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**The Short-Rotation
Woody-Crops Program:
1982 Program Summary**

J. W. Ranney
J. H. Cushman
J. L. Trimble

ENVIRONMENTAL SCIENCES DIVISION
Publication No. 2036

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THE SHORT-ROTATION WOODY-CROPS PROGRAM:

1982 PROGRAM SUMMARY

J. W. Ranney
J. H. Cushman
J. L. Trimble

MASTER

ENVIRONMENTAL SCIENCES DIVISION
Publication No. 2036

NOTICE This document contains information of a preliminary nature.
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ABSTRACT

RANNEY, J. W., J. H. CUSHMAN, and J. L. TRIMBLE. 1982.
The Short Rotation Woody Crops Program: 1982 Program
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This report describes the Short Rotation Woody Crops Program, a national program of basic research on the short-rotation intensive culture of trees and shrubs sponsored by the U.S. Department of Energy's Biomass Energy Technology Division with field management by the Environmental Sciences Division of Oak Ridge National Laboratory. The general objective and overall approach of the program are discussed, and the status, specific goals, and recent results of the three major research areas are presented. The report concludes with brief summaries of the individual research projects in the program.

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EXECUTIVE SUMMARY

Ideally, an energy resource occurs in large quantities close to its point of use and a continuous supply is assured for a long period of time. Considering wood for energy in light of this ideal led to the development of the concept of short-rotation intensive culture (SRIC) of woody plants. The successful application of SRIC will complement existing wood resources by creating new and stable supplies of wood where they are needed. This additional supply of wood is important in the development of wood energy systems, because it can assure the long-term supplies of feedstocks that capital investments in wood energy systems require.

Short-rotation intensive culture relies on dense spacings of fast-growing hardwood species on well-prepared land, using fertilizers, herbicides, and other agronomic techniques to maximize the growth rate of the trees and shrubs. In contrast to conventional forestry, which commonly carries investments 25 to 30 years before realizing any return, the closely spaced trees in SRIC are harvested every 3 to 10 years to capitalize on fast early growth and to realize early return on investment. Replanting costs are avoided by encouraging stumps to resprout vigorously. Reestablishment by stump sprouts (coppice growth) is a key aspect of SRIC. It saves time, money, and energy, but does place restrictions on the types of trees that can be used. Hardwoods (deciduous trees) and shrubs generally grow much better from stumps than softwoods (conifers). However, hardwoods as a group have received very little study compared to softwoods in forestry research programs

in the United States. For most species, information about planting techniques, early growth rates, and regrowth rates following stump sprouting is notably absent.

RESEARCH IN THE SHORT ROTATION WOODY CROPS PROGRAM

Research on short-rotation silviculture began in the late 1960s. The early studies were small, scattered, and generally directed toward producing biomass for non-energy uses. However, results were promising enough to start a research program in earnest in 1978, when the importance of biomass as a renewable energy resource was recognized. The Department of Energy's (DOE) Short Rotation Woody Crops Program (SRWCP) is the only national program studying SRIC in the United States. The Environmental Sciences Division at Oak Ridge National Laboratory has managed this program for the DOE's Biomass Energy Technology Division since the program's beginning. With help from the USDA Forest Service, industry, and universities, the SRWCP has identified the following major areas where research is needed to support the development of short-rotation intensive culture.

1. Genetic selection and improvement of woody species.
2. Determination of the optimum relationships between plant spacing and timing of harvests for maximum productivity.
3. Determination of the effects of fertilizer, weed control, irrigation, and other strategies on productivity.
4. Identification of risks from pests and diseases to minimize losses.

5. Economic evaluations, including sensitivity analyses, to determine the conditions for economic viability and to guide research.
6. Design of harvesting equipment for small-sized woody material.

