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Short Rotation Woody Crops Program Annual Progress Report for 1987

J. W. Ranney
A. R. Ehrenshaft
P. A. Layton
W. A. McNabb
L. L. Wright

Environmental Sciences Division
Publication No. 3030

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*Health and Safety Research Division, ORNL

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RANNEY, J. W., A. R. EHRENSHAFT, P. A. LAYTON, W. A. McNABB, and L. L. WRIGHT. 1988. Short Rotation Woody Crops Program Annual Progress Report for 1987. ORNL-6440. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 108 pp.

This report describes the technical progress of the individual research projects in the Short Rotation Woody Crops Program (SRWCP) as well as synthesizing the results for an overview of the program for the year ending September 30, 1987. The program is sponsored by the U.S. Department of Energy's Biofuels and Municipal Waste Technology Division and has the goal of developing a viable technology for producing renewable feedstocks for biofuels such as gasoline, diesel fuel, alcohol, and medium Btu gas in the United States. The most significant accomplishments have been the productivity rates achieved with *Populus* hybrids in the Pacific Northwest (20-30 $Mg \bullet ha^{-1} \bullet year^{-1}$), the establishment of monoculture viability trials, the bioengineering developments of *Populus* spp. (hybrid poplar), and the initiation of wood-energy quality definitions in cooperation with biofuel conversion specialists. The most serious challenges are now seen as control of diseases in *Populus*, lowering cutting and handling costs, increasing productivity on moderate to poor soils in the South and Midwest, local matching and development of clones with sites in monoculture trials, and identifying and learning about the physiological and genetic variability of important growth qualities within model species for genetic improvement.

EXECUTIVE SUMMARY

This report describes the technical progress of the individual research projects in the Short Rotation Woody Crops Program (SRWCP) as well as synthesizes the results for an overview of the program for fiscal year 1987. Most of the field results come from the 1986 growing season. This past year, program emphasis focused on more research on model species and the establishment of monoculture viability trials.

Populus was chosen as the lead model genera, and *Populus* research now comprises half the research effort of the SRWCP. The monoculture viability trials have been established and are seeking to determine disease and insect risks, accurate costs, accurate productivity estimates, and other special challenges, such as plantlet multiplication and weed control. Substantial research questions still remain.

Other model species besides *Populus* are *Robinia pseudoacacia* (black locust), *Platanus occidentalis* (American sycamore), *Liquidambar styraciflua* (sweetgum), and *Acer saccharinum* (silver maple). Research is in the process of determining their genetic makeup and the best methods of vegetative propagation for genetic testing and eventual improvement. The purpose of this research is to avoid the failures of many national programs resulting from pursuing one species for all conditions. Too many diverse site conditions exist to focus entirely on one species.

Robinia pseudoacacia (black locust) is considered the most important of these alternative species because of its tolerance to drought and poor soil conditions and its nitrogen fixing capabilities. Nutrients (primarily nitrogen) are important in the success of short-rotation intensive culture (SRIC) crops. More precise estimates are needed on how SRIC monocultures can best utilize the least amount of nutrients without soil nutrient depletion. Additional research is examining the processes of nitrogen fixation and nitrogen nutrient utilization.

Specific accomplishments include:

- Two *Populus* spp. (hybrid poplar) breeding centers were established to provide regional focal points for the exchange of information concerning physiological, cultural, biotechnical, and monocultural trial research for the improvement of energy clones.
- Monoculture viability plantations were established in the Pacific Northwest, the Lakes States and the Southeast. Private-sector interest in SRIC for biomass production is increasing: cost-shared and privately supported SRIC monoculture trials now number 16 in the United States.
- Researchers are currently evaluating tree clones or seed sources for disease resistance to major identified diseases of *Populus* spp. and *Platanus occidentalis* (American sycamore).
- Through the International Energy Agency, an international standardized cost-accounting method for the SRWCP is being evaluated in cooperation with British and Canadian scientists to provide accurate information on monoculture costs.
- The program goal of 20 $Mg{\bullet}ha^{-1}{\bullet}year^{-1}$ has been achieved in experimental trials of *Populus* hybrids in the Pacific Northwest and of *Eucalyptus* in subtropical regions (Hawaii and Florida). Maximum yields from those trials range from 14 to 30 $Mg{\bullet}ha^{-1}{\bullet}year^{-1}$ at age 4 year or older. Yields from other species and regions of the country are approaching that goal this year with maximum yields commonly ranging from about 8 to 16 $Mg{\bullet}ha^{-1}{\bullet}year^{-1}$ in coppice or age 4 and older plots of model species.
- It appears that biofuel conversion efficiency can be improved by a minimum of 10% (maximum of 25%) by improving the chemical and physical qualities of SRIC wood.
- Costs of delivered SRIC material are presently estimated at \$3.25/GJ (about \$55/dry Mg), down \$0.40/GJ from last year.
- Less fertilizer is necessary than was initially thought. Nitrogen fertilizer levels of 150 kg/ha applied annually or biannually on many sites should produce good tree growth response. On some sites, nitrogen-fixing leguminous trees planted along with nonleguminous ones may eliminate the need for additional fertilizer applications after the first year.

- SRIC crops appear to strongly stabilize potentially erosive sites as long as tree vigor can be maintained.
- Analytical standards for wood characteristics are being developed in conjunction with herbaceous energy crops and biofuel conversion researchers. SRIC wood samples were dispersed for testing in biofuel conversion research laboratories.
- The SRWCP technical database, under development for 2 years, has aided in the synthesis of project data such as preliminary SRIC coppice evaluations and productivity summarizations.

1. SHORT ROTATION WOODY CROPS PROGRAM

1.1 INTRODUCTION

This report is a summary of the technical progress made in the Short Rotation Woody Crops Program (SRWCP) during 1987. This research program, sponsored by the Biofuels and Municipal Waste Technology Division, U.S. Department of Energy (DOE), is directed toward developing a viable technology for producing renewable feedstocks for biofuels such as gasoline, diesel fuel, alcohol, and medium-Btu gas for the United States. Short-rotation intensive culture (SRIC) of woody crops was identified in 1977 as the major emphasis for program research. SRIC in this report refers to well-maintained, weed-free, cultivated tree stands harvested every 1 to 10 years. Spacings vary from 0.3 m to 3.0 m[1] between trees. Developing SRIC feedstocks will (1) help ensure against interruption of U.S. energy supplies, (2) diversify U.S. energy resources in meeting total energy demands, (3) avoid adverse wood-energy use impacts on the forest products industry, (4) offer economical alternatives to existing fuels, and (5) emit almost no sulfur dioxide and less particulates in state-of-the-art combustion facilities compared to coal-burning technology.

The SRWCP's primary charge is to ensure an adequate renewable supply of wood at low cost. Secondarily, it must seek to improve energy qualities in these wood supplies for more efficient biofuel conversion. As part of this effort, the SRWCP actively promotes technology transfer and environmental activities. The SRWCP is managed for DOE by the Environmental Sciences Division of Oak Ridge National Laboratory (ORNL). The progress reported has come from the institutions and agencies that participate in the SRWCP (see Fig. 1 and Table 1). Over three quarters of the program's research effort is subcontracted outside of ORNL.

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[1]Metric units are used throughout this report; conversion factors are provided in Appendix I.

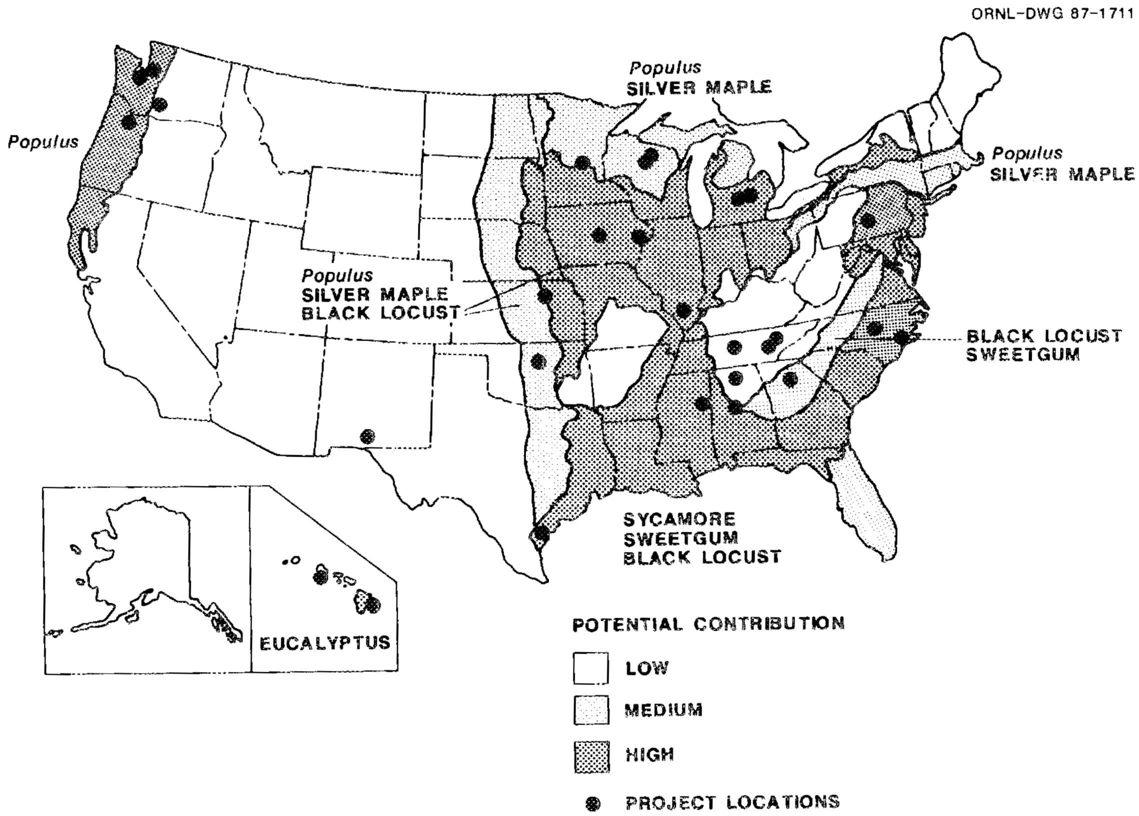

Fig. 1. The Short Rotation Woody Crops Program includes projects at many institutions, some having as many as 17 field sites. The darker tone on the map indicates highest biomass energy production potential for short-rotation intensive culture applications.

Table 1. Short Rotation Woody Crops Program projects

Institution	Investigator	Title
Amana Society	D. Shoup L. Gnewikow	Monoculture viability trial of woody crops for energy production
BioEnergy Development Corporation	T. B. Crabb	*Eucalyptus* plantations for energy in Hawaii
Energy/Development International	S. Hale, Jr. D. C. Deardorff R. D. Kirmse	Species screening and genetic selection at sites in Arizona, New Mexico, and Texas
Fisk University	M. Gunasekaran	Influence of N fertilization on glutamine synthetase activity in mycorrhizal and nonmycorrhizal sycamore plants
University of Florida	D. L. Rockwood	Woody species for biomass production in Florida
University of Georgia	B. C. Bongarten L. R. Boring R. O. Teskey	Optimizing energy yields in black locust through genetic selection
Iowa State University	R. B. Hall E. Hart	Breeding *Populus* and *Alnus* for intensive culture of biomass for energy
Kansas State University	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
Michigan State University	J. W. Hanover	Maximizing woody biomass production through genetic selection, hybridization, and intensive culture
Mississippi State University	S. B. Land	Early selection criteria and clonal propagation methods for increased productivity of sycamore in short-rotation energy systems

Table 1 (continued)

Institution	Investigator	Title
North Carolina State University	D. J. Frederick R. C. Kellison	Silvicultural and harvesting systems for producing fuels from woody biomass in the Southeast
North Carolina State University	R. Lea	Short-rotation sweetgum plantations: establishment and care in the southeastern United States
Northern States Power Company	L. D. Ostlie	Short-rotation woody crops trials for energy producing in north central United States
Oak Ridge National Laboratory	D. W. Johnson	Optimum nitrogen nutrition in short-rotation sycamore plantations
Oklahoma State University	C. G. Tauer	Evaluate *Populus* selections for fuelwood (U.S.-India Science and Technology Initiative)
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	Genetic biomass and growth analyses of clonal silver maple (*Acer saccharinum* L.) in several locations
Tennessee Valley Authority	D. T. Curtin	Short-rotation woody crops harvesting and field handling
Texas A&I University	P. Felker	Production of woody biofuels from mesquite (*Prosopis* spp.)
Tuskegee University, Carver Research Foundation	M. Tolbert R. Saini A. Weaver	Nutrient optimization research
USDA FS North Central Forest Experiment Station	E. A. Hansen J. G. Isebrands B. E. Haissig	Increasing yields of *Populus* energy plantations

Table 1 (continued)

Institution	Investigator	Title
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	R. F. Stettler	Evaluate *Populus* selections for fuelwood (US-India Science and Technology Initiative)
University of Washington/ James River Corporation	W. A. Atkinson	Monoculture viability trials of woody crops for energy production
University of Washington/ Washington State University	R. F. Stettler P. E. Heilman	Genetic improvement and evaluation of black cottonwood for short-rotation coppice culture

1.2 PROGRAM OVERVIEW

The goal of the SRWCP is to achieve a productivity rate of near 20 dry $Mg \bullet ha^{-1} \bullet year^{-1}$ at a cost of $2.00/GJ ($34/dry Mg) by the late 1990s (depending on funding). Wood-energy qualities will also be improved sufficiently to increase conversion efficiency 10 to 15% over present rates. Average productivity rates from research plots are 8 to 15 dry $Mg \bullet ha^{-1} \bullet year^{-1}$ while best results are 20 to 30 dry $Mg \bullet ha^{-1} \bullet year^{-1}$. The costs of delivered SRIC material is presently estimated at $3.25/GJ (about $55/dry Mg).

The SRWCP goals should be attainable in the Pacific Northwest, the subtropics, the Midwest-Lake States, and the coastal/bottomland Southeast. The attainment of SRIC potential in the semiarid Southwest, Northeast, and interior parts of the Southeast is more limited with productivity rates now at 5 to 12 dry $Mg \bullet ha^{-1} \bullet year^{-1}$. Other areas of the United States show little potential for SRIC of trees on a large scale because of climate or unavailability of suitable land. SRIC is appropriately applied only on land considered no worse than marginal or better for agricultural use. Exceptions to this may occur in the Pacific Northwest and subtropics.

1.2.1 Research Focus

Research has concentrated on hardwood coppice culture since hardwoods (1) can be harvested on short cycles (fast early growth), (2) resprout from the stump (low reestablishment costs after harvest and fast growth), (3) respond very well to intensive culture (high productivity), and (4) are responsive to biotechnology techniques. Other public and private institutions are addressing longer-rotation conifer crops rather than short-rotation hardwoods.

The SRWCP accomplishments have been ahead of schedule in the Pacific Northwest and subtropics, near interim target values for Midwest-Lake States, and somewhat behind target values for the Southeast. Based on a national average, the program is on schedule with private-sector interest increasing (see Fig. 2).

