A. 1988. Irrigating short rotation intensive culture hybrid poplars. Biomass 16(4) 237-250.

Lothner, D. C., E. A. Hansen and D. A. Netzer. 1988. Growing and utilizing intensively cultured woody crops for energy: Some recent economic evidence from the North Central United States. pp. 92-102. IN Proc., Economic Evaluations of Biomass Oriented Systems for Fuel. IEA International Workshop. June 6-7, 1988, Garpenberg, Sweden.

Berguson, W., E. A. Hansen, W. Johnson, C. B. Morse and D. Zimmerman. 1989. Short rotation intensive culture tree production in Minnesota. IN Proc., Institute of Gas Technology (In press).

5.11 USDA FOREST SERVICE, NORTH CENTRAL FOREST EXPERIMENT STATION–INCREASING YIELDS OF *POPULUS* ENERGY PLANTATIONS

Purpose and Background

Objectives are to produce new genetically improved plant materials and develop prototype systems for increasing yields of *Populus* energy plantations, construct an ecophysiological growth process model (ECOPHYS) based on field studies of SRWC poplars, develop broad spectrum herbicide tolerant poplar germ plasm using somaclonal biotechnology and recombinant DNA technology, and develop physiologically based selection criteria for a *Populus* breeding and selection program.

Research on intensive cultured tree plantations for fiber and energy began at the North Central Forest Experiment Station (USDA-Forest Service) in 1971 at Rhinelander,

Wisconsin. The research approach consists of an interdisciplinary team of Forest Service and university scientists with expertise in physiology, hydrology, genetics, and pathology working toward the common program goal through specific study objectives. Current emphasis is on whole-tree process modeling, biotechnology, and physiologically-based tree selection.

Accomplishments

Phase I of the development of an ecophysiological growth process model (ECOPHYS) was completed. This phase included scientific documentation of the model with the submission of the software and user's guide to the North Central Station for publication and distribution and the submission of a book chapter on the model concepts to Timber Press for publication in late 1989. Further documentation of the verification and validation of ECOPHYS was completed and manuscripts submitted to *Tree Physiology* and IUFRO Conference Proceedings. The model can be used for early selection and breeding, assessing the impact of environmental stress, identifying areas for further research, and teaching whole-tree physiology. Phase II will emphasize the linkage of ECOPHYS with an expert system to allow the model to adapt to a changing environment.

Greenhouse testing was completed for plants regenerated from leaf disks in the presence of either glyphosate (Roundup) or sulfometuron methyl (Oust). At this time, ten variant plants have been selected for further evaluation. These plants have survived three replicated spray tests and continue to express more tolerance to the herbicides than the nonselected parent clones.

Five variants have increased tolerance to sulfometuron methyl and another five to glyphosate. Results of enzyme activity assays show that four of the sulfometuron methyl-tolerant plants have greater ALS activity than parent clones (NC-11390 and 5272) and one has equal activity but still greater herbicide tolerance. The remaining five glyphosate-tolerant variants (NC-11390 AND 5272) are currently being assayed for PESPS enzyme activity.

Current funds have been allocated to maintain herbicide-tolerant variants. To plan for future work, preliminary field trials with nonselected parent clones (NC-5339, 5272, 11390, 5326, and 5331) were completed this summer to determine clonal tolerance to both herbicides for hardwood and softwood cuttings. Trees were sprayed with three rates of

herbicide (Roundup or Oust). Results are being analyzed, and this baseline information would be used to determine proper herbicide rates to use in the event that we proceed with field evaluation.

Experiments were conducted to determine optimum *Agrobacterium* cocultivation time and concentration. Also, plant and bacterial DNA extraction methods were tested and extractions and purifications of DNA from putative transformed shoot completed. Susceptibility of hybrid poplars to *Agrobacterium* was also determined to be maternally inherited in a population of six hybrid families. Southern blot analysis was performed on ten putative transformed NC-5339 subclones. Results verify insertion of an improved aroA glyphosate-tolerance construct into the nuclear genome of eight of the ten subclones tested (see Table 20).

A field study was planted at North Central Forest Experiment Station Harshaw Forest Research Farm in Rhinelander, Wisconsin, in 1986 to develop physiologically-based selection criteria. The experimental design consisted of a randomized complete block design with 36 *Populus* clones (2 clones per species). The 36 clones (1 tree per clone) were planted within each whole plot. The clones were planted at 2 x 2 m spacing in 3 soil moisture regimes (i.e., irrigation treatments) of none, -1.5 bar, and -0.5 bar. The whole-plot treatment was irrigation with four replications.

During the first 3 years (i.e., FY 1987, 1988, 1989) data were collected on phenology, leaf and branch morphology, stomatal size, frequency, conductance, leaf water potential, and photosynthesis. These data were related to aboveground tree growth under irrigated and unirrigated conditions.

Multivariate analysis techniques were used to develop selection functions based upon morphological and physiological traits. Results suggest that such selection functions are superior to more traditional mensuration selection methods (see Figs. 5-8).

After the third growing season (i.e., FY 1989) two groups of clones were selected: those that grew well under drought stress and those that did not. Five clones were then selected from each of the three species and their root was excavated with a "tree spade" in the spring. The root mass was destructively sampled for biomass by root size class for each of six 20-cm depth increments. This research will add the root morphology component to the aboveground component to help relate tree characteristics to drought tolerance/avoidance. From the past crown data and this root research, we hope to be able

Table 20. Results of Southern Blot analysis of putative transformed hybrid poplar NC-5339. All transformants resulted from 48h cocultivation at stated bacterial concentrations.