RESEARCH RESULTS

Potential improvements in productivity through careful selection of hardy fast-growing trees now appear greater than first believed. The University of Washington has developed a hybrid cottonwood which produces about 22.5 dry Mg ha⁻¹ year⁻¹ (10.0 dry tons acre⁻¹ year⁻¹) over a three-year period, more than double normal productivity. Even higher productivity rates are being achieved in Florida and Hawaii with species of eucalyptus. In general, results across the country show that the average productivity of short-rotation stands can be doubled just by selecting and using appropriate varieties and species. Nationally, 25 species have been identified as good candidates for short-rotation intensive culture, and some of them are now undergoing further genetic selection for strains showing higher productivity and hardiness.

Fertilizers and weed control appear mandatory for ensuring the success of short-rotation intensive culture crops. Experiments at Pennsylvania State University demonstrated that productivity can be doubled using the proper combination of fertilizer and weed control, more than recovering their costs. In contrast, increases in productivity from irrigation did not justify the investment required for the irrigation system. SRWCP projects across the country found

that fertilizers and weed control are needed in most situations to ensure good crops, and the most economical levels to apply are now being determined.

A large amount of research has been directed toward developing techniques for ensuring successful establishment and rapid early growth. Much progress has been made, and researchers can now expect 90 to 95% plantlet survival, with rapid early growth, under a wide variety of experimental conditions. However, experience indicates some additional experimentation will be needed to adapt techniques developed on research plots to large-scale field plantings.

All existing economic studies on SRIC are dominated by major assumptions about long-term SRIC productivity rates, because few data are available on regrowth after repeated cutting. Plantings in most studies started under the SRWCP were recently harvested for the first time, and critical questions remain about productivity rates in later growing cycles. Except for sycamore and poplar almost nothing is known about the survival and growth of woody species through repeated cycles of cutting and regrowth. The research which will give us this information is well under way, but several more years of monitoring and measuring are needed to collect the data that will allow us to determine the feasibility of the short-rotation concept.

The risks of losing crops to pests, diseases, and unusual weather are also poorly understood. Because an understanding of risks is necessary for evaluating the viability and possible use of short-rotation intensive culture, SRWCP research includes monitoring the effects of pests, diseases, and weather.

Harvesting short-rotation trees and shrubs offers problems for equipment design. At harvest, SRIC material will be too large for existing agricultural machinery but too small for conventional tree harvesters. In addition, the stumps must remain in relatively good condition to enable resprouting. Conceptual designs for short-rotation harvesters were developed and are being tested at Virginia Polytechnic Institute and State University in concert with the USDA Forest Service, the pulp and paper industry, and the International Energy Agency. Prototype construction is not planned as part of the SRWCP, although field testing will eventually be necessary.

It is now clear that the economic feasibility of short-rotation intensive culture depends on factors that are either very site specific or largely undefined, or both. The most significant of the undefined factors are (1) the cost of harvesting, which may reach 25 to 60% of the total costs, (2) productivity levels through repeated cuttings, and (3) the risks of partial and total crop failure. If commercial operations could achieve the same levels of productivity as experimental field plots, they should be feasible now in a number of places. At Kansas State University a preliminary economic study found that short-rotation wood as a source of energy would be cheaper than fuel oil and competitive with natural gas at \$2.20/million Btu's. Another study in Illinois showed that wood produced under SRIC would be competitive only with fuel oil. Oak Ridge National Laboratory is developing a system for evaluating different short-rotation intensive culture approaches around the country on a common basis, and all

projects in the SRWCP are collecting cost and productivity data to merge into an economic assessment of short-rotation intensive culture in the next few years.

RECOMMENDATIONS

Existing research on short-rotation intensive culture is at a critical and very productive stage. Five years have been invested in establishing field plots and growing trees to the point of first harvest. Data obtained from stand regrowth will enable researchers to assess the overall viability of the short-rotation intensive culture concept, because productivity figures and cost estimates will finally be available for a wide range of species and sites. SRWCP research has already produced a much better understanding of cultural requirements and productivity rates for young SRIC stands, but the studies now beginning on sprout regrowth after first harvest are critical to the viability of the SRIC concept.