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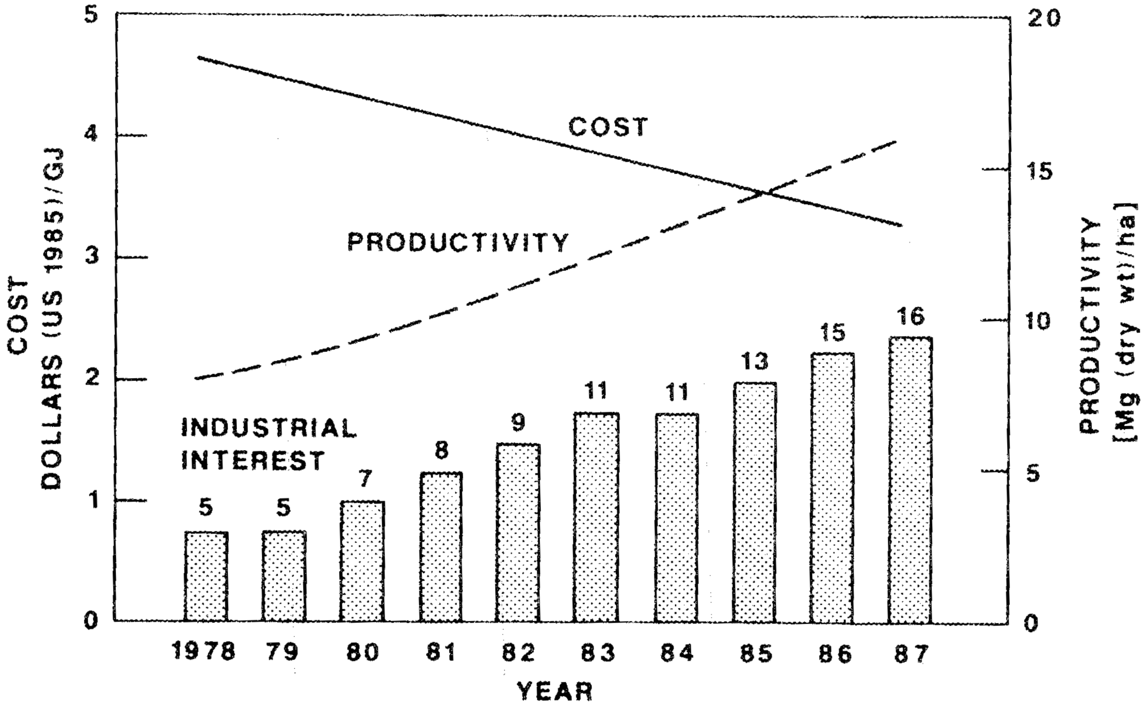

Fig. 2. The technology of short-rotation intensive culture is beginning to interest the private sector as costs have come down and productivity has gone up.

The most significant accomplishments achieved during this reporting period have been the productivity rates achieved with hybrids in the Pacific Northwest (20-30 $Mg \cdot ha^{-1} \cdot year^{-1}$), the establishment of monoculture viability trials, the bioengineering developments of *Populus* spp., and the initiation of wood-energy quality definitions in cooperation with biofuel conversion specialists. The most serious challenges are now seen as control of diseases in *Populus*, lowering cutting and handling costs, increasing productivity on moderate to poor soils in the South and Midwest, identifying clones for the wide range of sites in the monoculture viability trials, and identifying and learning about the physiological and genetic variability of important growth qualities within model species for genetic improvement.

Present efforts in research focus around five major issues. The primary goal involves advanced interdisciplinary research on the genus *Populus*,[2] now comprising half the SRWCP. This work is conducted under the framework of the Energy Poplar Consortium, involving 12 institutions (10 within the SRWCP) and a continually reviewed plan of action. Two poplar hybrid breeding centers, the University of Washington and Iowa State University, function as regional centers providing a hub for the exchange of information concerning physiological, cultural, biotechnical, and monocultural trial research at these and other institutions for the improvement of energy clones (see Fig. 3). An international exchange of information and materials through the International Energy Agency aids this effort. Universities, two private industries, a utility, and two U.S. Department of Agriculture (USDA) Forest Service experiment stations form a truly interdisciplinary team in this effort.

The second major goal involves monoculture viability trials. The trials consist of, at a minimum, 40-ha plantings in Minnesota (Northern States Power Company), Iowa (Amana Corporation),

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[2]Latin names are used throughout this report; common names are provided in Appendix II.

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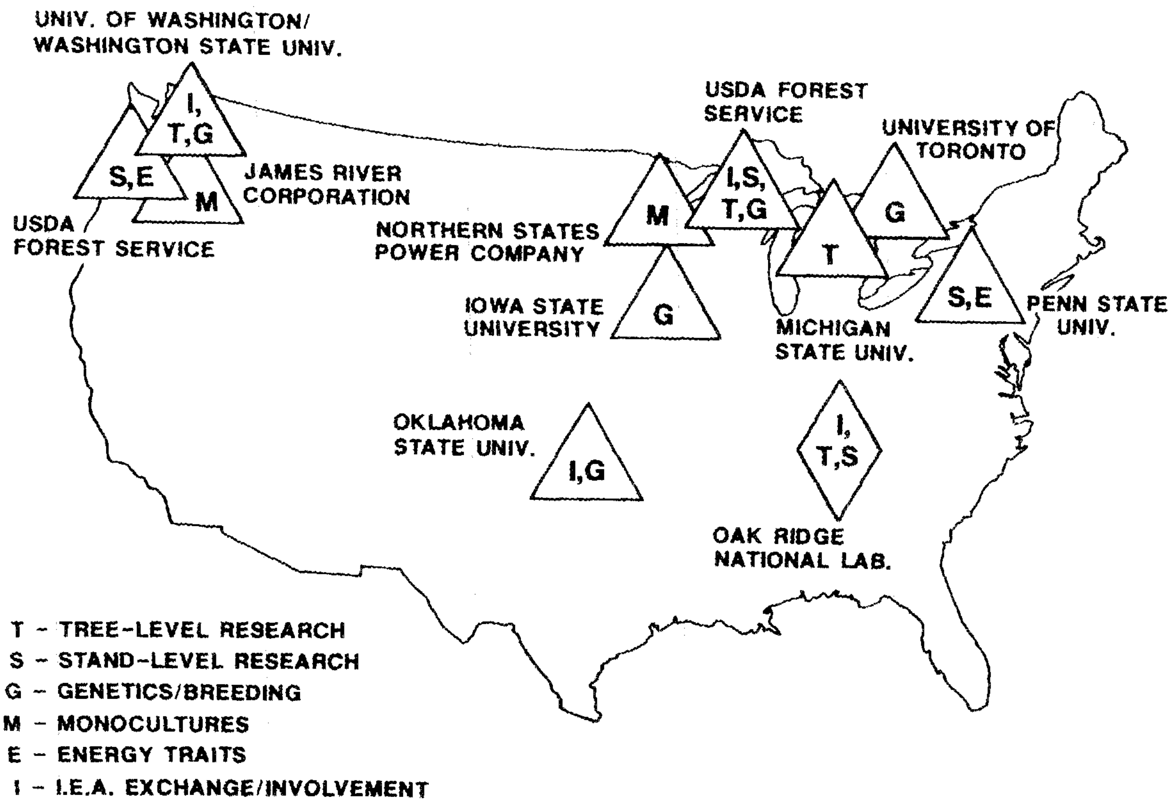

Fig. 3. The Energy Poplar Consortium enables an integrated approach to advanced research on poplars, cottonwoods, and aspens. Research is organized around centralized tree-breeding programs in the Pacific Northwest and Midwest-Lake States.

North Carolina (North Carolina State University), and Oregon (James River of Nevada). James River has now assumed all costs for their monoculture trials. The point of these trials is to determine disease and insect risks, accurate costs, accurate productivity estimates, and other operational challenges such as plantlet propagation and weed control. All but Amana Corporation have plantings that have gone through one growing season. Data are not yet in on these plantings. A completed monoculture trial (just under 300 ha) in Hawaii established in 1979 by the BioEnergy Development Corporation is now yielding accurate production figures, cost information, and results from many experiments. The USDA Forest Service Pacific Southwest Forest and Range Experiment Station (USFS-PSW) is compiling and publishing these results. These projects are major technology transfer efforts in addition to their research value. National data compilation and analysis at ORNL are major components in this effort.

Alternative species to *Populus* are *Robinia pseudoacacia* (black locust), *Platanus occidentalis* (American sycamore), *Liquidambar styraciflua* (sweetgum), and *Acer saccharinum* (silver maple). Study and improvement of these species for energy use is a third major goal. Research is in the process of determining the genetic makeup of these species and methods for vegetative propagation for genetic testing and eventual improvement. Advances made with *Populus* will provide detailed guidelines for the improvement of these other species. The purpose of this research is to avoid the failures of many national programs resulting from pursuing one species for all conditions. Too many site conditions exist to focus entirely on one species. This work is being conducted at four major universities.

Robinia pseudoacacia (black locust) is considered the most important of these alternative species because of its tolerance to drought and poor soil conditions and its nitrogen-fixing capabilities. Because of these traits *R. pseudoacacia* research has been combined with nitrogen fixation and nitrogen nutrient utilization research, the fourth major goal. Nutrient applications, especially nitrogen, are expensive and critical to the productivity and success of SRIC.

Indications are that tree crops do not require the quantities of fertilizers that agricultural crops do. More precise estimates are needed to determine how hardwood trees in intensively managed monocultures can best utilize minimum nutrient inputs without depleting soil nutrients. This research is being conducted predominantly at ORNL and two historically black universities, although several other institutions are conducting fertilizer studies. Nitrogen-fixing species, primarily *Alnus* spp. and *R. pseudoacacia*, appear to offer fertilizer savings when planted with other species. However, mixed-species plantings have proven difficult to manage. Limited research is being conducted on mixing species at the University of Washington, the USDA Forest Service Pacific Northwest Forest and Range Experiment Station (USFS-PNW), Iowa State University, and the BioEnergy Development Corporation/USFS-PSW.

A fifth major research goal involves the definition and development of useful energy qualities in SRIC material for biochemical and thermochemical conversion. This has meant becoming well acquainted with these conversion processes and reexamining the qualities of SRIC material from a new energy perspective.

1.2.2 Program Organization

The SRWCP is technically organized into major tasks (Fig. 4) and managerially organized by disciplines and functional areas (Fig. 5) to form a cross-referenced program. This means that each principal investigator may have responsibilities in more than one task. It also means that more than one technical manager at ORNL will in some way be involved in each subcontract. The objective is integration, interdisciplinary research, and a common mission within which each researcher can define his contribution as part of the larger whole.

Many scientists and institutions are involved in this program forming a national network with some regional specialization. The regional specialization is necessary to respond to environmental, economic, energy, and woody species differences that occur. Active research institutions for FY 1987 are listed in Table 1 and located on a map in Fig. 1.

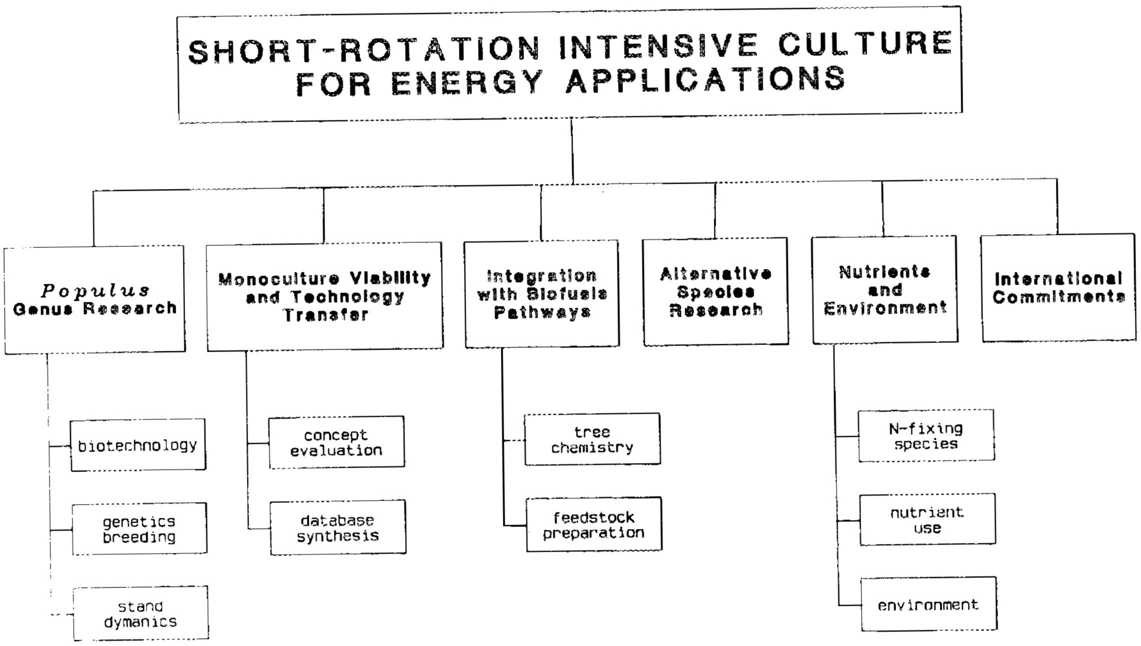

Fig. 4. Analysis of work structure for the Short Rotation Woody Crops Program involves six major tasks excluding program management. Approximately one-half of all research effort occurs in the *Populus* genus research task.

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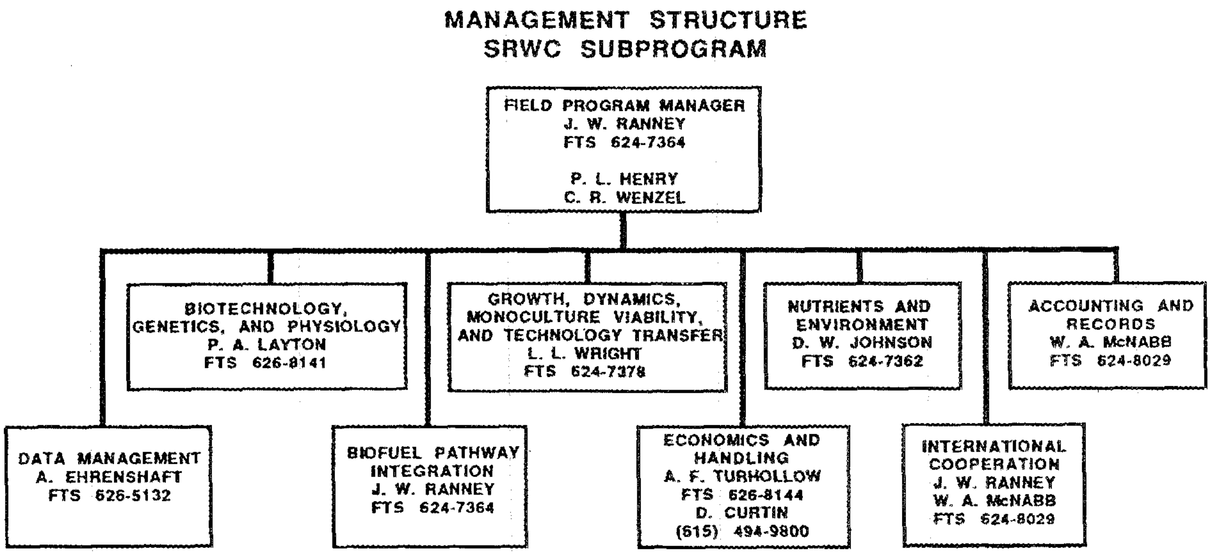

Fig. 5. The managerial organization of the Short Rotation Woody Crops Program (SRWCP) is designed to transcend individual projects to encourage an integrative program. Most projects have research components in more than one of these areas.

2. PROGRAMMATIC TECHNICAL PROGRESS

There has been broad and impressive technical progress in the research and development of short-rotation wood-energy crops. Applied field research has gone far in identifying, and in many cases solving, major risks associated with broadly applied short-rotation intensive culture (SRIC). Field and laboratory research is making major advances in determining why some tree clones grow faster than others, information that is vital for genetically improving wood-energy crops and meeting goals for competitive energy production. Efforts in biotechnology applications have increased to solve specific problems of disease susceptibility and herbicide sensitivity of new wood-energy monocultures. Basic laboratory research involving tissue culture, nutrient utilization, and studies of growth phenomena are providing the technical knowledge needed to achieve the genetic and culture advances predicted for SRIC.