Putative transformant no.	Bacterial concentration (cfu/ml)	Hybridization to aroA probe	Size of main fragment (Kb)
PT1a	1×10^8	Positive	4.6
PT1b	1×10^8	Positive	4.6
PT2	1×10^8	Negative	--
PT3	1×10^8	Positive	4.6
PT4	1×10^7	Negative	--
PT5	1×10^7	Positive	3.3
PT6	2×10^8	Positive	4.6
PT7	2×10^8	Positive	4.6
PT9	2×10^8	Positive	4.6
PT13	2×10^8	Positive	4.6
5339 (CONTROL)	--	Negative	--

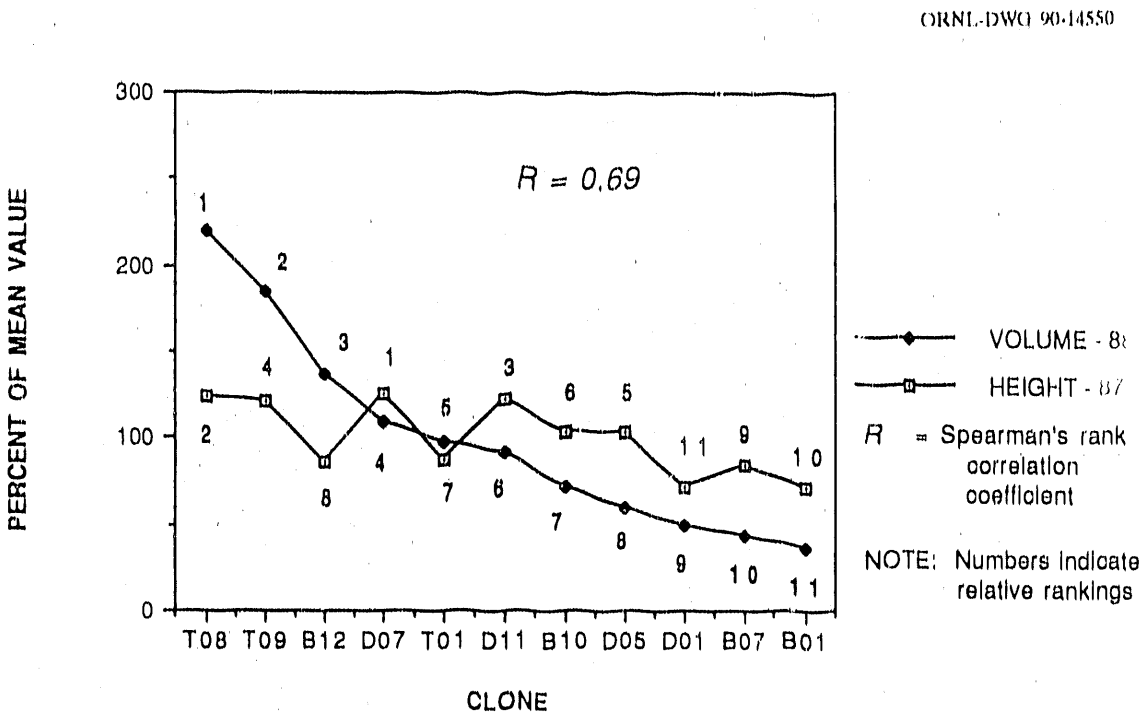

Fig. 5. Clonal rankings based on 1987 end-of-year height compared to rankings based on 1988 total tree (stem and branch) volume.

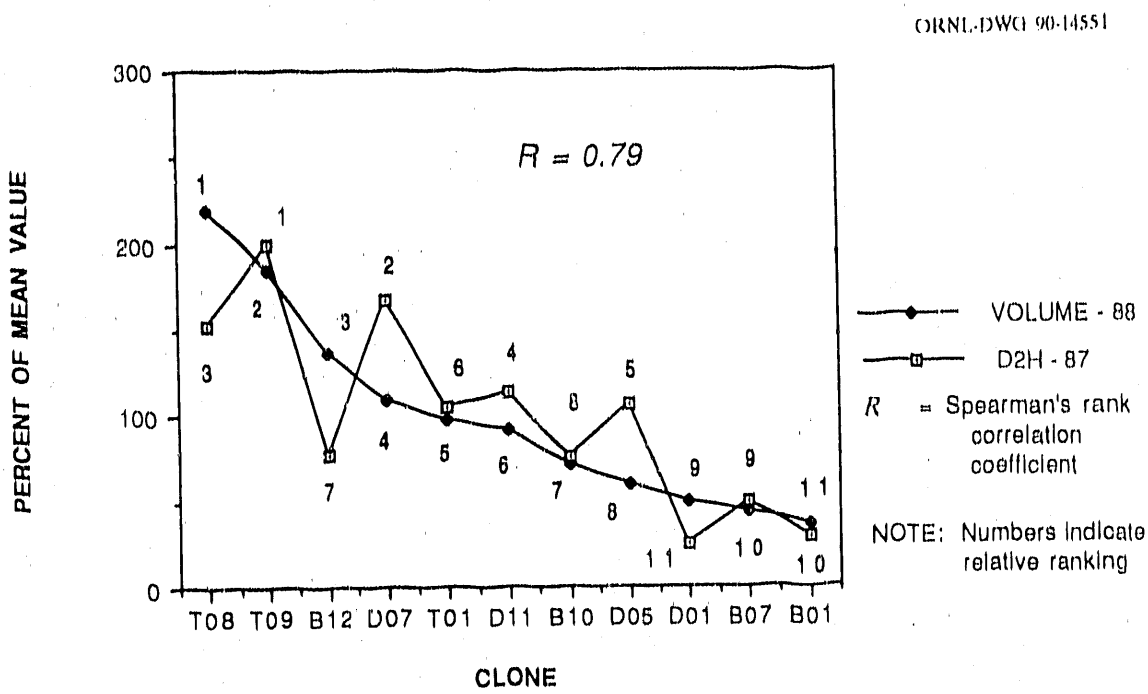

Fig. 6. Clonal rankings based on 1987 end-of-year D^2H compared to rankings based on 1988 total tree (stem and branch)volume.