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1.0 INTRODUCTION

This report provides a summary of the Short Rotation Woody Crops Program (SRWCP) sponsored by the Biomass Energy Technology Division of the U.S. Department of Energy (DOE) with field management by the Environmental Sciences Division of Oak Ridge National Laboratory (ORNL). The report, designed to serve as an introduction to the SRWCP, presents the program's objectives, approach, and research activities.

The SRWCP is an integrated program of research on a single concept, the short-rotation intensive culture (SRIC) of hardwood trees and shrubs. SRIC relies on using selected fast-growing species, fertilizers, weed control, and other agronomic techniques applied to trees and shrubs to maximize their rate of biomass production. The SRIC concept also includes harvests as often as every 3 to 10 years, followed by regrowth from the existing stumps.

Conceptually SRIC appears promising, especially in the face of a decreasing land base and increasing demands for all types of biomass products. But major questions remain about the biological productivity rates, costs, risks, and profits of short-rotation systems.

Seeking to answer some of these questions and to improve the productivity and increase the cost efficiency of growing woody plants for fuel and petrochemical substitutes, DOE issued a Program Research and Development Announcement (PRDA) on fuels from woody biomass in late 1977. The PRDA asked for research proposals in three major areas: (1) the selection of species with promise for SRIC; (2) stand establishment and management strategies for SRIC; and (3) harvest, collection,

transportation, and storage strategies for SRIC. In a competitive technical review, 25 of the proposed projects were chosen to form a new research program. The SRWCP, then called the Fuels and Chemicals from Woody Biomass Program, began with those projects. Although some of the original projects have ended and new ones have begun, the long-term research projects dating to the original PRDA still form the core of the SRWCP.

The SRWCP is a national program of basic research on SRIC. It relies heavily on field studies located in the regions that appear to have significant areas of land suitable for SRIC. Because climatic and site conditions vary greatly across the United States, regional approaches to SRIC also vary and a large number of sites and systems must be examined before the results can be generalized with any confidence. The program is designed so information will flow among all research areas and projects. The linkages among them are absolutely necessary for testing and improving the SRIC concept as quickly as possible.

Coordinating research on SRIC in a single program permits efficient use of the research funds required to produce the information needed to assess SRIC on a national basis. The research itself benefits because SRIC systems and SRIC research across the country have elements in common and investigators from all the research projects meet regularly to exchange information about their latest problems and progress. The ultimate assessment of SRIC as a biomass-producing technology also benefits because the research projects have been designed to provide consistent results at nearly the same time. Any research on tree

growth, even research systems designed for quick returns, takes time. Synchronizing SRIC research across the country will minimize the amount of time that must pass before the costs and benefits of SRIC can be evaluated.

Oak Ridge National Laboratory is conducting in-house economic and ecological research to support program-wide planning and coordination in the SRWCP. The economic studies involve the development and application of an analysis system for subcontracted field research. This work, undertaken jointly by the Environmental Sciences Division and the Energy Division, is preparing consistent economic evaluations and sensitivity analyses of SRWCP projects using a methodology that recognizes the interactions between biological processes and economic constraints. Results from the research will be used to evaluate the status of short-rotation intensive silviculture as a biomass-producing technology and to guide program research directions.

The Environmental Sciences Division is also conducting field research on nutrient movement in woody biomass production systems. The objectives are to increase understanding of basic processes affecting the management of short-rotation systems and to evaluate the environmental implications of intensifying woody biomass production and harvesting. Research results from these studies are coordinated with the Department of Energy's Biomass Energy Technology Division through the Division's Program Manager for Environmental Studies.

This report is divided into six major parts. The first discusses the general objective of the SRWCP, and the second describes the approach being taken in the SRWCP to reach that objective. The

next three sections cover the three major research areas in the SRWCP, discussing their status, their specific research goals, and some recent research results. The final section contains brief summaries of the individual research projects in the program.

2.0 PROGRAM OBJECTIVES

The overall objective of the SRWCP is to attain high productivity rates at competitive prices. This requires that research define the potential productivity of woody species under intensive culture and that it improve the productivity and increase the cost efficiency of SRIC systems. Specific goals, listed below, have been established for each of the major research areas in the SRWCP.