Interfacing processes of wood product and conversion to biofuels is revealing how these wood crops can best be manipulated to help the conversion process. This has highlighted the need for further genetic research to better define the opportunities for genetically improving energy qualities. Biotechnology may soon be used to manipulate energy qualities. The conversion interfacing has also highlighted the importance of biomass culture, handling, and storage as factors affecting the quality of material for biofuel conversion. At the same time, joint SRIC tests with utility companies and private industry provide opportunities to transfer the latest in SRIC technology to real energy-driven operations. Equally important in these tests is the discovery of technical problems requiring more research, a necessary feedback in making SRIC technology viable. The list in Table 2 describes some of the accomplishments in short-rotation wood energy research and development that have been significant across an entire front of disciplines. This balanced approach is needed to address a broad spectrum of highly interrelated challenges in achieving wood energy crop acceptance.

Table 2. Accomplishments (A) and challenges (C) of short-rotation intensive culture (SRIC) research

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A. Productivity rates have attained a level of 10-15 dry $Mg \bullet ha^{-1} \bullet year^{-1}$.
C. Thirty-five percent more productivity is needed through genetic improvements.

A. Production costs (delivered) have been reduced to about $3.25/GJ.
C. Thirty-five percent lower costs are needed to achieve near-competitive status with coal and for competitive land uses.

A. The significance of dealing with tree diseases is becoming recognized.
C. Disease risks need to be quantified to aid decisions in crop management, economics, and research.

A. New fast-growing clones have been released and are in use.
C. Better clones for a wider variety of sites are needed.

A. Plantations can now be successfully established.
C. Cutting, handling, and storage costs need to be reduced.

A. New propagation methods have been or are being developed.
C. Cheaper, hardier plants are needed than are presently available.

A. Model species have been successfully grown from tissue culture.
C. Bioengineering and genome mapping require substantial research.

A. Spacing and rotation optimization of maximum productivity are becoming very well defined.
C. Tree responses to competition need clarification to assist in the selection of traits for higher productivity.

A. The concept of coppicing and its viability are becoming well defined.
C. Breeding for coppice success is necessary to make coppice systems more dependable.

A. Production and biofuel conversion expertise has united to improve biofuels.
C. Energy qualities of highest priority and their genetic control in model species need definition.

A. Industrial monocultural trials have been established.
C. Accurate cost, risk, and productivity information must be collected and analyzed.

A. Initial success has been achieved in ideotype definition of growth.
C. Desirable traits must be genetically defined and controlled.

Table 2 (continued)

A.	Productivity rates in excess of 24 dry Mg•ha^{-1}•year^{-1} have been achieved..
C.	These rates need to be achieved over wider areas.
A.	A national database of SRIC research is nearing completion.
C.	Data extraction, updating, and trial analyses are needed.
A.	N-fixing species trials have been initiated to determine if fertilizer use can be avoided.
C.	N-fixation, nutrient-use efficiency, and other environmental factors must be defined in reducing fertilizer use.

2.1 PRODUCTIVITY

The Short Rotation Woody Crops Program (SRWCP) has field sites at numerous locations in the continental U.S. and Hawaii to evaluate factors affecting biomass productivity of fast-growing trees. The program goal of 20 dry $Mg \cdot ha^{-1} \cdot year^{-1}$ has been achieved only in exploratory or experimental trials of *Populus* hybrids in the Pacific Northwest and of *Eucalyptus* in subtropical regions (Hawaii and Florida). Maximum yields from those trials range from 14 to 30.1 dry $Mg \cdot ha^{-1} \cdot year^{-1}$ in age 4 or older crops. However, yields from other species and regions of the country are approaching that goal this year with maximum yields commonly ranging from about 8 to 16 dry $Mg \cdot ha^{-1} \cdot year^{-1}$ in coppice or age 4 and older establishment plots of model species.

The most recent yields reported as of March 1987 show an overall increase compared to last year of 1 $Mg \cdot ha^{-1} \cdot year^{-1}$ in both the average and maximum yields (Tables 3 and 4). Results that represent real progress in SRIC technology cannot be discerned by considering only the information available in Tables 3 and 4. For example the maximum *Populus* hybrid yield of 3.7 $Mg \cdot ha^{-1} \cdot year^{-1}$ obtained at age 1 in a 1 x 1 m spacing trial in Washington is 4 to 10 times higher than first-year establishment growth achieved in past SRWCP trials. These yields can be attributed to the use of select clones, fertilization, and weed-free conditions. Other aspects of productivity improvement not evident in these tables are gains being made by breeding and selection. There are several steps in testing new clones. The first steps do not include appropriate plot sizes for yield estimation, and thus yield results from field trials of that nature are not included in these tables. However, the growth parameters measured indicate that the potential for increased yields under SRIC stand conditions will be very high.

Select clones of *Populus* hybrids demonstrating particularly good juvenile growth characteristics are the subject of intense physiological and morphological studies to determine why such growth

Table 3. Most recent yield data as of March 1987--experimental yields based on at least 100 trees per replicate

State	Species	Test type	Root age	Stem age	No. treatments	No. replicates	Yield ($Mg \cdot ha^{-1} \cdot yr^{-1}$) Av.	Min	Max
PA	*Populus* hybrid	Culture	7	3	8	24	12.6	10.3	15.0
		Culture	6	2	8	24	11.0	9.7	12.1
WI	*Populus* hybrids	Clone/spacing	6	6	12	24	9.6	8.0	12.8
		Spacing	10	10	2	8	8.3	8.0	8.6
		Rotation length	var	var	4	4	8.8	8.2	9.4
		Irrigation	5	5	4	12	6.5	5.7	7.0
WA	*Populus* hybrids	1 x 1 m	1	1	4	12	3.0	1.3	3.7
		Woodgrass	1	1	4	12	3.6	3.0	4.2
WA	*Alnus rubra*	Spacing	11	11	5	10	7.2	5.3	8.0
HI	*Eucalyptus saligna*	Spacing	4	4	4	16	8.9	5.4	14.4
		Spacing	8	8	4	20	12.8	11.6	14.0
HI	Mixed	Species mix	5.4	5.4	3	9	11.2	6.8	17.3
		Species mix	4	4	7	28	23.6	16.7	27.5

Table 4. Most recent yield data as of March 1987--exploratory yields based on less than 100 trees per replicate

State	Species	Test type	Root age	Stem age	No. treatments	No. replicates	Yield ($Mg \bullet ha^{-1} \bullet yr^{-1}$) Av.	Min	Max
KA	*Populus deltoides*	Species/site	7	7	2	6	6.3	3.4	9.1
	Robinia pseudoacacia	Species/site	7	7	5	15	7.0	4.4	11.0
	Acer saccharinum	Species/site	6	6	3	9	7.5	5.8	8.5
	Ulmus pumila	Species/site	7	7	3	9	7.6	7.6	9.6
IA	*Alnus glutinosa*	Provenance	5	5	10		3.4		
		Provenance	6	1	10		5.8		
TX	*Prosopis alba*	Production	3	3	2	6	9.3	5.5	13.1
		Production	4	1	4	12	3.0	1.6	5.4
NC	6 species	Species/spacing	8	8	21	105	4.5	2.2	7.8
	6 species	Rotation length	5	2	14	70	0.6	0.2	1.8
	5 species	Species/spacing	7	7	15	90	3.3	0.1	16.3
AL	3 species	Species/spacing	5	5	9	54	5.3	4.0	10.2
		Rotation length	5	2	9	54	5.8	1.0	10.8
HI	*Eucalyptus saligna*	Spacing	4	4	6	24	17.4	12.0	27.0
		Spacing	2	2	4	16	15.4	11.2	23.4
		Fertilizer	6	6	4	16	12.9	2.2	22.8
		Fertilizer	6	6	5	20	12.2	6.5	18.2
		Fertilizer	4.5	4.5	12	48	19.0	11.0	26.6
HI	*Eucalyptus grandis*	Spacing	2	2	6	24	5.3	1.5	14.8
		Fertilizer	2	2	16	64	4.7	1.0	18.3
WA	*Populus trichocarpa*	Provenance	4	4	9	45	14.6	9.9	18.7
	Populus hybrids	Clonal	3	3	3	15	24.6	16.1	30.1
	Populus/Alnus	Species mix	4	4	12	60	15.4	12.0	18.8

is possible. To understand the reasons for such outstanding growth, comparisons are being made with clones of parental species and other hybrids with average growth rates. Characteristics that affect the rate of photosynthesis and CO_2 uptake are one area of investigation. These characteristics include (1) crown architecture and leaf display, which impact the amount of sunlight received by the plant; (2) stomatal mechanisms, which impact both CO_2 uptake and water loss; (3) number and size of cells in juvenile leaves, which affect the rate of growth of the leaves and consequently the whole plant; and (4) phenology, which determines the length of the growing season. Another related area of investigation is the determination of carbon allocation patterns in different clones, particularly allocation to roots. Allocation patterns can make a significant difference in the production of harvestable material and in the adaptability of clones to stress conditions. Understanding these processes and why they vary (whether genetic or environmental factors are responsible) will enable scientists to manipulate them, thereby increasing productivity.

Disease is a major threat to successful establishment and growth of SRIC plantations and can seriously affect yields. Some diseases such as *Septoria musiva* (septoria canker) damage the stem, resulting in death or breakage during windstorms. Other diseases such as *Melampsora medusa* (melampsora rust) infect leaves, reducing the leaf area available for photosynthesis and, therefore, reduce growth. Genetic variation in disease resistance does occur. For example, two hybrid poplar clones growing in Michigan were infected with *Melampsora medusa* in late August, and by mid-September one clone was almost completely defoliated, while the other remained relatively unharmed. Researchers are currently evaluating clones and seed sources for disease resistance to major identified diseases of all model species.

The realization that disease risks needed to be evaluated in larger plantings was a major reason for initiation of the monoculture viability trials. Already, in 4-ha clone-site trials established by Northern States Power (one of the monoculture viability projects), cankered stems have been found on several of the clones at age 1. At a recent International Energy Agency meeting, disease was seen as a major barrier to continuation and expansion of woody biomass plantations. These facts have forced the establishment of clonal selection procedures, which include as a first step disease screening with both natural and artificial inoculation by disease-causing organisms.

2.2 COSTS

Four accomplishments in economic analysis for SRIC were achieved over the past year. The Tennessee Valley Authority (TVA) conducted an economic evaluation in which various alternatives of SRIC management strategies were combined with various cutting and handling alternatives (Woodfin et al. 1987). Figure 6, derived from this study, indicates the relative costs of various components at certain spacings and rotation ages. This must be considered a preliminary study that draws on best estimates of costs under greatly varying conditions.

Pennsylvania State University has conducted a very detailed evaluation to determine that unfertilized (control) first-rotation plots had the best economic return, even though productivity was not at its highest (Blankenhorn et al. 1987). Average production costs from these plots were $30.41 per oven-dry Mg. The most recent information from second-rotation or coppiced plots is very preliminary but indicates that fertilized plots provide the best overall returns. This can be explained by the ability of the fertilized plots to produce sustained high yields in both the establishment and coppice rotations.

A very different type of evaluation conducted at ORNL has indicated that probable improvements in SRIC energy qualities can increase biofuel conversion efficiencies by 10 to 20% (Ranney et al. 1987). The economic benefit of this improved efficiency was highly dependent on the value of residues. Valuable residues meant little economic gain from increased conversion efficiency. Valueless

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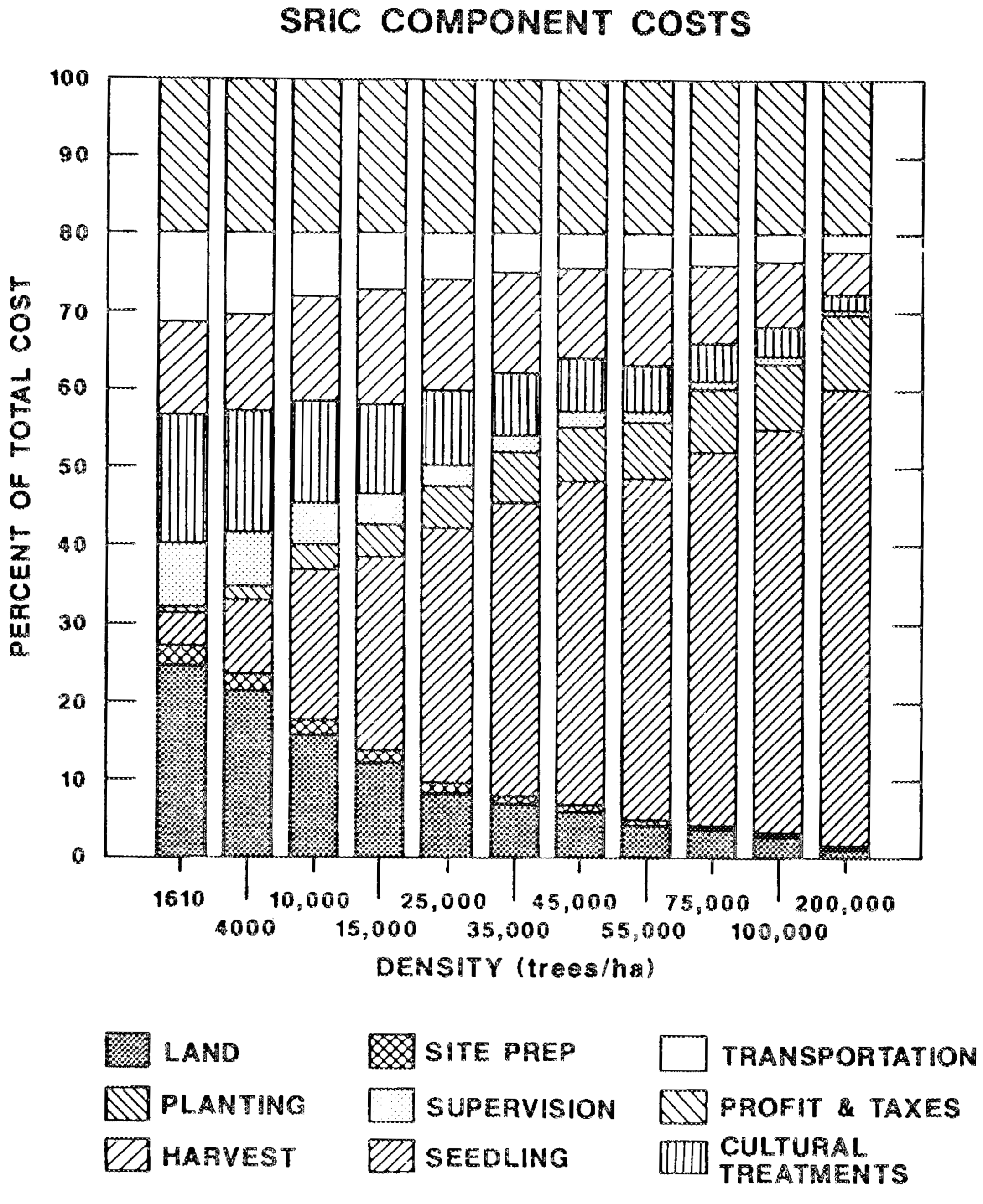

Fig. 6. Plantlet costs per hectare increase most as planting density increases and rotation age decreases in short-rotation intensive culture analyses. Until plantlet costs can be reduced, high-density plantings are prohibitively expensive.

residues meant that increased efficiency in conversion was directly related to economic improvement by up to 20%.

A significant development in the SRWCP has been the standardization of cost accounting in the monoculture viability trials (Wright and Ranney 1987).[3] The cost-accounting format is now being evaluated by Canadian and British scientists to determine if it may be internationally acceptable as a standard.The first real economic input into the system will occur in FY 1988 and provide the most accurate information yet on monoculture costs.