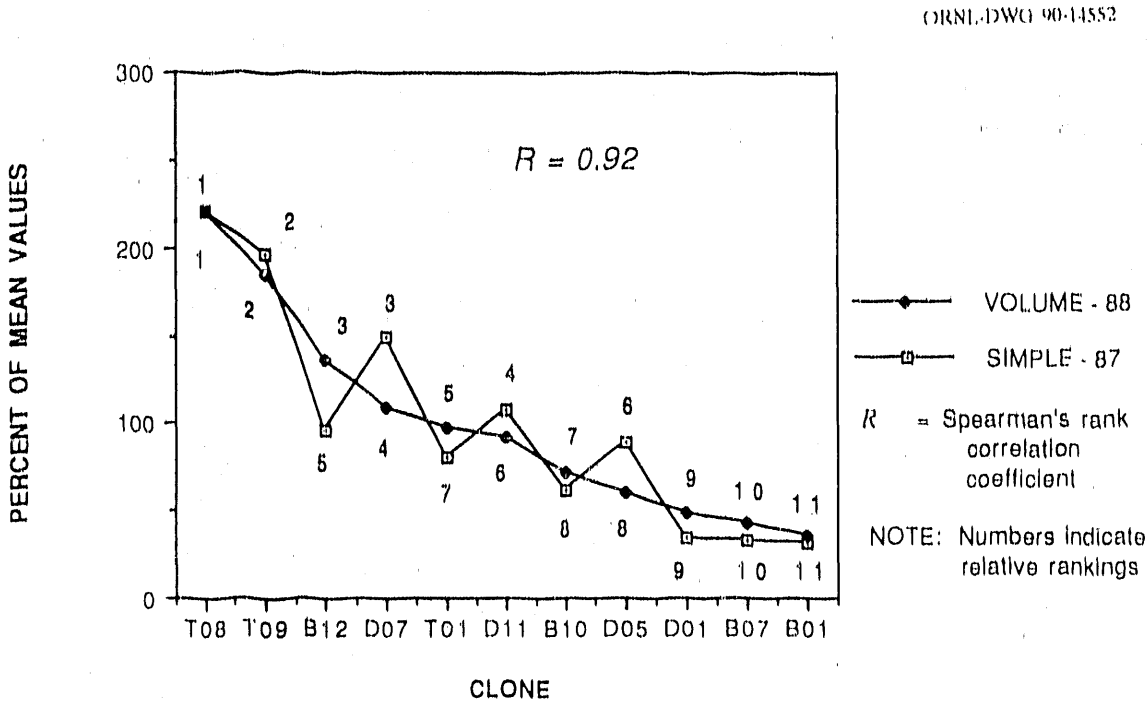

Fig. 7. Clonal rankings based on 1987 simple function compared to rankings based on 1988 total tree (stem and branch) volume.

ORNL-DWG 90-14553

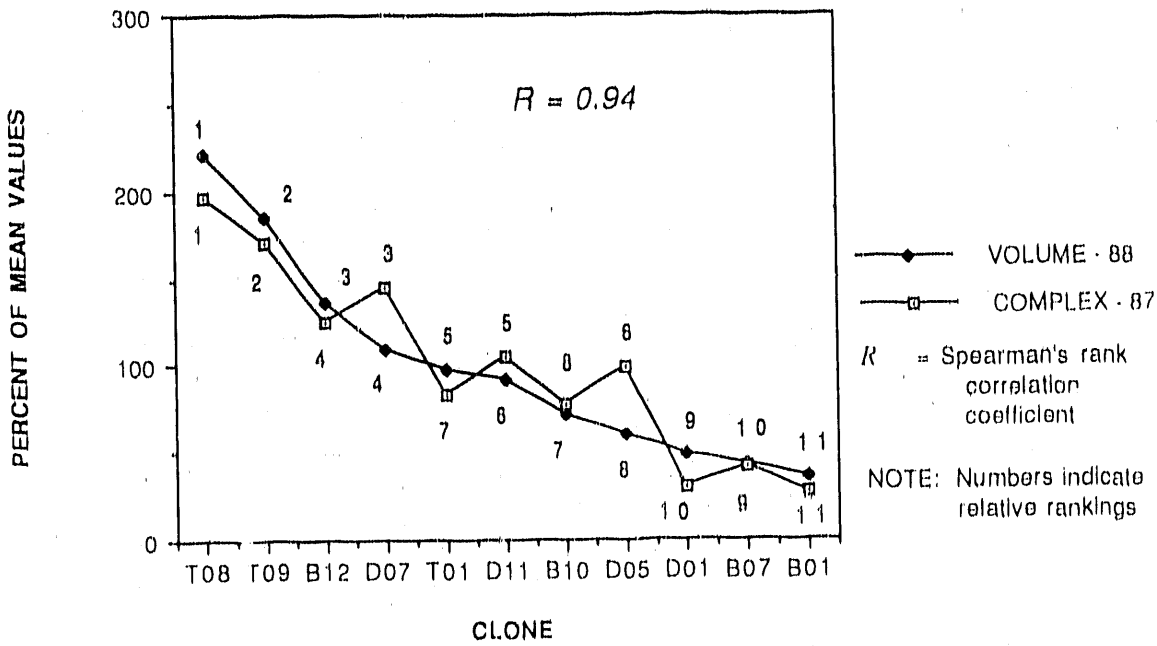

Fig. 8. Clonal rankings based on 1987 complex function compared to rankings based on 1988 total tree (stem and branch) volume.

to partition drought stress-related growth response between rooting habit, crown characteristics, or a combination of the two.

Technical Information Dissemination

Ceulemans, R., R. F. Stettler, T. M. Hinckley, J. G. Isebrands, and P. E. Heilman. 1989. Crown architecture of *Populus* clones as determined by branch orientation and branch characteristics. IN Isebrands, J.G., R. E. Dickson, and R. Ceulemans (eds.), Dynamics of Ecophysiological Processes in Tree Crowns and Forest Canopies. Proc., IUFRO Workshop, Rhinelander, Wisconsin, September 24-29 (abstract).

Davis, T. D., B. E. Haissig, N. Sankhla, and T. R. Dudley, (eds.). 1988. Adventitious root formation in cuttings. Advances in Plant Sci. Ser. Vol. 2., Dioscorides Press, Portland, Oregon. 315 pp.

Haissig, B. E. 1988. Future directions in adventitious rooting research. pp. 303-310. IN Davis, T. D., B. E. Haissig, and N. Sankhla (eds.), Adventitious Root Formation in Cuttings. Advances in Plant Sci. Ser., Vol. 2., Dioscorides Press, Portland, Oregon.

Haissig, B. E. 1988. Status of forest tree vegetative regeneration for biotechnology. American Biotechnology Laboratory 7(1):48-51.

Haissig, B. E., and D. E. Riemenschneider. 1988. Genetic effects on adventitious rooting. pp. 47-60. IN Davis, T. D., B. E. Haissig, and N. Sankhla (eds.), Adventitious Root Formation in Cuttings. Advances in Plant Sci. Ser., Vol. 2., Chapter 3, Dioscorides Press, Portland, Oregon.