1. The objective of the species selection research is to improve the productivity of SRIC through genetic studies, including testing, selecting, and developing species and strains of trees and shrubs for use in intensively managed systems.
2. The objective of the stand management research is to improve the productivity and decrease the costs of SRIC by developing effective and efficient techniques for SRIC stand establishment and management.
3. The objective of the economic studies is to increase the cost efficiency of SRIC by integrating economic considerations into SRIC system design and research planning.

Achievement of these objectives will be measured by:

1. defining SRIC systems suitable for a range of available sites across the country and establishing their baseline costs and biological productivities,
2. developing SRIC systems whose technical and economic readiness for producing woody biomass can be demonstrated, and
3. industry use of SRIC techniques for energy production.

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3.0 APPROACH

Resource management is the key to maintaining a supply of wood for energy. In the face of declining forest acreages and projected increases in demands for all types of wood products, SRIC may become an important management approach. SRIC has as its objective producing the maximum sustainable amount of wood per unit of land each year. SRIC systems adjusted to local conditions would permit wood to be grown where needed, using available sites. It would require the least amount of land of all forest management approaches.

Realizing the potential of wood as an energy feedstock, the U.S. Department of Energy started the SRWCP in 1978 to examine the possibilities for SRIC across the country and to improve the biological productivity and economic efficiency of SRIC systems. Prior to the SRWCP, experience with SRIC was limited to a few species on a few types of sites. The SRWCP was designed to provide baseline information about a much larger range of species and sites and to improve the productivity and efficiency of those systems. Most of the research projects are at universities, although some of the research is being done by private corporations and some by the USDA Forest Service. Figure 3.1 shows the locations of the active SRWCP research projects. The SRWCP is now providing a comprehensive, consistent data base on SRIC. It is already possible to draw some conclusions about early SRIC productivity from SRWCP research. Most of the field studies supported by the SRWCP are now 4 years old, and their experimental plantings are reaching the projected age of first harvest. The SRWCP data base will be even

SHORT ROTATION WOODY CROPS PROGRAM

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Fig. 3.1. Location of research projects in the Short Rotation Woody Crops Program.

more valuable as these research plots are harvested and their regrowth is recorded and compared.

There are three major research areas in the SRWCP: (1) species selection, (2) stand management, and (3) economic studies. Figure 3.2 shows the structure of the program and the individual research projects in each area. The specific objectives of each research area are discussed in later sections. By 1987 four major products will be produced by the program as a whole. These products, which will integrate information from all three research areas, are:

1. a definition of the conditions under which SRIC is economically viable,
2. descriptions of the most promising SRIC systems for each region and comparisons among regional outlooks for SRIC,
3. a national estimate of the biomass production potential of SRIC, and
4. a discussion of the major assumptions used to produce item (3) and the information still needed to verify them.

Considerable field experimentation and economic evaluation are still required to create these products. However, intermediate products, including a bank of information on species/site relationships, are already being produced. Cost and risk analyses for SRIC systems will be a continuing part of program management and research planning.

Fig. 3.2. Three major subject areas for research projects in the Short Rotation Woody Crops Program.

The research on stand management is complex enough to warrant further description here. Figure 3.3 diagrams the subjects covered in this area, which contains the majority of research in the SRWCP and is also the critical time path in attaining the program's objective. Stand management research is studying the relationships among site types, species, management approaches, and productivity rates. The economic viability of SRIC systems will depend on the productivity rates attained and the costs of the management systems used to reach them. Until these relationships are defined for a range of regions, sites, and species, predictions about SRIC will remain speculative and uncertain. Figure 3.4 shows the flow of information among tasks through the projected life span of the SRWCP and emphasizes the central position of the biological results from the stand management studies in the overall program.

Fig. 3.3. Subtasks in the stand management area within the Short Rotation Woody.

Fig. 3.4. Information flow among tasks in the Short Rotation Woody Crops Program. Projected time frames for results from specific projects and regions.