2.3 QUALITY

Interactions with Battelle Pacific Northwest Laboratory, the Solar Energy Research Institute, and TVA at Muscle Shoals have provided valuable guidance on what wood qualities are desirable in biofuel conversion technologies. Definition of these wood qualities is still under refinement. The major conclusions to date are that wood qualities are important for both biochemical and thermochemical conversion and that the qualities that are important are different for these two conversion approaches. Extractives, hemicellulose, lignin, and ash quality have been defined as major concerns. Results from Pennsylvania State University are providing information on how energy qualities vary under different cultural strategies. Others in the SRWCP are measuring various qualities for genetic variation. A list of energy qualities was developed during a work session of representatives from the SRWCP, the Herbaceous Energy Crops Program, the Biochemical Conversion Program, and the Thermochemical Conversion Program (Table 5). A consistent system of measurement and analytical methods is being developed through these interactions. Other participants included the USDA Forest Products Laboratory, an International Energy Agency representative, and Colorado State University.

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[3]A more complete description of this methodology is found in Appendix III.

Table 5. Major energy qualities of concern in biomass growth and conversion

Ash content . (including silica, cations, volatile alkali, chlorine sulfate, nitrate, phosphorous)
Specific gravity/moisture content oven dry wt/green volume (for wood only)
Cellulose, hemicellulose (wood only)
Cellulose, hemicellulose, nonstructural carbohydrates (herbaceous only)
Monosaccharides (by high--ressure liquid chromatography)
Lignin ($KMnO_4$ for herbaceous)
Lignin (Klason and soluble for wood)
Extractives (wood)
Hot water extractives (herbaceous crops), nonstructural carbohydrates
Energy content (GJ/kg)
Ultimate analysis (C, H, O, N) (high priority for thermochemical)
Acetyl groups (may be significant, study later)
Protein (from nitrogen content)
Pectin (for herbaceous crops, unproven method from literature)

2.4 ENVIRONMENTAL CONSIDERATIONS

Environmental considerations have focused on soil nutrient depletion, nutrient utilization efficiency, and the potential for groundwater pollution from the use of fertilizers. Studies at ORNL, Tuskegee University, the USDA Forest Service, and other institutions are indicating that nitrogen fertilizer levels of 150 kg/ha on many sites will produce good tree growth response. Preliminary results at ORNL show that later in the first growing season (July and August)--when trees are larger--higher or repeated fertilization will significantly increase aboveground growth. Conversely, heavy nitrogen applications (450 kg/ha) early in the growing season produce about the same growth response as lighter ones (150 kg/ha). This remains true until mid growing season. Surprisingly, similar conclusions are coming from *Eucalyptus* fertilizer studies in Hawaii, where semiannual nitrogen applications at relatively low rates are now recommended. Nitrogen status parameters examined at ORNL (e.g., nitrate reductase assay, protein, chlorophyll) were observed to reach a ceiling at relatively low levels of nitrogen applications, suggesting that early nitrogen levels were sufficient. Also, there was not simply a redistribution of carbon to excessive leaf area production as is often reported.

The nutrient studies indicate a very important phenomenon: less fertilizer is needed for SRIC crops than for agricultural food crops to attain high productivity. However, in practically every experiment, with the exception of some periodically flooded bottomlands, at least small levels of fertilizer additions are recommended to avoid soil nutrient depletion and to attain maximum economic return. Effects of SRIC fertilizer applications on runoff and leaching into groundwater now appear to be of minimal environmental concern. Further, required soil nitrogen levels for successful SRIC plantations appear to be much closer to the potential contributions from nitrogen-fixing species than first believed. It may be possible to eventually avoid commercial nitrogen fertilizer applications with the use of nitrogen fixing species.

Erosion has been under evaluation in SRIC *Eucalyptus saligna* (Eucalyptus) stands in Hawaii for 7 years. These evaluations have been conducted on relatively poor soils, moderate slopes, and under heavy rainfall (5080 mm) conditions where ground vegetation (weeds) was minimal. Leaf litter accumulation and slope steepness proved to be of most concern. Slope length is of less concern than originally thought. Plots covered with naturally accumulating litter showed good protection against runoff and erosion. However, when leaf litter was removed, runoff doubled and erosion dramatically increased to 11 Mg/ha (upper tolerance limit). No other SRIC sites under study represent such severe potential erosion conditions. SRIC crops appear to strongly stabilize potentially erosive sites as long as tree vigor is moderate to good.

3. PROJECT SUMMARIES

3.1 AMANA SOCIETY/IOWA STATE UNIVERSITY/IOWA DEPARTMENT OF NATURAL RESOURCES - A MONOCULTURE VIABILITY TRIAL OF WOODY CROPS FOR ENERGY PRODUCTION

3.1.1 Goals

The Amana Society is taking a lead role in an effort begun in 1986 devoted to planning, designing, and establishing a large-scale monoculture viability trial (Amana Society et al. 1987). Participating with the Amana Society are Iowa State University and the Iowa Department of Natural Resources. Overall objectives of the project are to (1) estimate more accurately the costs associated with growing wood for energy in short-rotation intensive culture (SRIC) plantations, (2) determine biomass yields under operational conditions, (3) identify short-rotation risks, and (4) transfer information from research universities to the private sector. Phase I can be characterized as the planning stage, while Phase II is the actual establishment and maintenance of the plantation.

3.1.2 Highlights

Phase I was completed during this reporting period. A 28-ha bottomland site along the Iowa River was selected for the plantation. Yield, growth habits, and resistance to pest and disease were among the criteria used in selecting a species. *Acer saccarinum* (silver maple) was selected as the species because it is well suited to the bottomland regime of the site and has good resistance to pests and disease. Plans were made to start site preparation following implementation of the Phase II contract. Cost accounting of the plantings is being done under a standardized format. This format is compatible with other DOE cost-shared monoculture trials and similar trials conducted by the International Energy Agency in the United Kingdom and Canada.

3.2 BIOENERGY DEVELOPMENT CORPORATION - *EUCALYPTUS* ENERGY PLANTATIONS IN HAWAII

3.2.1 Goals

Since 1979 this project has developed information on the economic and technical feasibility of using eucalyptus trees for energy farming in Hawaii and similar subtropical regions. The acquisition and integration of knowledge about silviculture, economics and harvesting of short-rotation (6-8 years) crops are prime objectives. Major emphasis for this reporting period was placed on collecting data related to stand establishment and development, genetics, and tree improvement.

3.2.2 Highlights

Previously established spacing, *Eucalyptus*/legume admixture, fertilizer, species and provenance experiments were measured in 1986. Preliminary results indicate that a spacing between 1 x 3 m and 2 x 3 m with repeated applications of nitrogen fertilizer produces a stand with an average diameter breast height (dbh) of 15 cm in 4.5 to

6.5 years (Crabb et al. 1987). Applications of nitrogen fertilizer, repeated perhaps as frequently as every 6 months, seem to be necessary to maintain adequate growth rates. Nitrogen-fixing leguminous trees planted along with *Eucalyptus* can eliminate the need for additional fertilizer applications after the first year. In the species and provenance trials, *E. saligna*, *E. grandis*, *E. robusta*, and *E. urophylla* continue to be the most promising species for biomass plantations on sites similar to those on Hawaii. Yields ranging from 11.8 to 53.5 dry Mg/ha for trees 3-7 years old were obtained for several tests established at Onomea, Kamae, and Akaka.

3.2.3 Technical Information Dissemination

Laarman, J. G., J. M. Vasievich, and P. B. Durst. 1986. Technologies to harvest fast-growing energy plantations in Hawaii and the Philippines. pp. 256-267. IN Proc., 18th IUFRO World Congress.

Schubert, T. H., and G. P. Markin. 1987. Control of ambrosia beetle in Eucalyptus stumps. 1984. Insecticide and Acaricide Tests 12:351-352.

Skolmen, R. G. 1986. Performance of Australian Provenances of *Eucalyptus grandis* and *E. saligna* in Hawaii. Res. Paper PSW-181. USDA/FS Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

3.3 ENERGY/DEVELOPMENT INTERNATIONAL - SPECIES SCREENING AND GENETIC SELECTION AT SITES IN ARIZONA, NEW MEXICO, AND TEXAS

3.3.1 Goals

A cost-sharing arrangement between the Short Rotation Woody Crops Program (SRWCP) and a consortium composed of Energy/Development International, Mountain States Wholesale Nursery, Storm Nursery, and New Mexico State University funds research to screen and select suitable arid-land species and develop establishment and management guidelines for private biofuel farming in the arid and semiarid southwest United States (Kirmse et al. 1987). The project started in

1984 with sites in Arizona, New Mexico, and Texas. Specific goals include (1) initial species selection to narrow the number of candidate species to a set that can be tested experimentally; (2) for some of the identified species, germplasm collection from as wide a genetic base as feasible, as well as acquisition of previously identified superior lines for testing under southwest conditions and for comparison to locally native lines; (3) establishment and evaluation of experimental plantations to determine survival, growth rates, and growth forms for candidate species under a variety of environmental conditions typical of the Southwest; and (4) selection of the most promising accessions for maximizing biomass production over a range of site conditions.

3.3.2 Highlights

Final acquisition of germplasm was completed. Native stands of drought hardy *Leucaena retusa* have been identified in West Texas. Systematic site maintenance continued. Biomass prediction equations were developed and the first biomass estimates were made on select species. For second-year growth, estimated yields ranged from 4.5 to 12 dry Mg/ha with irrigation. *Atriplex canescens* (fourwing saltbush), a shrub, yielded the most oven-dry biomass, with a standing crop of 12 dry Mg/ha. *Leucaena* clone K636 yielded 9.4 Mg/ha and clone K743 yielded 6 Mg/ha. At the three sites, yields for *Prosopis alba* (mesquite) ranged from 4.5 to 7.3 dry Mg/ha. The different levels of rainfall at the three sites did not appear to affect the productivity.

3.3.3 Technical Information Dissemination

Deardorff, D. C., and R. D. Kirmse. 1986. Expanded New Mexico woody biomass species trials and genetic improvement. Final technical report. NMRDI Project No. 2-73-4610.

Kirmse, R. D., and J. T. Fisher. Screening and biomass trials for potential fuelwood species in the semi-arid Southwest United States (in press).

3.4 FISK UNIVERSITY - INFLUENCE OF N FERTILIZATION ON GLUTAMINE SYNTHETASE ACTIVITY IN MYCORRHIZAL AND NONMYCORRHIZAL SYCAMORE PLANTS

3.4.1 Goals

The objective of this investigation is to measure the change in the ammonia-assimilating enzyme, glutamine synthetase (GS_1), when it is used as a biochemical marker to study the physiological characteristics in response to the addition of N-fertilizer to *Platanus occidentalis* (American sycamore) that have been infected with a Virginia mycorrhizae (Gunasekaran 1987).

3.4.2 Highlights

Work focused on testing different methods including affinity chromatography and gel electrophoresis for purifying the glutamine synthetase from both leaves and spores. Under certain conditions, two peaks of enzymatic activity were found, whereas only one peak was found under different conditions. A high pH solution seemed to improve the detection. The maximum enzyme activity occurred at a pH of 6.5 and 1 mM Mn^{++} concentration (standard assay conditions being 7.0 pH and 3 mM Mn^{++} concentration).

3.5 IOWA STATE UNIVERSITY - BREEDING *POPULUS* AND *ALNUS* FOR INTENSIVE CULTURE OF BIOMASS FOR ENERGY

3.5.1 Goals

The primary objective of this research, which began in 1984, is to produce genetically improved *Populus* and *Alnus* planting stock for use in intensive culture of biomass for energy. New foundations will be laid for the continued long-range genetic improvement of the black (European) alder by establishing large base populations for selection and by determining the genetic variation in specific traits that influence the energy content of *Alnus* biomass. The project is undergoing a major realignment, with the focus being shifted towards a

Populus breeding program for the North Central United States as part of the Energy Poplar Consortium.

3.5.2 Highlights

Seed was harvested from the 1986 *Alnus* breeding efforts, yielding viable seed from 11 full-sib families. Additional selections were made in the Iowa provenance test to support the breeding efforts. A nursery trial of 11 clones of *A. glutinosa* x *A. rubra* was established. The inheritance of hardiness from the *A. glutinosa* (European black alder) parent looks promising.

Work was initiated on the biology and host interactions of *Fenusa hohrnii* (Tischbein) European alder leafminer (EAL). Intensive leaf samples were taken from trees of different ages, heights, and families that had received various pesticide treatments. Examination of leaves in central Iowa indicates that the following are true for the region: (1) there are three complete generations per year; (2) heavy rains cause significant adult drowning and a consequent reduction in oviposition; (3) 15 g DiSyston (band applied at label rate at the base of trees) does not affect oviposition but effectively eliminates mining damage; and (4) highly favorable growing conditions minimize EAL impact (Hall et al. 1987).

The best Iowa selections were used to expand the experimental seed orchard. Measurement made under seed-orchard conditions indicated that seven trees were enough to produce 3.4 million viable seed. Strobili can be harvested in late August (while they are still green) with no loss in seed viability. These results will be used to formulate guidelines for applied genetic improvement of *Alnus*. During the second half of FY 1987 a draft genetic improvement plan for *Populus* in the north central region was prepared. The plan identified improvement goals, such as productivity and disease resistance; outlined a strategy for testing; and identified sources of *Populus* to be included in the project. The draft plan has been sent to reviewers for comment, and a final plan will be produced by June 1988.

3.5.3 Technical Information Dissemination

Hall, R. B., and R. N. Nyong'o. 1987. Design, establishment and management of a black alder (*Alnus glutinosa* L. Gaertn.) seed orchard. pp. 261-268. IN Proc., 19th Southern Forest Tree Improvement Conference. National Technical Information Service, Springfield, Virginia.

3.6 KANSAS STATE UNIVERSITY - GREAT PLAINS ENERGY FOREST RESEARCH PROGRAM

3.6.1 Goals

The objectives of this study are to (1) determine the productivity of selected hardwood tree species adaptable to SRIC for fuel wood production in the Great Plains using species screening tests with varied planting densities; (2) develop models with the capabilities to approximate financial and production costs and energy efficiencies; (3) evaluate the effectiveness of selected herbicides in weed control on a variety of sites as well as determine the toxicity to desirable species under different establishment methods; and (4) assess the feasibility of multicoppice (multirotation) management and the use of cultural techniques to sustain productivity.

3.6.2 Highlights

Evaluation of 5-year growth data at the western sites shows that cultivated plots continue to be higher biomass producers than plots with only herbicide applications. *Ulmus pumila* (Siberian elm) appears to be the most adaptable species because it grows well on most sites throughout the state; however *Populus deltoides* (eastern cottonwood), *Acer saccharinum* (silver maple) and *Robinia pseudoacacia* (black locust) often produce higher yields in the eastern portion of the state. In eastern and central Kansas, *R. pseudoacacia* and *P. deltoides* plantations, at an average spacing of 1.6 x 1.6 m, have produced yields as high as 13.5 dry $Mg \bullet ha^{-1} \bullet year^{-1}$ after 4 to 6 years (Geyer 1987).

Economic analyses indicate that longer rotations appear to lower production costs. Energy wood costs before cutting and for the best sites in eastern and central Kansas run between $1.56-$1.77/GJ. This means that about half of all production costs occur before cutting. The figure also indicates that further cultural improvements must be made. Coppice productivity is critical, and most species tested produce abundant stump sprouts, with coppice yields being greater than those for seedling yields because of optimum site utilization by established root systems. Results were collected from plantations of plant materials available in 1980.

Results indicate that many herbicide combinations are effective in controlling grass and broadleaf weeds without damaging newly planted trees or direct-seeded tree seed. Strip application of herbicides with mechanical cultivation was found to be the best for operational plantings.