Haissig, B. E. 1989. Carbohydrate relations during propagation of cuttings from sexually mature *Pinus banksiana* trees. Tree Physiology 5:319-328.

Hansen, E. A. 1988. Irrigating short-rotation intensive culture hybrid poplars. Biomass 16(4):237-250.

Host, G. E., H. M. Rauscher, J. G. Isebrands, and D. A. Michael. 1989. Validation of the photosynthate production submodel of ECOPHYS and ecophysiological growth process model of *Populus*. IN Isebrands, J. G., R. E. Dickson, and R. Ceulemans (eds.), Dynamics of Ecophysiological Processes in Tree Crowns and Forest Canopies. Proc., IUFRO Workshop, Rhinelander, Wisconsin, September 24-29 (abstract).

5.12 USDA FOREST SERVICE, PACIFIC NORTHWEST EXPERIMENT STATION–INCREASING THE PRODUCTIVITY OF BIOMASS PLANTATIONS OF ALDER AND COTTONWOOD IN THE PACIFIC NORTHWEST

Purpose and Background

The project's objective is to develop guidelines for crop management and identify morphological and physiological traits that might be used for evaluating and improving cultural practices and for selecting superior genotypes.

Red alder (*Alnus rubra*), black cottonwood (*Populus trichocarpa*), and various *Populus* hybrids are the trees most suitable for bioenergy plantations in Oregon and Washington. Biological information is needed to provide guidelines for growing productive, cost-effective crops on various sites. Red alder research was begun in 1981 and consists of an integrated group of studies which: (1) assess the influence of several cultural practices on tree growth and stand development, (2) examine genetic variability within the species, and (3) develop tools for predicting the relative productivity of land for short-rotation plantations. Much of the initial work used natural stands, lathhouse tests, and the few existing alder plantations to obtain quick leads for subsequent research. In 1986, we established a series of research plantings in cooperation with Washington State Department of Natural Resources to test specific and combined effects of several intensive cultural practices on productivity of *Populus* as well as *Alnus*. The new poplar work includes a comparison of tree growth and stand development of two hybrid clones in stand densities ranging from "woodgrass" (300 K plants per ha) to 2 m x 2 m (2500 plants per ha). Red alder is also being tested over a range of stand densities. In addition, the 1986 plantings include evaluation of several nutrient regimes, irrigation, and several genotypes of both genera (21 half-sib families of *Alnus* and 4 clones of *Populus*). Supplementary studies are assessing physiological processes and conditions and their relationship to biomass production at the tree and the stand level.

Accomplishments

Growth of the two hybrid clones in the *Populus* density study has been outstanding, especially at the wider spacings. Mortality or root stocks in the woodgrass spacings has begun, but survival in the wider spacings (0.5 m to 2.0 m) remains at 99%.

5.12 USDA FOREST SERVICE, PACIFIC NORTHWEST EXPERIMENT STATION-INCREASING THE PRODUCTIVITY OF BIOMASS PLANTATIONS OF ALDER AND COTTONWOOD IN THE PACIFIC NORTHWEST

Purpose and Background

The project's objective is to develop guidelines for crop management and identify morphological and physiological traits that might be used for evaluating and improving cultural practices and for selecting superior genotypes.

Red alder (*Alnus rubra*), black cottonwood (*Populus trichocarpa*), and various *Populus* hybrids are the trees most suitable for bioenergy plantations in Oregon and Washington. Biological information is needed to provide guidelines for growing productive, cost-effective crops on various sites. Red alder research was begun in 1981 and consists of an integrated group of studies which: (1) assess the influence of several cultural practices on tree growth and stand development, (2) examine genetic variability within the species, and (3) develop tools for predicting the relative productivity of land for short-rotation plantations. Much of the initial work used natural stands, lathhouse tests, and the few existing alder plantations to obtain quick leads for subsequent research. In 1986, we established a series of research plantings in cooperation with Washington State Department of Natural Resources to test specific and combined effects of several intensive cultural practices on productivity of *Populus* as well as *Alnus*. The new poplar work includes a comparison of tree growth and stand development of two hybrid clones in stand densities ranging from "woodgrass" (300 K plants per ha) to 2 m x 2 m (2500 plants per ha). Red alder is also being tested over a range of stand densities. In addition, the 1986 plantings include evaluation of several nutrient regimes, irrigation, and several genotypes of both genera (21 half-sib families of *Alnus* and 4 clones of *Populus*). Supplementary studies are assessing physiological processes and conditions and their relationship to biomass production at the tree and the stand level.

Accomplishments

Growth of the two hybrid clones in the *Populus* density study has been outstanding, especially at the wider spacings. Mortality or root stocks in the woodgrass spacings has begun, but survival in the wider spacings (0.5 m to 2.0 m) remains at 99%.

Third-year heights and diameters in the 2.0 m spacing averaged 6.2 m and 7.6 cm for the Dula (D-01, taxonomy unknown) clone, and 9.6 m and 9.4 cm for the other hybrid (H-11, *P. trichocarpa* x *P. deltoides*) x clone. Third-year yield of the woodgrass plots averaged only 8.1 Mg per ha, whereas third-year increment in the wider-spaced treatments ranged from 15 to 30 Mg per ha. The cumulative biomass production in all wider-spaced plots of both clones, except D-01 at 2.0 m, has surpassed the cumulative production of any woodgrass treatment. The cumulative production of H-11 at 1.0 m is more than double that of any woodgrass treatment.

Red alder trees averaged about 5-m tall in irrigated plots and 3.2 m in unirrigated plots at the end of the third growing season; canopies had closed in all spacings. Competition-related mortality was greatest in the 0.5-m spacing, reaching 45% in the irrigated plots and 28% in the nonirrigated plots; the level of the self-thinning line, however, was higher in the irrigated plots. Trees in 2.0-m spacings averaged twice as large in diameter as those in 0.5-m spacings. Woody biomass production increased greatly during the third year, with increments of 10 to 15 Mg per ha in irrigated plots of the 0.5-m and 1.0-m spacings. Cumulative production in these plots now equals or exceeds that of the *Populus* woodgrass plots.