3.6.3 Technical Information Dissemination

Cable, T. T., T. D. Warner, and W. A. Geyer. 1987. Residential fuelwood use in Kansas. pp. 145-150. IN Proc., International Conference on Residential Wood Energy.

Geyer, W. A. 1987. Overview of short-rotation energy plantation research in the United States. pp. 161-167. IN Proc., International Conference on Residential Wood Energy.

Geyer, W. A., L. Melichar, and C. E. Long. 1987. Preemergent herbicide trials with direct-seeded black locust grown in different soils. J. of Arboriculture 13(4):105-107.

3.7 MICHIGAN STATE UNIVERSITY - MAXIMIZING WOODY-BIOMASS PRODUCTION THROUGH GENETIC SELECTION, HYBRIDIZATION, AND INTENSIVE CULTURE

3.7.1 Goals

The primary objective of this project was to develop high-yielding genotypes of biomass species and hybrids for maximum production on a range of sites in the Lakes States. Secondarily, the project was to integrate genetic improvement with establishment and management techniques to make biomass plantations commercially viable.

3.7.2 Highlights

This project was terminated during this reporting period, and a draft final report was submitted that describes the results of 9 years of research, as well as recommendations for woody biomass production in the Lake States. As a result of rigorous field testing, several species were identified as prime biomass producers for the Lake States: *Robinia pseudoacacia* (black locust), *Populus* (including aspen hybrids), *Ailanthus altissima* and *Pinus nigra* x *P. densiflora* (Kellogg hybrid pine). Of these, *R. pseudoacacia* has the best potential for meeting Michigan's diverse biomass energy needs because of its superior yields, site adaptability, and relative pest resistance. *Populus* hybrids are recommended only when specific, disease-resistant clones are used and when planted on the best sites (Hanover et al. 1987). In addition to these species recommendations, the report reviews cultural methods for biomass production, seed source recommendations, and genetic information about the selected species.

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

3.8.1 Goals

This project was initiated in October 1986 and is divided into three experiments (Dickmann et al. 1987). The objectives of the first experiment are to determine how moisture and coppicing affect net assimilation, whole-tree carbon allocation, and water relations in two *Populus* clones with contrasting morphology and phenology. The second experiment is designed to determine how and why moisture and nitrogen influence whole-tree carbon partitioning in two *Populus* clones in their patterns of seasonal growth and carbon allocation. Experiment 3 will be a field trial to establish differences in carbon partitioning and fine root dynamics among five *Populus* clones during an initial and coppice rotation. This information is extremely important in the breeding and genetic improvement of *Populus*.

3.8.2 Highlights

Activities focused on setting up experiments 1 and 2. Thirty-two minirhizotron tubes (providing access to roots for video camera) were installed in the existing 3-year-old plantation of *Populus* clones Tristis and Eugenei (experiment 1). Water treatment was modified to maximize effects and to double the number of observations by eliminating the previous low-water treatment and changing the medium-water treatment to high-water treatment. The experiment now consists of 2 treatments irrigation and control (no water), with 12 trees of Tristis and Eugenei. A high-resolution video camera was used periodically to take root images. Photosynthesis, transpiration, and leaf water potentials were measured using an ADC CO_2/H_2O analyzer. Experiment 2 was established during the second week of April 1987, with 286 Tristis and 300 Eugenei cuttings, 224 of each in plastic pots and the remainder serving as a border. As of June 25, the average height of Eugenei and Tristis trees was 76.8 and 71.4 cm, respectively; ground-level diameter averaged 7.1 mm for Eugenei and 6.2 mm for Tristis trees. Treatment differences were not apparent. Stool beds for Tristis, Eugenei, I45/51, *P. deltoides* (eastern cottonwood), and *P. nigra* were established; materials from these beds will be used to establish experiment 3.

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

3.9.1 Goals

Platanus occidentalis (American sycamore) has been identified as a "model" species for short-rotation energy plantations in the South (Land et al. 1987). The objectives of this project are to determine the magnitude of genetic and female parent tree effects on seed and seedling traits, to estimate the sizes of genetic correlations between seed or seedling traits and 3-year productivity in the field, and to develop "hedging" techniques to produce stecklings (rooted cuttings). Work began in October 1986.

3.9.2 Highlights

Unpublished seed germination data from a 10-year-old sycamore progeny test were analyzed for seed lot mean germination values. Eighteen clones of second-generation sycamore selections in the Mississippi State University Clone Bank were identified for use. Percentage of full seeds, full-seed weight, and embryo weight are positively correlated for the 18 clones. Four chemical growth regulators were identified for use in a preliminary study of "hedging" methods for production of stecklings.

3.9.3 Technical Information Dissemination

Schultz, E.B., and S.B. Land, Jr. 1987. Juvenile-mature correlations in sycamore. pp. 376-383. IN Proc., 19th Southern Forest Improvement Conference. National Technical Information Service, Springfield, Virginia.

3.10 NORTH CAROLINA STATE UNIVERSITY/FEDERAL PAPER BOARD - SHORT-ROTATION SWEETGUM PLANTATIONS: ESTABLISHMENT AND CARE IN THE SOUTHEASTERN UNITED STATES

3.10.1 Goals

Along with the Federal Paper Board, North Carolina State University is involved in a project to (1) estimate more accurately the costs associated with growing wood for energy in southern SRIC plantations, (2) determine biomass yields under operational conditions, (3) identify short-rotation risks, and (4) transfer information from universities to the private sector. The species under investigation is *Liquidambar styraciflua* (sweetgum).

3.10.2 Highlights

The Phase I planning has been completed, and a report has been prepared. Topics covered in the report include site selection, site preparation, planting stock acquisition and handling, planting, and plantation maintenance. An approximately 8-ha (20-acre) site was prepared, and 48 continuous forest inventory (CFI) plots (each 0.04 ha) were established in June. Plots were established in a diamond and cross pattern to quantify longitudinal, latitudinal, and diagonal variation on the site. An 89% seedling survival rate was estimated.

Eight of the CFI plots were chosen to be kept in a weed-free condition. The plots were sprayed over a period with a 0.8% active ingredient solution of salt of glyphosate (2.0% glyphosate) during early morning and late evening hours to minimize herbicide drift and volatilization. Three weeks after the spraying, a visual inspection of the site showed excellent competition control. In the future, these plots will be kept weed-free using manual cultivation and herbicides.

3.10.3 Technical Information Dissemination

Lea, R. 1987. Sweetgum handbook: Short-rotation sweetgum plantations, establishment and care in the southeastern United States. ORNL/Sub/86-95909/1. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

3.11 NORTH CAROLINA STATE UNIVERSITY - SILVICULTURAL AND HARVESTING SYSTEMS FOR PRODUCING FUELS FROM WOODY BIOMASS IN THE SOUTHEAST

3.11.1 Goals

The North Carolina State University Hardwood Research Cooperative has been conducting a research project on SRIC in the southeastern United States since 1978. The SRWCP is jointly sponsoring hardwood plantation research with the cooperative on several projects related to energy plantations. Specific objectives for this year were to

(1) evaluate different silvicultural systems for short-rotation woody crop production and determine seedling and coppice production plus nutrient and energy yields under a variety of plantation conditions; (2) harvest seedling and coppice plantations in Alabama and determine costs and efficiency; (3) measure and maintain a 15-ha operation *Liquidambar styraciflua* (sweetgum) plantation at Hoffman Forest, Onslow County, North Carolina; (4) continue biomass and root sampling in detailed coppice studies involving effects of fertilizers and harvesting methods on coppice productivity, which includes an evaluation of the effects of various herbicides applied over cut stumps for controlling competition; and (5) evaluate *L. styraciflua* and *Platanus occidentalis* (American sycamore) progeny trials and determine regional variations. Major emphasis was placed on coppicing studies and genetic-related work.

3.11.2 Highlights

A fertilizer season of harvest study was installed in a 10-year-old sycamore stand harvested in January and June. Fertilization resulted in heavy weed competition and necessary herbicide control. In addition to tree biomass, soil, water, stems, and roots were also sampled. Significant seasonal differences were found in root size classes in the upper 20 cm of soil. Mean oven-dry root biomass (all size classes) was highest during the dormant season (February-March) and declined until October. (During this later period a severe drought occurred).

Stump damage assessment of dormant (January) and growing season (June) harvest treatment in the shear versus chain-saw cutting test showed that shear harvest caused more damage than chain-saw harvest and that more damage occurred in June than in January. Damage to the major roots near the stump following shearing and skidding was greatest for growing season operations. Severe root shattering from the stump occurred with equal frequencies during dormant and growing season harvests.

Seventeen *L. stryciflua* (sweetgum) and 11 *P. occidentalis* (American sycamore) progeny trials from across the South were evaluated. The *L. stryciflua* tests are from 4 to 24 years old on 6 site types in 6 states. The 11 *P. occidentalis* trials ranged in age from 7 to 12 years, on 5 site types in 5 states. Biomass production was related to age and site type for *L. stryciflua* but not for *P. occidentalis* (Frederick et al. 1987). Of the two species, *L. stryciflua* had the highest mean annual yield of 6.44 $Mg \bullet ha^{-1} \bullet year^{-1}$ at growth age 10 on a bottomland site. Productivity would have been higher with better early weed control.

3.11.3 Technical Information Dissemination

Ariyadasa, K. P., and D. J. Frederick. 1987. Aboveground biomass estimation for seven tree species growing on the coastal plain of Georgia. Hardwood Research Cooperative Internal report. North Carolina State University, Raleigh. 11 pp.

Ellwood, E. L. 1987. Short rotation woody crops research at North Carolina State University. Presentation made to Senator Jesse Helms and the North Carolina Congressional delegation, September 1987.

Frederick, D. J. 1987. Biomass, nutrient and energy research at North Carolina State. Presentation to the North Carolina State University Hardwood Research Cooperative Advisory Board Representatives, June 1987, Atlanta.

Frederick, D. J., R. Lea, A. Clark, III, and D. R. Phillips. 1987. Site classification and productivity of hardwood wetlands in the Southern United States. Paper presented at the Eight Annual Meeting, Society of Wetland Scientists, May 1987, Seattle.

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3.12 NORTHERN STATES POWER/USDA FOREST SERVICE NORTH CENTRAL EXPERIMENT STATION - SHORT-ROTATION WOODY CROP TRIALS FOR ENERGY PRODUCING IN NORTH CENTRAL UNITED STATES

3.12.1 Goals

Begun in 1986, this project is a cooperative effort between the Northern States Power Company, the Department of Energy, the USDA Forest Service North Central Forest Experiment Station and the Minnesota University system. The primary objectives are to improve the productivity and cost efficiency of growing woody plants for energy and to develop the database necessary to predict the future contribution of biomass plantations to the U.S. energy supply. Additionally, establishment of large SRIC plantations in cooperation with an industrial user will facilitate transfer of research expertise to the private sector and help to identify operational problems that may require more research. One large plantation plus 11 smaller hybrid *Populus* plantations in the Lake States will be established. Standardized cost accounting will match the methods used by Amana Corporation and North Carolina State University projects.

3.12.2 Highlights

A 35-ha (80-acre) plantation located in Howard Lake, Minnesota, and 11 other 4-ha (10-acre) sites were established over a 5-state area. All of the smaller plantations and half of the larger one were planted at 2.44 x 2.44 m spacing. The remaining half of the large plantation was planted at 1.22 x 2.44 m spacing. These spacings were chosen to achieve maximum mean annual biomass production with rotation of 10 and 7 years, respectively. The plantations were subdivided into smaller monoclonal plots with a different hybrid in each plot to increase the probability of having one or more superior growing clones on each site. The clones selected are those that have performed best in clonal trials at Rhinelander over the past 15 years and those most frequently recommended by larger poplar nurseries.

The plantations were under severe drought stress from the time they were planted. The weather for 50 days following planting consisted of above normal temperatures, low humidity, and almost no rain. Initial growth of the cuttings has been slow and has varied from site to site because of differences in rainfall.

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

3.13.1 Goals

The research evaluates optimum nitrogen fertilization regimes. For the purposes of this study, optimum is defined as (1) optimum growth response, (2) fertilizer recovery, (3) minimal nitrate leaching, and (4) minimal susceptibility to environmental stress such as frost, drought, and insect and disease attack. The experimental design calls for urea fertilization under various timing regimes and is designed to expand and build upon the optimum nutrition experiments involving multiple nitrogen fertilizations conducted in Sweden in the late 1960s and early 1970s.

3.13.2 Highlights

A pilot study was initiated to test for potential toxicity of the highest level of urea fertilization and to develop techniques for root harvesting, physiological measurements, mycorrhizal estimation, soil-measurements of available N, and measurements of nitrification potential (Johnson et al. 1987). No toxicities were noted, but there was no consistent height growth response to fertilization, perhaps due to a lack of rain. Very high levels of soil solution nitrate were noted in the highest fertilization levels (250 and 450 kg-N/ha). Protocols for chlorophyll sampling were established; fertilization did not affect leaf longevity. Methodologies for photosynthesis and nitrate reductase measurements were tested and refined. An assay for mycorrhizal inoculation potential of the soil was initiated, and new procedures for estimating soil-available N in microbial biomass and nitrification potential were tested.

3.14 OAK RIDGE NATIONAL LABORATORY - SRIC DATA SYNTHESIS, GROWTH AND ECONOMIC MODELING, AND RESEARCH PLANNING

3.14.1 Goals

The SRWCP management staff at ORNL have responsibilities that go beyond straightforward program management and technology transfer. These include the organization and synthesis of data from all SRWCP projects; assessment of the economic viability of short-rotation wood energy crops and development of economic cost-accounting standards; the selection of analytical standards for wood energy crop evaluation and facilitation of information transfer between SRIC research and biofuel conversion research; the topical evaluation of potential new research directions (e.g., biotechnology); development of growth and competition models; and the facilitation of program-wide integrated research as exemplified by the Energy Poplar Consortium plans.

3.14.2 Highlights

The organization and synthesis of project technical data has been accomplished through the development of a database management system using KNOWLEDGEMAN (KMAN) software. During the past year an updated version of KMAN was placed in operation, and procedures for selecting and reporting specified sets of data were streamlined. A major milestone was reached when many of the contractors reported current-year data for the first time according to a specified format. This allowed immediate input of information into the database. Much more historical data remains to be entered into the database, but it has already proved useful for preliminary SRIC coppice evaluations and productivity summarizations.

Analysis of the economics of SRIC plantations have continued, and two papers by ORNL staff on this topic are currently in press. The September issue of the *Journal of Forestry*, a Society of American Forestry publication, featured an article prepared by SRWCP staff about SRIC management. The article, "Hardwood Energy Crops: The Technology of Intensive Culture," presented an analysis of the last

10 years of research by the SRWCP. An overall picture of the research was described, and certain aspects were highlighted, including DOE's role in funding woody biomass research. An effort to standardize future reporting of economic data was undertaken as part of the development of Phase II contracts for monoculture viability trials. A computer or financial spreadsheet created with Lotus 1-2-3 release 2 software has been prepared and sent along with documentation to all economists associated with the monoculture viability trials and to interested individuals in Canada and Britain.

Meetings and working sessions on developing analytical standards for wood characteristics have been held in conjunction with biofuel conversion researchers at the Solar Energy Research Institute and Pacific Northwest Laboratories. These meetings have resulted in the tentative selection of analytical standards for review and in the dispersal of SRIC wood samples for testing in biofuel conversion research laboratories. These standards and tests will be closely coordinated with the Herbaceous Energy Crops Program, as well as with other DOE biofuel programs.

Biotechnology applications relevant to the improvement of SRIC crops have been under scrutiny. Briefings on this topic have been presented to DOE, and continued assessments are under way by staff at ORNL.

A visiting faculty member, Dr. Doris Garcia from Universidad Metropolitana in Puerto Rico, spent a summer at ORNL collecting data from first-, second-, and third-year coppiced SRIC field plots of *Platanus occidentalis* (American sycamore). The results will be used to assess the dynamics of competition and crowding under SRIC conditions. Various growth concepts will be tested for validity using these results. Efforts have continued to revise the growth-modeling paper prepared by Dr. Sam Landsberg during his visit to ORNL in 1985.

The development of an integrated plan of research for the SRWCP top priority model species, *Populus*, has been a major effort of the SRWCP staff this past year. This effort has involved the organization of two meetings, the preparation of a planning document and a proceedings publication, and much thought on the part of the SRWCP staff. The group of individuals working toward accomplishment of the goals and milestones outlined in the *Populus* research plan is being referred to as the Energy Poplar Consortium.

3.14.3 Technical Information Dissemination

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Layton, P. A. 1987. Biotechnology for improving biomass energy crops. Briefing to U.S. Department of Energy, Office of Renewable Technology, March 26, 1987.

Layton, P. A. 1987. Recent developments in biological research on southern forest biomass. Paper presented at Southern Forest Biomass Workshop, June 9, 1987, Biloxi, Mississippi.

Layton, P. A. 1987. U.S. biotechnological activities concerning poplars and alders. Paper presented at International Energy Agency Workshop on Biotechnology Development, Uppsala, Sweden.

Layton, P. A., and L. L. Wright. 1987. Energy crop research advances the fundamentals of forest biology. Paper presented at 9th Southern Forest Biomass Workshop, Gulfport, Mississippi.

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Wright, L. L., and J. W. Ranney. 1987. Validation and standardization of SRIC production costs. Paper presented at International Energy Agency Workshop on Economic Evaluations of Short Rotation Biomass Systems, August 11-13, 1987, USDA Forest Service North Central Forest Experiment Station, Duluth, Minnesota.

Wright, L. L., P. A. Layton, and J. W. Ranney. 1987. Development of a research strategy for poplar. Paper presented at Annual Meeting of U.S. Poplar Council, June 21-24, 1987, State University of New York, School of Environmental Studies, Syracuse.

Wright, L. L., P. A. Layton, and J. W. Ranney. 1987. Plan for *Populus* research in the Short Rotation Woody Crops Program. Prepared for DOE.

3.15 OKLAHOMA STATE UNIVERSITY/UNIVERSITY OF WASHINGTON - EVALUATE *POPULUS* SELECTIONS FOR FUELWOOD (U.S.-INDIA)

3.15.1 Goals

As a result of a Presidential-Prime Ministerial agreement (between the United States and India), Oklahoma State University and the University of Washington initiated tests to evaluate and identify the adaptability of a wide range of *Populus* clones under diverse environmental conditions. Results from such a study will be used for breeding superior hybrid clones in the United States and India as part of a technology exchange program. Particularly needed traits such as tolerance to high soil pH can be introduced from a particular clone into new hybrid material for better local adaptability to site conditions. The Washington study is concentrating on determining physiological factors (e.g., photosynthesis, leaf display, etc.) affecting arid land crop production. Two sites were established in Washington, one east of the Cascades, the other on the west side. The Oklahoma project will establish a plantation on a site with conditions similar to those found in India.

3.15.2 Highlights

A set of 168 clones of poplar trees are being cooperatively tested at five sites to assess their performance and tolerance to environmental stresses. One site is near Oklahoma State University, two are in the state of Washington, and two are in northern India.

These tests are in their second year of growth and were considered well established in their first year, except for those in Oklahoma. In India, cuttings will be taken this winter from these plots to establish more plots over a wider area. Since the genetic identity of each clone is being maintained, considerable knowledge is being gained on the amplitude of tolerance to a set of conditions (photoperiodism, soil pH, climatic and precipitation regimes, frost, diseases, and other conditions). Analysis of first- and second-year performance has not yet been reported for all sites, although verbal communications have indicated some very clear clonal winners in each region. Results will be reported next year, as these sites are being well maintained and monitored.

3.16 PENNSYLVANIA STATE UNIVERSITY - ECONOMIC ANALYSES FOR PRODUCING *POPULUS* HYBRIDS UNDER FOUR MANAGEMENT STRATEGIES

3.16.1 Goals

The goals of this project 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 *Populus* using four management strategies (control, irrigation, fertilization and combined fertilization/irrigation) for two rotations; (3) wood energy properties related to 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) management and conversion strategies to recommend the most advantageous approach for two rotations (Blankenhorn et al. 1987).

3.16.2 Highlights

The 1980 plantings, now in their second rotation, will be harvested in the fall of 1987. In anticipation of these massive undertakings, researchers adapted an electronic caliper and a load cell (to measure weight) to feed data into a portable personal computer. They also developed a program with immediate error checks and prompting for the appropriate sample. Height data are input directly into the computer also. This should greatly increase their overall efficiency in data manipulation.

The financial model was updated this year with 1987 costs. This was also done in anticipation of the harvest data that will be available in the next 2 years. Wood quality analysis was made on trees with septoria canker. This information can be used to determine the effects on the feedstock quality if significant disease problems occur in an energy plantation.

Overall coppice yield was estimated to be 21 dry Mg/ha after two growing seasons. The overall coppice yield of 38 dry Mg/ha from the same plots at the end of three growing seasons exceeds the amount produced in the 4 years of the first rotation for all site and treatments of the 1980 planted trees. A risk analysis model is under development to analyze the production, harvesting, and storage of biomass as a cost cumulative system organized under the particular volumes of biomass from two production strategies: control and fertilization.

3.16.3 Technical Information Dissemination

Bowersox, T. W., P. R. Blankenhorn, and C. H. Strauss. 1987. Second rotation growth and yield of *Populus*. Paper presented at IEA/BA Task 11, Coppice Workshop, Oulu, Finland.

Strauss, C. H., S. C. Grado, P. R. Blankenhorn, and T. W. Bowersox. 1987. Microeconomic accounting model for woody biomass systems. Paper presented at the International Energy Workshop on Economic Evaluations of Short-Rotation Biomass Energy Systems, August 11-13, 1987, Duluth, Minnesota.

Strauss, C. H., P. R. Blankenhorn, T. W. Bowersox, and S. C. Grado. 1987. Production costs for first rotation biomass plantations. Biomass 12:215-226.

Strauss, C. H., P. R. Blankenhorn, T. W. Bowersox, and S. C. Grado. 1987. Setting standards for the economic analysis of woody biomass: Total cost systems. Paper presented at International Energy Agency and USDA Forest Service Workshop on Economic Evaluations of Short-Rotation Biomass Energy Systems, August 11-14, 1987, Duluth, Minnesota.

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

3.17.1 Goals

The purpose of this project is to utilize genetic and physiological technology to maximize biomass production of *Acer saccharinum* as a short-rotation woody crop in the Great Plains, Midwest, Lake States, and northeast United States (Ashley et al. 1987). The genetic objectives are to secure seed from vigorous trees throughout the range, select the best trees within each provenance for clonal increase, propagate large numbers of the selected trees, plant equal portions of these plantlets in test plantations within several biomass production regions, and measure and compare biomass production of the selected clones from the original planting and from coppice regrowth. The physiological objectives focus on (1) developing a methodology for clonal propagation; (2) assessing mineral nutrient uptake and distribution in the plant; (3) evaluating growth rates including height, canopy development, and foliage production; and (4) extent and vigor of coppice development.

3.17.2 Highlights

Test sites in southern Illinois were plowed, cultivated, fertilized, and covered with a winter crop in preparation for spring planting. Soil samples were collected and analyzed for pH, organic matter, cation exchange capacity, and nutrient levels at the Illinois, Oklahoma, and New Hampshire sites. The availability and quality of seed have been highly variable. Seed lots from Mississippi, Illinois, Iowa, Wisconsin, northern Pennsylvania, and Connecticut grew best. Seed crop failures and absences of native trees were reported by cooperators in the westernmost and southeastern part of the range. Micropropagation and tissue culture studies resulted in explant establishment *in vitro*, proliferation of axillary shoots, rooting of these shoots, establishment of the plantlets in the greenhouse, and outplanting into the nursery.

3.17.3 Technical Information Dissemination

Ashby, W.C., J.E. Preece, C.A. Huetteman, D.F. Bresnan, and P.L. Roth. 1987. Silver maple tree improvement for biomass production. Paper presented at the 5th North Forest Central Tree Improvement Association Meeting, August 11-13, 1987, North Dakota State University, Fargo.

Farm-grown energy taking root in Illinois. 1987. Biologue Energy Newsletter 4(4):4-5.

3.18 TENNESSEE VALLEY AUTHORITY - SHORT-ROTATION WOODY CROPS HARVESTING AND FIELD HANDLING

3.18.1 Goals

Work previously conducted under this project concentrated on identifying and evaluating harvesting components that could economically harvest SRIC biomass. Current efforts focus on an integrated components approach, which combines biomass production and harvesting cost functions. Combining these factors in order to determine total system effectiveness allows analysis of compromises within the system, which can improve total system performance.

3.18.2 Highlights

As well as continuing to test felling, bunching, yarding, and baling machines, considerable effort was expanded to develop a predictive methodology that integrates harvesting costs and biomass production variables. Various methods for determining the best rotation age of multiple-rotation hardwood stands were evaluated as was the determination of maximum current annual increment. A regression equation of the favored rotation in relation to planting density (spacing) was formed. This relationship led to other regressions comparing biomass yield to planting density and production (growing) costs to density. Harvesting productivity rates were simulated from research data for the range of tree sizes that plantations of various planted densities should produce. The production and harvesting costs for each density were combined in the form of present net worth values and annual equivalent values and illustrated as a function of planting density. The results showed a logarithmic increase in costs as planting density increased (Woodfin et al. 1987).

3.18.3 Technical Information Dissemination

Curtin, D. T., D. L. Sirois, and J. Sturos. 1987. Roll splitting as field process. Paper presented at Harvesting Early Thinnings (HET) conference, September 14, 1987, Aberdeen, Scotland.

Woodfin, S. L. 1987. Preliminary evaluation of round baler for biomass recovery. Biologue Energy Newsletter 4(2):8-9.

Woodfin, S. L., L. L. Wright, and D. Curtin. 1987. SRIC: Integration of production and harvesting system costs. Paper presented at International Energy Association Workshop on Economic Evaluations of Short-Rotation Biomass Systems August 11-13, 1987, USDA Forest Service North Central Forest Experiment Station, Duluth, Minnesota.

Woodfin, S. L., and B. J. Stokes. 1987. Preliminary evaluation of round baler for biomass recovery. APA technical release 87-R-8. American Pulpwood Association, Washington, D.C.

Woodfin, S. L., and B. J. Stokes. 1987. Preliminary evaluation of round baler for biomass recovery. Paper presented at Southern Forest Biomass Workshop, June 11, 1987, Mississippi State University, Gulfport.

3.19 TEXAS A&I UNIVERSITY - PRODUCTION OF WOODY BIOFUELS FROM MESQUITE (*PROSOPIS* spp.)

3.19.1 Goals

The major objective is to develop biomass production systems (mesquite) for nonirrigated, semiarid lands that will produce competitively priced renewable fuels. Specific goals are (1) the selection and propagation of commercially viable clones based on evaluation of biomass production and tolerance to disease, pests, and cold; (2) development of commercially viable mechanized prototype cultural management systems; (3) development of quantitative mathematical relationships between leaf mineral nutrient concentrations and growth for *Prosopis* species; (4) development and testing of appropriate prototype harvesting equipment; (5) stimulation of awareness in commercial energy sector in south Texas where no commercial wood industry currently exists; and (6) demonstration of commercial viability of *Prosopis* and analysis of risk factors.

3.19.2 Highlights

This is the final year for this project. The *Prosopis alba* (mesquite) clone (B2V50) plot in Kingsville, Texas, was harvested at 2.75 years old. The first, second, and third year's standing dry biomass were 3.46, 17.6, and 39.3 dry Mg/ha, with average current annual increments of 3.46, 14.1 and 21.7 dry Mg/ha, respectively (Felker et al. 1987). The thorny hybrid clone (B9V18) produced less than half the biomass of B2B50, with a three-season standing dry biomass of 16.6 Mg/ha.

The first foliar fertilization was completed at the Zachary Ranch, a very dry site. While no biomass increases resulted from this fertilization, foliar levels of copper increased by 600%, and iron, manganese, and zinc levels doubled. Stepwise linear regressions between growth and foliar nutrient concentrations of 75 trees revealed that calcium, iron, and phosphorus were most correlated with growth.

3.19.3 Technical Information Dissemination

Felker, P. 1987. Progeny testing nitrogen fixing trees *Prosopis*. Paper presented at Southeastern Forestry Improvement Conference, July 16-18, 1987, College Station, Texas.

Felker, P., D. Smith, C. Wiesman, and R. L. Bingham. 1987. Biomass production of *Prosopis alba* at 2 non-irrigated field sites in semiarid south Texas. Unpublished final report submitted to DOE's Short Rotation Woody Crops Program.

Glumac, E. L., P. Felker, and I. Reyes. 1987. A comparison of cold tolerance and biomass production in *Leucaena leucocephala*, *L. pulverulenta* and *L. retusa*. For. Ecol. Manage. 18:251-271.

Glumac, E. L., P. Felker, and I. Reyes. 1987. Correlations between biomass productivity and soil and plant tissue nutrient concentrations for *Leucaena leucocephala* (K-8) growing on calcareous soils. For. Ecol. Manage. 18:241-250.

Klass, S., J. Wright, and P. Felker. 1987. Influence of auxins, thiamine and fungal drenches on the rooting of *Prosopis alba* clone B_2V_{50} cuttings. J. Hortic. Science 62(1):97-100.

Wightman, S. J. 1987. Effects of soil fertility and foliar fertilization on biomass productivity of *Prosopis* spp. in south Texas. M.S. thesis. Texas A&I University, Kingsville.

3.20 TUSKEGEE UNIVERSITY/CARVER RESEARCH FOUNDATION - NUTRIENT OPTIMIZATION RESEARCH

3.20.1 Goals

This research effort is designed to determine the nutrient-use efficiency of SRIC plantations under different fertilizer regimes.

3.20.2 Highlights

A *Fraxinus pennsylvanica* (green ash) pilot plantation (approximately 800 trees) was established to study the effects of various levels of fertilization. A full-scale *Platanus occidentalis* (sycamore) plantation (approximately 4,000 trees) was established to study nitrogen optimization. Each of the 15 plots measures 24 m x 24 m, with 17 trees per row and 17 per column per plot, set 1.5 m apart.

Soil samples were taken at the *F. pennsylvanica* (green ash) plantation and analyzed for pH, phosphorus, potassium, magnesium, and calcium contents. Results indicate that pH values range from 4.7 to 5.1. The soil is also low in magnesium. The elemental analysis seems to indicate that the 1986 and 1987 soil applications of nitrogen and phosphorus have caused a depletion of these essential elements (Weaver 1987).

Periodic lysimeter readings were taken to measure soil-water retention and predation on both sites. Observations on insect/disease infestation were also made. At the *F. pennsylvanica* (green ash) pilot plot, the lysimeter readings ranged from -17.5 (June) to -58.3 (September) mean centibars. At the *P. occidentalis* (American sycamore) plantation, the readings ranged from -13.3 (June) to -59.0 (September) mean centibars. The September levels can be attributed to a decline in precipitation from July to September 1987. Insect/disease conclusions have not been developed.

3.21 UNIVERSITY OF FLORIDA - WOODY SPECIES FOR BIOMASS PRODUCTION IN FLORIDA

3.21.1 Goals

Activities from 1983-1987 were directed toward genetic improvement of *Eucalyptus* species, determining productivity of *Eucalyptus* in response to silvicultural factors, clonal propagation and testing, estimating the economics of various biomass production strategies, evaluating basic physical properties of *E. grandis* as affected by cultural variables, and the continuing assessment of other species for SRIC (Rockwood et al. 1987).