Fertilizer trials have identified phosphorus as the nutrient most likely to stimulate alder growth and nitrogen and lime additives that will improve *Populus* growth. There are significant differences among genotypes of both genera; for example, the *Populus* (H-11) hybrid requires more nitrogen and lime for good growth than does native *P. trichocarpa*. Growth of trees of both genera was stimulated by phosphorus in unirrigated plots; the possibility that these hardwoods will respond to phosphorus applications on droughty sites has implications of considerable practical significance.

Many intriguing ideas and findings have developed from the physiological research on tree growth and stand development conducted in conjunction with some of these trials. Our ideas on the importance of stockability as a major determinant of stand productivity were further developed and demonstrated in a paper on *Pinus taeda* that was recently published in Forest Science. Preliminary studies have shown that substantial differences in stand structure, leaf area, and branch mortality are associated with stockability differences.

Crown structure and dynamics, competition, and physiological processes and conditions in leaves are being characterized in many treatments to provide the basic underpinning for crop-management guidelines and tree-selection criteria.

Technical Information Dissemination

DeBell, D. S., W. R. Harms, and C. Whitesell. 1989. Stockability: A major factor in productivity differences between *Pinus taeda* plantations in Hawaii and South Carolina. For. Sci. 35:708-719.

DeBell, D. S., W. R. Harms, and J. C. Zasada. 1988. Yield of *Populus* hybrids in woodgrass and other short-rotation density regimes. IN Proc., Institute of Gas Technology Conference on Energy from Biomass and Wastes, New Orleans, Louisiana, February 1988 (in press).

DeBell, D. S., and T. C. Turpin. 1989. Control of red alder by cutting. USDA Forest Service Res. Pap. PNW-RP-414, Pacific Northwest Research Station, Portland, Oregon.

Hook, D. D., D. S. DeBell, A. Ager, and D. Johnson. 1989. Dry weight partitioning among 36 open pollinated red alder families. Biomass (in press).

Lester, D. T., and D. S. DeBell. 1989. Geographic variation in red alder. USDA Forest Service Res. Pap. PNW-RO-409, Pacific Northwest Research Station, Portland, Oregon. 18 pp.

Radwan, M. A., and D. S. DeBell. 1988. Nutrient relations in coppiced black cottonwood and red alder. Plant and Soil 106: 171-177.

Radwan, M. A., and D. S. DeBell. 1988. Phosphorus fertilizer and growth of red alder seedlings in waterlogged soil. Northwest Sci. 62(2): Abstract No. 29.

Radwan, M. A., and D. S. DeBell. 1988. Soil waterlogging, phosphorus, and growth of red alder seedlings. Plan Physiol. Suppl. 86(4): Abstract No. 546.

Radwan, M. A., T. A. Max, and D. W. Johnson. 1989. Softwood cuttings for propagation of red alder. New Forests (in press).

Wright, L. L., D. S. DeBell, C. H. Strauss, W. A. Geyer, L. Sennerby-Forsse, L. Zsuffa, and E. White. 1989. Panel discussion on the relative merits of woodgrass and SRIC. IN Proc., Institute of Gas Technology Conference on Energy from Biomass and Wastes, New Orleans, Louisiana, February 1988 (in press).

5.13 UNIVERSITY OF WASHINGTON/WASHINGTON STATE UNIVERSITY–GENETIC IMPROVEMENT AND EVALUATION OF BLACK COTTONWOOD FOR SHORT-ROTATION BIOMASS PRODUCTION

Purpose and Background

Objectives are to develop genetically improved black cottonwood cultivars for the Pacific Northwest which maximize the production of desirable woody biomass under intensive culture, to identify critical components of productivity and determine ways in which they can be manipulated genetically and environmentally, and to provide material and information to regional industry and agencies interested in developing poplar culture and conversion of poplar biomass.

Populus trichocarpa in its central distribution range in Southern British Columbia, Washington and Oregon, occurs in extensive riparian populations on both sides of the Cascade Range. Genetic analyses of these populations, conducted in common-garden plantations at 3-4 years, have shown pronounced differences between sources from east and west of the Cascades, in growth, morphology, phenology, physiology and resistance to *Melampsora occidentalis* leaf rust. By contrast, north-south differentiation revealed moderate gradients only (Weber *et al.* 1985, Can. J. For. Res. 15:384-388). In most characteristics studied, clonal variation exceeds that at the family and population levels (Rogers *et al.* 1989, Can. J. For. Res. 19:372-377). Thus, clonal selection within suitable populations is an effective way of improving *P. trichocarpa* for short-rotation culture.

Additional gains in productivity have been made by hybridizing *P. trichocarpa* with *P. deltoides* (Heilman *et al.* 1985, Can. J. For. Res. 15:376-383). Many parental combinations are being tested, representing the latitudinal range of *P. deltoides* and concentrating on plantation proven parents. More than 2000 selected clones are currently under testing in 12 field trials on both sides of the Cascades. Results to date have shown a consistent superiority of *P. trichocarpa x P. deltoides* F_1 hybrids over both parental species, F_2 hybrids and backcrosses. Heterosis values (hybrid superiority relative to the better of the two parents, *P. trichocarpa*) in 4-year volume growth have ranged from 2.9 in single-tree plots with high competitive interactions to 1.5 in monoclonal multiple-tree plots (Stettler *et al.* 1988, Can. J. For. Res. 18:745-753).

Intensive physiological studies have been conducted in the field, greenhouse, and growth chamber to elucidate components of productivity and heterosis. Key characteristics include stomatal response to drought; leaf anatomy; leaf diurnal growth patterns; canopy architecture with special emphasis on proleptic and sylleptic branches, leaf orientation, leaf area index and leaf area duration; leaf rust resistance; carbon allocation patterns; and root growth and distribution as well as root response to stress (Hinckley *et al.* 1989, *Structural and functional responses to environmental stresses*, pp. 199-217, SPB Academ. Publishing, The Hague). Heterosis seems to derive from the multiplicative and cumulative effects of these components, most of which, individually, show either intermediacy or dominance in the F_1 hybrids.

Continued breeding will include some of the above components as selection criteria for parents and progenies. In addition, hybridization has been initiated between *P. trichocarpa* and two other species: *P. maximowiczii*, for the purpose of increased herbivore resistance and nutrient efficiency and *P. nigra* for hybrids that will be better adapted to the hot and dry conditions east of the Cascades.