3.21.2 Highlights

This is the last year of this project. *Eucalyptus grandis* of superior vigor and frost resilience in a fourth-generation genetic base population can now be propagated by seed or vegetatively. One year after the orchard was developed by roguing the base population, most of the over 1700 trees in the seedling nursery produced seed. Seed from 24 of the best trees was highly viable. Three clones with proven frost resilience and vigor have adapted readily to tissue culture. Additionally, presumably equally superior 4.5-year-old clones produced 49 or more rooted cuttings each when a propagation regime of stem-girdling, shoot-collection, section-cutting, and sticking procedure was used. This regime is suitable for propagating and outplanting a modest number of ramets of a clone in one growing season.

The risk associated with culture of *Eucalyptus* was evidenced by coppice failure and freeze-damage assessment. Warm, dry winter weather was devastating to coppicing of *E. grandis* and *E. robusta* in southern Florida, whereas *E. amplifolia* may be more tolerant of such extremes. Results from an image processing project suggest that the LANDSAT Thematic Mapper can accurately identify *Eucalyptus* plantations and differentiate freeze-damaged stands, thus providing estimates of the extent of damage.

3.21.3 Technical Information Dissemination

Meskimen, G. F., D. L. Rockwood, and K. V. Reddy. 1987. Development of *Eucalyptus* clones for a summer rainfall environment with periodic severe frosts. New For. 3:197-205.

Reddy, K. V., and D. L. Rockwood. 1987. Breeding strategies for coppice production in *Eucalyptus grandis* base population with four generations of selection. Silvae Genet. (accepted for publication).

Reddy, K. V., and D. L. Rockwood. 1987. A strategy for converting an *Eucalyptus grandis* genetic base population to a seedling seed orchard. pp. 613-621. IN Proc., IUFRO Conference on Breeding Theory, Progeny Testing, and Seed Orchards.

Rockwood, D. L., and D. R. Dippon. 1987. Prospects for commercialization of *Eucalyptus* biomass plantations in Florida. pp. 233-249. IN D. L. Klass (ed), Proc., Energy from Biomass and Wastes X. Institute of Gas Technology, Chicago.

Rockwood, D. L., D. R. Dippon, M. S. Lesney, and K. V. Reddy. 1987. Woody species for biomass production in Florida. Unpublished draft final report submitted to DOE's Short Rotation Woody Crops Program.

Rockwood, D. L., K. V. Reddy, E. I. Warrag, and C. W. Comer. Development of *Eucalyptus amplifolia* for woody biomass production. Aust. For. Res. (in press).

Warrag, E. I., V. Ortega, M. S. Lesney, and D. L. Rockwood. Recent progress in tissue culture methods for *Eucalyptus* species and implications for genetic improvement. IN Proc., 9th Southern Forestry Biomass Workshop (in press).

3.22 UNIVERSITY OF GEORGIA - OPTIMIZING ENERGY YIELDS IN BLACK LOCUST THROUGH GENETIC SELECTION

3.22.1 Goals

This project, started in late 1986, has identified six essential areas of investigation needed to design a program for the improvement of biomass productivity in *Robinia pseudoacacia* (black locust). These include (1) defining the base population to be improved; (2) determining the relative efficacies of clonal, family, and within-family selection; (3) determining and developing means to eliminate sources of environmental variation; (4) determining the basic physiological determinants of growth variation and developing efficient selection algorithms for them; (5) determining the extent and nature of genotype x environment interactions; and (6) determining the genetic relationships between nitrogen-fixation and productivity (Bongarten et al. 1987).

3.22.2 Highlights

A site for the field evaluations was selected and surveyed. The selected property, donated by the Georgia Power Company, is a 13-ha open field that borders on a stream. The soil type is a Davidson clay-loam, typical of upland Piedmont sites. Selected genetic material (ortets) from a range-wide provenance-progeny test in Georgia and clones from a Soil Conservation Service clone bank in Cape May, New Jersey, were chosen for the proposed genetic investigations.

Previously established progeny tests indicate that common environmental effects bias estimates of genetic parameters. One source of common environmental effects is familial variation in germination rate. Tests of pregermination treatments, which included exposure to (1) concentrated H_2SO_4 (0 to 60 min), (2) hot water (45°C for 90 min) and (3) vacuum pressure over water (-30 psi for 90 min), indicate that germination is most rapid and uniform when seeds are treated with sulfuric acid for 15 to 30 min and exposed to hot water under vacuum for 90 min thereafter.

Results of isozyme analyses indicate that at least 54 loci may be evaluated from leaf extracts and that half of these are polymorphic. This extreme level of polymorphism supports the view that *Robinia pseudoacacia* (black locust) is very diverse genetically. The relatively high levels of heterozygosity suggest that the mating system is predominantly outcrossing.

3.23 UNIVERSITY OF WASHINGTON/WASHINGTON STATE UNIVERSITY - GENETIC IMPROVEMENT AND EVALUATION OF BLACK COTTONWOOD FOR SHORT-ROTATION COPPICE CULTURE

3.23.1 Goals

This project has two major objectives: (1) to develop genetically improved *Populus trichocarpa* T. & G. (black cottonwood) suitable for short-rotation coppice culture and adaptable to varied sites as well as variable climate and (2) to determine the critical components of productivity (traits) to be selected in this material and the cultural methods by which their effects can be enhanced. The program is designed to identify superior clones derived from natural populations and from hybrids produced using pollen from superior *P. deltoides* (eastern cottonwood). Field trials compare productivity of first and second rotations of *Populus* plantations and 1:1 mixtures of *Populus* with *Alnus rubra* (red alder).

3.23.2 Highlights

Field Trials 1a and 1b were harvested for the second time on a 4-year cycle. Processing of samples was completed and analysis of data was initiated. The crossing program, started in 1986, was expanded. A total of 40 crosses with 6 *P. maximowiczii* (Japanese poplar) pollen parents succeeded, resulting in approximately 6000 seedlings. Additional crosses were made between *P. trichocarpa* (black cottonwood) clones east and west of the Cascades to study transmission of physiological traits and rust resistance. The crosses resulted in 28 families, with several hundreds of seed for each family (Stettler et al. 1987).

F_1 hybrids from Illinois and Texas *P. deltoides* (eastern cottonwood) were superior to all other materials in field trials established at the University of Washington's Pack Forest and James River Corporation's Westport, Oregon, location. Superior growth continues at Westport where mean height of the top clone after 4 years was 16 m. The superiority of F_1 hybrids is also reflected in higher tolerance to adverse soil conditions--both wet and dry soils. Their greater tolerance to dry soils is exhibited in greater retention of green leaves throughout the dry summers of western Washington.

Three-year growth data from 211 clones in Field Trial 3c in Alger confirm the fact that clone and clone x block interaction account for most of the natural variation. Moderate clonal traits persisted:

trees from northern/western sources tended to outperform trees from southern/eastern sources.

Factors responsible for the superior growth of hybrid material (*P. trichocarpa* x *P. deltoides*) were identified and studied. They are stomatal mechanisms, leaf growth, leaf orientation, photosynthesis and carbon allocation, and root physiology. It was found that hybrids had stomata that are more open and sensitive to drought than the *P. trichocarpa* (black cottonwood) parent and may have stomata equally open and even more sensitive to drought than the *P. deltoides* (eastern cottonwood) parents. Hybrid material had greater leaf area and greater rates of leaf growth than either of the parents when grown under identical conditions. It was found that hybrids had slightly higher export rates of photosynthesis from leaves early in the season. Definite differences between clones were found in their patterns of photosynthates translocation.

3.23.3 Technical Information Dissemination

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3.24 UNIVERSITY OF WASHINGTON/JAMES RIVER CORPORATION - MONOCULTURE VIABILITY TRIALS OF WOODY CROPS FOR ENERGY PRODUCTION

3.24.1 Goals

During Phase I of a multiphased project, the major goal was to develop a detailed proposal on the establishment and maintenance of a multiacre monoculture viability trial for the purpose of developing more accurate estimates of the costs and risks associated with growing wood for energy. Preparation of the proposal as a joint venture between a research organization and a private sector applications-oriented organization was an important component of the work. An additional goal of the Phase I period was the preparation of a technical paper summarizing the state-of-the-art technology on establishment and maintenance of SRIC plantations in the Pacific Northwest.

3.24.2 Highlights

The original proposal for the monoculture viability trials was submitted by W. A. Atkinson of the University of Washington with the cooperation of Crown Zellerbach scientists in Camus, Washington. All of the work in fulfillment of the Phase I contract was completed by Brian Stanton of Crown Zellerbach. An excellent report was prepared entitled "Establishing and Maintaining Short-Rotation, Intensively Cultured Plantations of Hybrid Cottonwood in the Pacific Northwest." A Phase II proposal with detailed plans for collecting information on costs and risks of monoculture plantations was submitted and found to be acceptable. Phase II negotiations were underway when James River Corporation took over Crown Zellerbach's Fiber Farm operations and research in the Columbia River Valley. James River Corporation has decided that it would prefer to fund its own studies of costs and risks of SRIC plantations without SRWCP assistance. This is seen as a very positive development demonstrating the interest of industry in the SRIC concept. James River Corporation has expressed an interest in cooperating with the SRWCP in areas of mutual interest, and negotiation of a modified Phase II contract is still in process.

3.25 USDA/FS NORTH CENTRAL FOREST EXPERIMENT STATION - INCREASING YIELDS OF *POPULUS* ENERGY PLANTATIONS

3.25.1 Goals

Research dealing with intensively cultured plantations for fiber and energy production began at the North Central Forest Experiment Station (NCFES) in Rhinelander, Wisconsin, in 1971, with SRWCP funding beginning in 1976 as a cooperative agreement with the Forest Service (Hansen et al. 1987). The current program goals are to (1) introduce and test new *Populus* selections in the northcentral states for the purpose of breeding fast-growing, disease-resistant clones, (2) develop physiologically based selection criteria for breeding and selection, (3) develop herbicide- resistant poplar clones through somaclonal techniques, (4) develop a physiologically based growth model to aid in identifying faster growing trees, (5) continue cultural studies in the area of mid rotation management, and (6) measure productivity in first-rotation and coppice plantations.

3.25.2 Highlights

A *Populus* breeding program was begun in 1984 to assemble base breeding populations, establish stool beds for future propagation of collected plant material, establish field tests, make selections for SRIC plantings, and make crosses between select individuals to produce hybrid progeny. In 1986, work concentrated on first-year phenology, growth, and *Septoria* canker resistance of *P. trichocarpa* (black cottonwood) clones and controlled crossing between select *P. deltoides* (eastern cottonwood) and Tacamahaca poplars. The establishment of the *P. trichocarpa* plantation was adversely effected by hot, dry conditions and deer browsing, necessitating additional outplanting.

A set of "principles," based on the results of the fertilization study, was formulated to guide field N fertilization of hybrid poplar plantations.

1. Weeds are the major nitrogen sink the first few years in *Populus* plantations.
2. If weeds are eliminated, N fertilization is not necessary on moderately fertile sites for at least the first few years.
3. On infertile sites, N fertilization is necessary even if weeds are eliminated.
4. After canopy closure, N fertilization may be greatly reduced or even eliminated on some sites.
5. N fertilization rates on the order of 112-168 $kg{\bullet}ha^{-1}{\bullet}year^{-1}$ may be a good first approximation in the absence of specific local data.
6. Tree foliar N concentrations as sampled in mid-July should be maintained above 3% for good growth.

The clonal nutrient study plots established in 1982 on two soil types were harvested in the fall of 1986 when the trees were 5 years old. Results of leaf NPK analyses demonstrated a stability of clonal ranking across tree age and site, suggesting that clonal screening for tissue nutrient concentrations may be independent of tree age and site fertility. This would allow early screening for desirable nutrient traits and implies that results may be extrapolated to a wide range of sites.

Coppice production of clone NC-5331 established in 1980 at the Harshaw Farm was measured. The third coppice cycle of a 2-year rotation and the second coppice cycle of a 3-year rotation were measured and harvested. Yields dropped about 30% between the first and second coppice cycle in the 1-year and 3-year rotation stands and dropped more than 80% between the first and second coppice cycle in the 2-year rotation stand. These results suggest that this clone does not coppice well, and that a better coppicing clone needs to be identified.

Mean annual biomass increment (MABI) of the irrigated 1.0 x 1.0 m spaced plot of clone NC-41 averaged 12.8 $Mg{\bullet}ha^{-1}{\bullet}year^{-1}$ at age 6 and was still increasing. This high yield is encouraging and indicates that it may be possible to reach 15 Mg ha^{-1} $year^{-1}$ with this clone and spacing combination.

An operational version of the ECOPHYS tree growth model was completed. The model can be used to compare photosynthetic production and growth in clones with contrasting crown architecture over a season. It can also be used to assess the impact of air pollution on photosynthetic production and growth of *Populus* and to examine the hourly projections of photosynthesis over the day in control versus ozone- exposed plants. With ECOPHYS the physiologist or geneticist can compare and/or rank newly acquired clones in the laboratory. Clonal rankings and growth comparisons are being made over an entire growing season and compared to actual field data collected at the Harshaw Experimental Farm. Progress has been made extending the ECOPHYS concept to a 2-year SRIC poplar with lateral branches.

Work continued on the development of broad-spectrum, herbicide-resistant poplar clones using somaclonal biotechnology. Shoot regeneration culture regimes for target poplar clones were established and refined. *In vitro* callus, leaf, and explant culture systems were refined, and methods of challenging cultures with herbicides were developed. Cell lines resistant to glyphosate and sulfmeturon (NC-5339, NC-5272, NC-5331) are being subjected to three rechallenges in toxic levels of the herbicide before rooting and transfer to the greenhouse.

A study was initiated to measure a variety of physiological parameters related to water relations and tree growth and to correlate them to tree growth under a range of soil moisture conditions. The study consists of a randomized block design with 3 soil moisture regimes (i.e., irrigation levels), 4 replications, 3 *Populus* species, and 12 clones per species. Measurements were collected after the summer. Height growth within each of the species was related to clonal origin. A wide range of leaf sizes, shapes, and orientation within and among the three species was noted.

3.25.3 Technical Information Dissemination

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3.26 USDA/FS PACIFIC NORTHWEST STATION - INCREASING THE BIOMASS PRODUCTION OF ALDER AND COTTONWOOD PLANTATIONS IN THE PACIFIC NORTHWEST

3.26.1 Goals

The purpose of the project is to provide guidelines for producing bioenergy crops of *Alnus rubra* (red alder) and *Populus* spp. and hybrids (cottonwood). The *Alnus* research assesses the influence of cultural practices such as spacing, coppicing, fertilizing, weed control and irrigation on tree growth and stand development, examines genetic variability within the species and develops tools for predicting the relative productivity of land for short-rotation plantations. The *Populus* work includes the first clear evaluation of the "wood grass" concept, including a comparison of two hybrid clones over a range of stand densities.

3.26.2 Highlights

The *Alnus* productivity trial was successfully reestablished after last year's killing spring frosts. Average survival rate and height at the end of the first year were 97% and 88 cm, respectively. Effects of spacing, irrigation level, and phosphorus fertilization became apparent. A density trial for *Populus* clones was established. Survival averaged 97% and mean height was 1.62 m. Performance of D-01 and Hybrid-11 were similar in the "wood grass" spacings (0.18 and 0.30 m), but growth of Hybrid-11 increased more than D-1 as spacing widened (0.5 to 2.0 m). Comparison of these two hybrid clones with native *Populus* at 1.0 m spacing revealed that the latter was equal or superior to Hybrid-11 in first-year height and diameter growth (DeBell et al. 1987).