Now in its 12th year, the project has made significant progress toward its objectives. It has provided a promising new tree material to the region and, through close cooperation with private industry, demonstrated the feasibility of short-rotation culture in the Pacific Northwest. Selected hybrid clones are now in operational trials on more than 3200 ha (8,000 acres). The project has also served as a catalyst for the multidisciplinary collaboration of many scientists, with expertise ranging from the molecular domain to the stand level.

Accomplishments

Close to 4000 seedlings from the 1988 breeding were transplanted to the field. They include *P. trichocarpa x P. deltoides* F_2 hybrids (TDxTD) and backcrosses to *P. deltoides* (TDxD); and *P. trichocarpa x P. nigra* F_1 hybrids (TxN)

Two-year growth of 4740 seedlings from the 1987 breeding with *P. maximowiczii* (M) and/or *P. trichocarpa* (T) parentage showed a ranking of TxM > MxM > TDxM = MxTD > TxT crosses. Ten pairwise comparisons of TxM and TxT half-sib families revealed a consistent superiority of TxM hybrids in mean height and diameter growth. Selected clones were included in new field trials by James River Corporation.

Coppice yields of 51 black cottonwood clones and 4 hybrids averaged slightly less (12.6 $Mg \bullet ha^{-1} \bullet year^{-1}$) than initial harvest yields (13.1 $Mg \bullet ha^{-1} \bullet year^{-1}$). Yield of clones in the first rotation (X) was a relatively poor predictor of clonal yield in the coppice rotation (Y): $Y = -1.49 + 1.08X$, $r^2 = 0.49$, $P < 0.0001$.

A number of *P. trichocarpa* clones failed to produce well as coppice despite their relatively high production in the first rotation. Mortality at the end of the coppice rotation averaged 29.5% with a C.V. of 58% and a range among *P. trichocarpa* clones of 4-60%. Failure of plants to sprout following harvest and subsequent mortality in the coppice rotation accounted for most of the losses.

Hybrids 11-05 and 11-11 produced well in both rotations and had substantially less mortality than the average for *P. trichocarpa* clones (particularly Hybrid 11-11 with total mortality of 6.2%).

At 2 years, Field Trial 1c, Puyallup, with 128 clones from four rivers showed river, clone within river, and block to account for most variation. Due to high site variation in 1d at Wenatchee most variation was attributed to nongenetic sources. Low-elevation Yakima (E) clones had higher rates of photosynthesis at high light intensity than low-elevation Nisqually (W) clones. But Wenatchee-grown material, regardless of source, had higher rates than Puyallup-grown material. The results thus reflect both adaptation and acclimation.

In the F_1 hybrid superiority test, 6-year data showed the largest clone (49-177, a TD hybrid) at Westport to have the greatest diameter increase indicating not only its superiority in this trial, but also the problems associated with single tree plots due to competitive interactions. Preservation of a broad genetic base in the hybrid materials is possible, thanks to the spread of top-ranked clones among families with diverse parentage (for instance, the top 25 clones at Westport were from 14 different families).

Patterns of clonal performance related to geographical differences (climate and soil) are appearing. At the northernmost planting site, hybrids with Illinois parentage dominate the superior clones; whereas, in the most southern and eastern location where the climate is hotter and drier, Illinois clones are less represented and hybrids with Oklahoma, Texas and Missouri parentage become the dominant group.

One Phase I field trial was planted in Vancouver, Washington (324 clones of *P. trichocarpa*, *P. deltoides*, and *P. trichocarpa x P. maximowiczii* hybrids). Two Phase II trials

were established with selected TxD hybrid clones, one at Puyallup, the other at the Washington State University Experiment Station in Prosser, Washington, (east of the Cascades).

As part of the integrated physiological studies for, among other things, stress resistance, the analysis of $^{13}C/^{12}C$ discrimination ratios for 11 clones showed that ratios were positively correlated with declines in wood volume production under conditions of low soil moisture. Clearly, the potential to rank clonal differences in productivity and water use efficiency on the basis of stable isotope ratios needs further study.

The physiology plantation was harvested after 4 years. Hybrid clones outperformed the parental species by 1.5 (*P. trichocarpa*) to 2.5 times (*P. deltoides*) in stem volume, largely due to greater diameter growth. Fourth-year volume increment, however, was lower than in previous years due to competitive interaction in the tight 1 x 1 m spacing. Biomass data, collected from all clones, are being analyzed. Measurements of total leaf area were obtained at different times during the 1988 growing season for each of the four intensive study clones. Single trees were periodically harvested to determine leaf distribution on terminal and branches.

In support of the validation of the ECOPHYS model in cooperation with Dr. J. G. Isebrands, U.S. Forest Service, North Central Range and Experiment Station, measurements of leaf morphology and orientation were obtained during the growing season on five different study clones. Differences among clones reflected their relative physiological compatibility with regional climatic and soil conditions and inherent sensitivities to herbicide treatments.

Sampling for determination of root biomass in the physiology plantation to a depth of three meters was completed. Measurements of canopy density were completed for a fertilizer trial with six clones, two fertilizer treatments and three replications. The trial is now in its third growing season and all measured parameters, including percent canopy cover, canopy absorption of photosynthetically active radiation and leaf area index were found by ANOVA to be significantly affected by fertilization treatment, clone, replication, fertilizer x clone and fertilizer x replication.

The above measurements were made with the Decagon "Ceptometer." Additional measurements include periodic assessment of crown development for a number of clones,

spacings, ages and cultural treatments. Results to date show the instrument to be very sensitive to crown differences.

In a study of 72 clones, superiority of root development during the first growing season was in the order TxD hybrids > *P. trichocarpa* > *P. deltoides*. Initial root development may be the factor exhibiting the greatest heterosis in these hybrids that have been measured to date.

Planting cuttings in previously prepared ripping slots significantly increased root development and tree growth during the first growing season. Soaking cuttings (prior to planting) to a depth of only 2.54 cm (1 inch) or less resulted in full (and perhaps greater) benefits than soaking to a depth of 15-20 cm (6-8 inches).

The Skagit Forest Nursery which makes 60 of the superior hybrid clones commercially available sold 110,000 one-foot-long cuttings and 30,000 four-foot-long whips. However, the demand exceeded the supply. Additional sources of cuttings will be needed in future to keep pace with the rapidly increasing demand for the new hybrids.

Technical Information Dissemination

Ceulemans, R., T. Hinckley and I. Impens. 1989. Stomatal response of hybrid poplar to incident light, sudden darkening and leaf excision. Physiol. Plant. 75:174-182.

Ceulemans, R., T. M. Hinckley, P. E. Heilman, J. G. Isebrands, and R. F. Stettler. 1989. Crown architecture in relation to productivity of *Populus* clones in the Pacific Northwest, USA. Ann. Sci. Forestieres (in press).

Ceulemans, R., T. M. Hinckley, J. G. Isebrands, R. F. Stettler, and B. M. Wiard. 1988. Leaf orientation and net photosynthesis of different *Populus* clones. Plant Physiology 86 (Suppl.):424 (Abstract).

Ceulemans, R., T. M. Hinckley, R. F. Stettler, and P. E. Heilman. 1988. Growth, leaf area and dry weight distribution of different *Populus* clones grown under short rotation intensive culture. 39th Annual Meeting, AIBS, Davis, California (Abstract).

Ceulemans, R., R. F. Stettler, T. M. Hinckley, P. E. Heilman, and J. G. Isebrands. 1988. Crown architecture and leaf demography in intensively cultured hybrid *Populus* clones. pp. 98-107. IN J. Worrall, J. Loo-Dinkins, D. P. Lester, eds., Proc. 10th North American Forest Biology Workshop, Vancouver BC.

Scarascia-Mugnozza, G. E., J. G. Isebrands, T. M. Hinckley, and R. F. Stettler. 1989. Dynamics of light interception, leaf area and biomass production in *Populus* clones in the establishment year. Ann. Sci. Forestieres (in press).

Heilman, P. 1989. Performance of *Populus* on Mt. St. Helens mudflow. Can. J. For. Res. (in press).

Hinckley, T. M. and R. Ceulemans, 1989. Current focuses in woody plant water relations and drought resistance. Ann. Sci. Forestieres 46:(in press).

Hinckley, T. M., R. Ceulemans, J. M. Dunlap, A. Figliola, P. E. Heilman, J. G. Isebrands, G. Scarascia-Mugnozza, P. J. Schulte, B. Smit, R. F. Stettler, E. Van Volkenburgh, and B. M. Wiard. 1989. Physiological, morphological and anatomical components of hybrid vigor in *Populus*. *In*: Structural and Functional Responses to Environmental Stresses (K. H. Kreeb, H. Richter and T. M. Hinckley, eds.), pp. 199-217, SPB Academic Publishing, The Hague.

Pezeshki, S. R. and T. M. Hinckley. 1988. Water relations characteristic of *Alnus rubra* and *Populus trichocarpa*: Responses to field drought. Can. J. For. Res. 18:1159-1166.

Rogers, D. L., P. E. Heilman and R. F. Stettler. 1989. Genetic variation and productivity of *Populus trichocarpa* (T. & G.) and its hybrids. III. Structure and pattern of variation in a three-year field test. Can. J. For. Res. 19:372-377.

Stettler, R. F. and R. Ceulemans. 1989. Clones as a focus for genetic and physiological research in forest trees. *In* (M. Raj Ahuja and W. J. Libby, eds.) Clonal Forestry: Genetics, Biotechnology and Application. Springer (in press).

The researchers participating in this project made numerous presentations made all over the world as well as hosting many visiting scientists.

APPENDIX I - CONVERSION FACTORS

ABBREVIATIONS AND EQUIVALENTS

Common Metric Units

Length	
kilometer	km
meter	m
centimeter	cm
millimeter	mm

Area	
square kilometer	km^2
hectare	ha
square meter	m^2
square centimeter	cm^2
square millimeter	mm^2

Volume	
cubic meter	m^3
cubic centimeter	cm^3
liter	ℓ
milliliter	mℓ

Mass	
megagram	Mg
kilogram	kg
gram	g
milligram	mg

Density	
kilogram per cubic meter	kg/m^3

Energy, work, or quantity of heat	
gigajoule	GJ
megajoule	MJ
kilojoule	kJ
joule	J
kilowatt-hour	kWh

Power or heat flow rate

kilowatt	kW
watt	W

Metric Unit Prefixes

Prefix	Symbol	Factor
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deka	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}

Metric Equivalents

1 km	1000 m
1 m	100 cm
1 cm	10 mm
1 km2	100 ha
1 Ha	10,000 m^3
1 m2	10,000 cm^2
1 cm2	100 mm^2
1 m3	1000 ℓ
1 liter	1000 cm^3
1 metric ton	1000 kg
1 metric ton	1 Mg
1 quintal	100 kg
1 kg	1000 g
1 g	1000 mg
1 cal	4.1840 J
1 cal	1.5586×10^{-6} hp-h
1 cal	1.1622×10^{-6} kWh

English-Metric Conversions

Length

Multiply	by	To obtain
miles	1.6093	kilometers
kilometers	0.6214	miles
feet	0.3048	meters
meters	3.2808	feet
inches	2.5400	centimeters
centimeters	0.3937	inches

Area

Multiply	by	To obtain
square miles	2.5901	square kilometers
square kilometers	0.3861	square miles
square miles	259.0000	hectares
hectares	0.0039	square miles
square feet	0.0929	square meters
square meters	10.7639	square feet
square inches	6.4516	square centimeters
square centimeters	0.1550	square inches
square yards	0.8361	square meters
square meters	1.1960	square yards
hectare	2.4710	acres
acres	0.4047	hectares

Volume

Multiply	by	To obtain
cords	3.6246	cubic meters
cubic meters	0.2759	cords
thousand board feet	2.3598	cubic meters
cubic meters	0.4238	thousand board ft
cubic feet	0.0283	cubic meters
cubic meters	35.3145	cubic feet
cubic inches	16.3872	cubic centimeters
cubic centimeters	0.0610	cubic inches
gallons	3.7853	liters
liters	0.2642	gallons

Mass

Multiply	by	To obtain
ounces	28.3495	grams
grams	0.0353	ounces
pounds	0.4536	kilograms
kilograms	2.2046	pounds
tons (2000 lb)	907.1940	kilograms
kilograms	0.0011	ton (2000 lb)
tons (2000 lb)	0.9072	tonne (Mg)
tonne (Mg)	1.1023	tons (2000 lb)