First-year results in the continuous-function fertilizer test showed that the design included both "optimum" and "toxic" nutrient conditions. Substantial differences in growth were associated with fertilizer treatment, and effects varied between *Populus* clones and *Alnus* families. Strong correlations were found between average size (area) and weight of fully-expanded leaves and height growth of both species; leaf thickness was also positively correlated with height growth in *Populus*.

Measurement and analysis of an unfertilized 12-year-old *Alnus* spacing test under minimum maintenance showed that density strongly affected stand development. Seventy percent of the trees died in the 0.6 x 1.2 m spacing, while only 10-15% of those in the two widest spacings (2.5 x 2.5 m and 3.2 x 3.2 m) died. Total aboveground dry matter averaged 90 Mg/ha. Although annual growth has peaked in the closer spacings, the increment in the 2.5 x 2.5 m spacing was nearly 14 Mg/ha, approximately twice the mean annual production.

Evaluation of nutrient relations in coppiced *Populus* and *Alnus* at the Lady Island site showed that nutrient concentrations and contents varied between the species: *Populus* was more efficient than *Alnus* in the use of N, S, and Cu, and less efficient in the use of Ca. Results of two *Alnus* fertilizer experiments conducted in the lathhouse indicated the potential of phosphorus fertilizer to increase growth and demonstrated that fertilizer mixtures (additional elements) might significantly reduce growth response.

Alnus rubra (red alder) was successfully propagated vegetatively, especially from epicormic sprouts obtained by girdling trees of known superior performance. Cuttings made from sprouts of several stock trees were rooted with and without treatment with indole-3-butyric acid. Rooted cuttings were successfully cultivated into 1-year-old planting stock.

3.26.3 Technical Information Dissemination

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3.27 USDA/FS PACIFIC SOUTHWEST STATION - *EUCALYPTUS* PLANTATIONS FOR ENERGY PRODUCTION IN HAWAII

3.27.1 Goals

The purpose of this contract is to document the *Eucalyptus* research in Hawaii.

3.27.2 Highlights

Several manuscripts are in various stages of completion. Topics include the effects of planting density on biomass yields, an evaluation of mixed plantings of *Eucalyptus* and *Albizia*, the effects of different soil types on growth and yield, a comparison of provenances of four *Eucalyptus* species, harvesting, and economic risk assessment.

Mixing *Eucalyptus saligna* with *Albizia falcataria* (a nitrogen-fixing mimosa tree) provided some very interesting results compared to pure stands of either *Eucalyptus* or *Albizia*. Mixing species generally caused both species to either outperform or match height growth in pure stands. The mix apparently adds a small degree of productive stability to stands. However, the merits of planting *Eucalyptus-Albizia* mixtures vary with site. On drier sites, *Albizia* performance was reduced as was its influence on *Eucalyptus*. Benefits will depend not only on the relative growth of the two species but also on the most influential growth-limiting factors--nitrogen, moisture, light, and wind--at each site.

Use of abandoned, low-yielding sugarcane land in Hawaii for *Eucalyptus* plantations has been under investigation. Spacing studies, fertilizer evaluations, and weed control (less than maximum) on these sites over 8 years have shown that 1 x 2 m spacings and successive fertilizer applications (during and after establishment) achieve maximum production. Production from these low-quality sites ranged from 11.6 to 14.0 dry $Mg \cdot ha^{-1} \cdot year^{-1}$. Previous *Eucalyptus* plantings in Hawaii were generally at 2.5 x 2.5 m.

3.27.3 Technical Information Dissemination

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4. TECHNOLOGY TRANSFER AND RELATED ACTIVITIES

More transfer of short-rotation intensive culture (SRIC) technology from researchers to users took place in 1987 than any other year in the history of the United States. The success of technology transfer has resulted in at least 16 industries and utilities employing the technology on a trial basis, and many more are seeking information. There are several motivations for this development. One has been the growing maturity of the technology. More good information, better tree clones, and a clearer understanding of success rates and risks are now available from reputable researchers.

A second reason for greater technology transfer has been the potential match between SRIC and the United States Department of Agriculture's (USDA's) Conservation Reserve Program for soil protection. SRIC technology appears to offer a good type of crop for erosive agricultural land that is to be set aside for at least 10 years. Perhaps 15 million ha will be involved in this program, with 12.5% finding its way into SRIC applications. State agencies, extension agents, and farmers are struggling to learn more about SRIC. Minnesota, Iowa, Wisconsin, and Washington are leading in this effort.

Third, recently initiated monoculture viability trials by Northern States Power Company and others with energy interests are requiring some companies to lear the new technology quickly. With some of their own resources invested in making SRIC work, these companies are working closely with the Short Rotation Woody Crops Program (SRWCP) researchers in applying the latest techniques and materials to maximize the success of their projects. This reason and the previous one have been significantly aided by DOE's Lake States Regional Program and the USDA Forest Service, as well as some land-grant universities and state departments of natural resources.

A fourth and significant reason for successful technology transfer has been direct contact of SRWCP participants with public and professional media. Farm show interviews, TV clips, newspaper coverage, scientific journal articles (734 since the initiation of the SRWCP), informative brochures, and tours involving the lay public and congressional groups are only some of the ways in which researchers at almost every project have transmitted information about the program. These types of activities have led to success in other technology transfer activities.

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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 centimer 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 km^2 = 100 ha
1 Ha = 10,000 m^2
1 m^2 = 10,000 cm^2
1 cm^2 = 100 mm^2
1 m^3 = 1000 liters
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 feet
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)	0.9470	British thermal units (Btu or MBtu)
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
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	5.556×10^{-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 ft	Area in F^2	Area in [illegible]^2
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	2023.36
1	.4047	117.7522	35.8909	43560	4046.72

Diameter at breast height (dhb) = 4 1/2 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/ft^3
= 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 intensive culture wood 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 ft^3 of natural gas
- 4,981 kWh of electricity

1 Quad = 1 quadrillion Btu or 1 x 10^{15} Btu
= 1.0559 x 10^{18} joules or 1 exajoule

APPENDIX II - LATIN AND COMMON NAMES OF WOODY SPECIES

Latin name	Common name
Acer saccharinum	Silver maple
Alnus glutinosa	European alder
Alnus rubra	Red alder
Atriplex canescens	Fourwing saltbush
Betula pendula	European white birch
Elaeagnus umbellata	Autumn olive
Eucalyptus saligna	Eucalyptus
Fraxinus americana	White ash
Leucaene retusa	Leucaena
Liquidambar styraciflua	Sweetgum
Pinus radiata	Monterey pine
Pinus taeda	Loblolly pine
Platanus occidentalis	American sycamore
Populus balsamifera	Balsam poplar
Populus deltoides	Eastern cottonwood
Populus tremuloides	Quaking aspen
Populus trichocarpa	Black cottonwood
Prosopis alba	Mesquite
Pseudotsuga menziesii	Douglas-fir
Quercus rubra	Northern red oak
Robinia pseudoacacia	Black locust

APPENDIX III - STANDARDIZED COST-ACCOUNTING METHOD

To collect data from Short Rotation Woody Crops Program (SRWCP) monoculture viability projects in a consistent manner and in a readily accessible format, SRWCP uses a Lotus 1-2-3 (release 2) spreadsheet. The spreadsheet has a general format that should be useful for all the projects; however, not all the projects have costs in all categories and there may be a cost that does not fit conveniently into any category listed. A description of the project should be included along with the spreadsheet to make the information more complete. Only actual costs incurred by the projects should be entered into the spreadsheet.

Costs are to be calculated on the basis of the whole scale-up project or a readily identifiable part of the project, but they should be entered into the spreadsheet on a per-hectare basis. These major cost categories are included in the spreadsheet: infrastructure, establishment, cultural management, and overhead. Within each of these major categories are finer breakdowns of costs. (At this time, harvesting is not included in the spreadsheet because this activity is 6 to 8 years away.) Within these finer breakdowns of costs (e.g., disking, subsoiling, fertilizing) are these cost categories: material, fixed, variable, and labor.

Fixed costs are incurred regardless of whether an activity is undertaken. For example, the costs of depreciation and interest on a piece of machinery are incurred even if the machinery is not used during the year. Variable costs are incurred when an activity occurs. For example, the cost of fuel to operate a tractor is incurred only when the tractor is used. Vehicle maintenance, repair, and lubrication are also considered to be variable costs. The distinction between a fixed and variable cost is not always clear, as can be the case with machinery maintenance. Therefore, an explanation of what activities are included with each category is important. A custom operation used for certain activities such as herbicide spraying or land clearing is considered to be a variable cost because the expense would not have been incurred unless the activity was undertaken. A separate cost category has been established for materials (e.g., fertilizers, herbicides) even though they could be considered variable costs. In an effort to ensure consistency, costs of depreciable equipment (e.g., tractors, sprayers, fertilizer spreaders, irrigation pumps) are included with fixed costs, while those of permanent structures (e.g., irrigation ditches, roads) are included with infrastructure.

Infrastructure costs are initial capital-outlay expenses for installing features of the plantation such as buildings, drainage and irrigation systems, fencing, and roads. Charges for equipment (prorated for the use of the equipment as determined by standard budgeting techniques), materials, labor, and supervision are included. Costs of irrigation equipment, such as pumps, could be included under either infrastructure or irrigation fixed costs. We have chosen to include them with irrigation fixed costs. In the case of an irrigation system using ditches and gravity feed, there may be no irrigation fixed costs. Costs for upkeep of the infrastructure are included under **Overhead**. Some infrastructure costs do not occur in year 0 or 1. For example, a better road required for harvesting or transporting equipment may not be built until the year of the first harvest. It may be discovered that inadequate drainage was initially installed, and a bigger system may be constructed sometime after year 0. Not all projects require infrastructure expenditures; for example, a pasture could be simply plowed and then planted with short-rotation seedlings or cuttings.

Establishment costs include land clearing (shearing, piling, burning, chopping); mechanical preparation (plowing, disking, bedding, subsoiling, harrowing, other); chemical inputs (spraying for weeds, insects, and other pests; liming; fertilizers); and planting costs inclusive of seedling costs. Mechanical operations and burning have fixed, variable, and labor costs. Chemical applications and planting seedlings have material costs (e.g., fertilizers, pesticides, seedlings) in addition to fixed, variable, and labor costs. An example of the fixed cost associated with a chemical application activity is the fixed cost of the machinery (e.g., tractor, sprayer) used in the operation. Examples of the variable costs associated with a chemical operation are the costs of fuel and repairs for the machinery used. If a nursery has been established to produce seedlings or cuttings, it would be useful to develop a sub-budget of the master spreadsheet to show how the cost per 1000 seedlings or cuttings was obtained.

Once the seedlings or cuttings are planted, then **cultural management** costs occur. Included in cultural management charges are fertilizer; weed control (mowing, cultivating, and herbicides); pest control and management of browsing animals; disease control; and irrigation. Under most of these categories are a cost for materials and labor, as well as fixed and variable costs.

Overhead costs include administration; land rent (or equivalent); land and property taxes; protection (e.g., fire prevention and control); insurance; monitoring (e.g., pest control, performing soil tests for fertilizers); upkeep for buildings, drainage, fencing, irrigation, and roads; and maintaining a vehicle for traveling from the office to the site. Variable costs associated with irrigation, such as repairs, could be included with overhead, but we have chosen to include them with irrigation variable costs under cultural management. The costs for irrigation included with overhead are for maintenance of the irrigation infrastructure (e.g., ditches). Costs of maintaining buildings, drainage ditches, fencing, and roads would be included with overhead.

The importance of providing a description of the project activities cannot be overemphasized. The spreadsheet contains a number of aggregate categories, but important details are lost because of the aggregation. For example, there is an aggregate category for fertilizer, yet there are many fertilizers. The description should indicate how much nitrogen, phosphorus, potassium, sulfur, etc. was used and the form (e.g., urea) in which the chemical was applied. Machinery complements should be indicated. Difficulties encountered, such as replanting necessitated by seedling mortality, should also be listed. The spraying program used for pest control is important information. It should be determined if weed control was needed. This type of information is important in understanding why costs are what they are and can indicate areas where improvements are needed if short-rotation intensive culture of woody crops is to be a viable technology.

SRIC COST ACCOUNTING CATEGORIES

VARIABLES		UNITS	UNIT NO.	UNIT COST	YR 1 COST	UNIT NO.	UNIT COST	YR 2 COST
INFRASTRUCTURE								
FENCING		\$/m						
BUILDINGS		$\$/m^2$						
ROADS		\$/km						
IRRIGATION		\$/ha						
DRAINAGE		\$/ha						
ESTABLISHMENT								
LAND CLEARING		\$/ha						
shearing	- fixed	\$/ha						
	- var.	\$/ha						
	- labor	\$/ha						
	- total	\$/ha						
piling	- fixed	\$/ha						
	- var.	\$/ha						
	- labor	\$/ha						
	- total	\$/ha						
burning	- fixed	\$/ha						
	- var.	\$/ha						
	- labor	\$/ha						
	- total	\$/ha						
chopping	- fixed	\$/ha						
	- var.	\$/ha						
	- labor	\$/ha						
	- total	\$/ha						
LAND PREP								
plowing	- fixed	\$/ha						
	- var.	\$/ha						
	- labor	\$/ha						
	- total	\$/ha						
disking	- fixed	\$/ha						
	- var.	\$/ha						
	- labor	\$/ha						
	- total	\$/ha						
bedding	- fixed	\$/ha						
	- var.	\$/ha						
	- labor	\$/ha						
	- total	\$/ha						
subsoiling	- fixed	\$/ha						
	- var.	\$/ha						
	- labor	\$/ha						
	- total	\$/ha						

SRIC COST ACCOUNTING CATEGORIES (cont.)

VARIABLES		UNITS	UNIT NO.	UNIT COST	YR 1 COST	UNIT NO.	UNIT COST	YR 2 COST
harrowing	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
	- total	$/ha						
ditching	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
	- total	$/ha						
tiling	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
	- total	$/ha						
herbicide	- mater.	$/ha						
	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
	- total	$/ha						
liming	- mater.	$/ha						
	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
fertilize	- mater.	$/ha						
	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
	- total	$/ha						
PLANTING								
seedlings	- fixed	$/1000						
	- var.	$/1000						
	- labor	$/1000						
	- total	$/1000						
establish	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
	- total	$/ha						

SRIC COST ACCOUNTING CATEGORIES (cont.)

VARIABLES		UNITS	UNIT NO.	UNIT COST	YR 1 COST	UNIT NO.	UNIT COST	YR 2 COST
CULTURAL MANAGEMENT								
FERTILIZER	- mater.	$/ha						
	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
	- total	$/ha						
WEED CONTROL								
mowing	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
	- total	$/ha						
cultivate	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
	- total	$/ha						
herbicide	- mater.	$/ha						
	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
	- total	$/ha						
PEST CONTROL								
insects	- mater.	$/ha						
	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
	- total	$/ha						
disease	- mater.	$/ha						
	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
	- total	$/ha						
browse	- mater.	$/ha						
	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
	- total	$/ha						

SRIC COST ACCOUNTING CATEGORIES (cont.)

VARIABLES		UNITS	UNIT NO.	UNIT COST	YR 1 COST	UNIT NO.	UNIT COST	YR 2 COST
IRRIGATION								
irrigate	- mater.	$/ha						
	- fixed	$/ha						
	- var.	$/ha						
	- labor	$/ha						
	- total	$/ha						
OVERHEAD								
ADMINISTRATION		$/ha						
LAND RENT		$/ha						
LAND TAXES		$/ha						
PROTECTION		$/ha						
ROAD MAINT		$/ha						
IRRIGATION		$/ha						
FENCING		$/ha-cm						
MONITORING		$/ha						
INSURANCE		$/ha						

Var. = variable.
Mater. = materials.

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