Density

Multiply	by	To obtain
pounds per cubic foot	16.0184	kilograms per cubic meter
kilograms per cubic meter	0.0624	pounds per cubic foot
pounds per cord	0.1251	kilograms per cubic meter
kilograms per cubic meter	7.9910	pounds per cord
tons per cord	0.2503	tonne per cubic meter
tonne per cubic meter	3.9954	tons per cord

Energy

Multiply	by	To obtain
calories	4.1900	joules
joules	0.2387	calories
British thermal units (Btu or MBtu)	1.0559	kilojoules (or GJ)
kilojoules (or GJ) (Btu or MBtu)	0.9470	British thermal units
horsepower-hours	0.7457	kilowatt-hours
kilowatt-hours	1.3410	horsepower-hours
Btu	0.2520	kilogram calories
kilogram calories	3.9680	Btu
kWh	3412	Btu

Power

Multiply	by	To obtain
Btu per hour	0.2928	watts
watts	3.4153	Btu per hour
horsepower	0.7457	kilowatts
kilowatts	1.3410	horsepower

Temperature

Fahrenheit = 1.8 [(Celsius) + 32]

Celsius = .556 [(Fahrenheit) - 32]

Kelvin = .556 [(Fahrenheit) + 459.67]

Fahrenheit = [1.8 (Kelvin) - 273.15] + 3

Cubic Volume per Area

Multiply	by	To obtain
cubic feet per acre	0.0700	cubic meters per hectare
cubic meters per hectare	14.2913	cubic feet per acre
cords per acre	8.9565	cubic meters per hectare
cubic meters per hectare	0.1117	cords per acre

Weight per Area

Multiply	by	To obtain
pounds per square foot	4.8824	kilograms per square meter
kilograms per square meter	0.2048	pounds per square foot
tons per acre	2.2417	tonne per hectare
tonne per hectare	0.4461	tons per acre
pounds per acre	0.91	kilograms per hectare
kilograms per hectare	1.1	pounds per acre

Costs

Multiply	by	To obtain
$/ton	1.1023	$/Mg
$/Mg	0.9072	$/ton
$/MBtu	0.9470	$/GJ
$/GJ	1.0559	$/MBtu

Energy per Weight or Area

Multiply	by	To obtain
Btu per pound	2.3244	kilojoules per kilogram
kilojoules per kilogram	0.4302	Btu per pound
Btu per pound	5.556 x 10-4	kilocalories per gram
kilocalories per gram	1800	Btu per pound
MBtu per acre	2.6054	GJ per hectare
GJ per hectare	0.4231	MBtu per acre

Areas and Radii of Circular Plots

Plot size in acres	Area in ha	Radius ft	Radius m	Area in F2	Area in m2
1/10	.0405	37.2365	11.3497	4356	404.67
1/5	.0809	52.6604	16.0509	8712	809.34
1/4	.1012	58.8761	17.9454	10890	1011.68
1/2	.2024	83.2634	25.3787	21780	2023.26
1	.4047	117.752	35.8909	43560	046.72

Diameter at breast height (dhb) = 4.5 feet above ground = 1.372 meters above ground

Standard U.S. Fuel Energy Values

Coal: Anthracite: High heat value (HHV) = 12,700 Btu/lb or 29,540 kJ/kg
= 25.4 MBtu/ton (2000 lb) or 29.54 GJ/Mg

Coal: Bituminous: HHV = 11,750 Btu/lb or 27,330 kJ/kg
= 23.5 MBtu/ton or 27.33 GJ/Mg

Coal: Lignite: HHV = 11,400 Btu/lb or 26,515 kJ/kg
= 22.8 MBtu/ton or 26.515 GJ/Mg

Crude oil: HHV = 18,100 Btu/lb or 42,100 kJ/kg = 138,100 Btu/gallon
= 36.2 MBtu/ton or 42.1 GJ/Mg also 5.8 MBtu/barrel (42 gallons)

Natural gas (dry): HHV at 24,700 Btu/lb or 57,450 kJ/kg = 1021 Btu/ft3
= 49.4 MBtu/ton or 57.45 GJ/Mg

Wood (dry) at 8,500 Btu/lb* or 19,805 kJ/kg
= 17.0 MBtu/ton or 19.805 GJ/Mg

*Short-rotation woody crops may vary from 6000 to 8600 Btu/lb

Useful Equivalents for Energy Comparisons

1 dry ton of wood at 8,500 Btu/lb has the approximate energy value of the following:

0.72 tons of bituminous coal,
2.93 barrels of average-weight crude oil,
16,642 ft3 of natural gas, and
4,981 kWh of electricity.

1 Quad = 1 quadrillion Btu or 1 x 1015 Btu
= 1.0559 x 1018 joules or 1 exajoule

APPENDIX II - COMMON AND LATIN NAMES OF WOODY SPECIES

Common name	Latin name
American sycamore	*Platanus occidentalis*
Autumn olive	*Elaeagnus umbellata*
Balsam poplar	*Populus balsamifera*
Black cottonwood	*Populus trichocarpa*
Black locust	*Robinia pseudoacacia*
Black poplar	*Populus nigra*
Douglas-fir	*Pseudotsuga menziesii*
Eastern cottonwood	*Populus deltoides*
Eucalyptus	*Eucalyptus grandis*
Eucalyptus	*Eucalyptus saligna*
European alder	*Alnus glutinosa*
European white birch	*Betula pendula*
Fourwing saltbush	*Atriplex canescens*
Himalayan balsam poplar	*Populus tristes*
Japanese poplar	*Populus maximowiczii*
Honey locust	*Glenditsia triancanthus*
Leucaena	*Leucaene retusa*
Loblolly pine	*Pinus taeda*
Mesquite	*Prosopis alba*
Monterey pine	*Pinus radiata*
(none)	*Populus lasiocarpa*
Northern red oak	*Quercus rubra*
Quaking aspen	*Populus tremuloides*
Red alder	*Alnus rubra*
Silver Maple	*Acer saccharinum*
Sweetgum	*Liquidambar styraciflua*
White ash	*Fraxinus americana*

-END-

DATE FILMED

11/06/90