4.0 SPECIES SELECTION STUDIES

4.1 APPROACH

The species screening and genetic selection studies are designed to improve the productivity of SRIC by identifying superior species, strains, and hybrids of trees and shrubs for intensively managed systems. Selection work is proceeding at several levels. Many species that appear to have desirable characteristics have never been grown under intensive culture before and are now being tested for the first time. Some species that appeared promising in early SRIC trials are being examined in more detail in studies designed to determine the amount of genetic diversity available for selection. Experimental hybridization is also being used to produce strains with traits especially valuable in SRIC.

The goals of the four major stages of selection studies are to:

1. identify the best woody species for SRIC systems in each major region of the United States that appears to have potential for supporting SRIC,
2. define the genetic diversity within promising species to identify the possibilities for further improvement,
3. select strains within species or hybridize species for traits valuable in short-rotation systems, and
4. test the selected species, strains, and hybrids for production under intensive management on a range of sites.

4.2 RESULTS AND IMPLICATIONS

The results from first-generation genetic selection studies in the SRWCP give an indication of improvements in productivity which may be possible using selected stock. Table 4.1 summarizes these tests, in which the best individuals grew almost 50% more than average. Later generations of selection studies could easily raise this figure. Of special significance are the results from Mississippi on sycamore. They indicate selection for disease resistance could improve productivity by 17%, and selection for dry matter production could add an additional 10 to 25% to yield a total increase of 27 to 42% above current average yields. Selection may offer such improvements for other species too, although the range of possible improvements is not known for the vast majority of hardwood species and sites. Genetic studies related to tree improvement hold great promise and have a high research priority. They may become even more important if conversion processes sensitive to wood components are developed and if genetic studies become the link between biomass production and its end uses.

Table 4.1. Anticipated and realized production gains through genetic selection

Species	Location	Percent production gain	Variable
Sycamore	Mississippi	17	Disease resistance
Sycamore	Mississippi	10	Dry matter productivity
Sycamore	Mississippi	25	Dry matter productivity
Slash pine	Florida	90	Extractive productivity
Eucalyptus	Florida	50	Volume
Sand pine	Florida	83	Energy content
Black cottonwood	Washington	47	Dry matter productivity
Black cottonwood	Washington	50	Dry matter productivity
Mesquite	California	50	Dry matter productivity
Eucalyptus	Hawaii	15	Volume
Hybrid poplar	Vermont	100	Dry matter productivity

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5.0 STAND MANAGEMENT STUDIES

5.1 APPROACH

Stand management studies are improving the productivities and decreasing the costs of SRIC by developing efficient techniques for establishing and maintaining SRIC systems. This area contains the largest number of individual research projects in the SRWCP and covers the largest number of research topics.

Stand management research is being performed in different regions and on different sites. Therefore, even projects covering the same subjects are not duplicating work but are producing complementary information which will be very important in assessing and improving the economic efficiencies of SRIC. The data linking specific management practices and their costs to productivity rates will later be used in economic studies to evaluate SRIC systems and their components.

The specific goals of the SRWCP stand management research, listed below, will all lead to information needed to evaluate SRIC as a biological and economic concept.

1. Develop procedures that permit a high degree of genetic control for the mass propagation of planting material.
2. Develop and improve techniques for ensuring high survival and rapid early growth of newly planted seedlings and cuttings.
3. Identify the most efficient means for controlling competing vegetation in SRIC.
4. Determine the most cost-effective systems for using fertilizers in SRIC.

5. Determine the costs and benefits of using irrigation in SRIC.
6. Determine the relationships among species, spacing, rotation length, and production in SRIC.
7. Determine the major pests and diseases in SRIC systems and develop ways to control them.

5.2 RESULTS AND IMPLICATIONS

The productivity rates seen to date in over 350 different tests of SRIC are presented in Fig. 5.1. These rates are the results of the first SRIC studies in the United States and in many cases do not include rates of coppice regrowth because the stands are not yet old enough. The productivity rates in Fig. 5.1, average 6 dry Mg ha⁻¹ year⁻¹ (2.64 dry tons acre⁻¹ year⁻¹).

Although these rates are low compared to some predictions for SRIC, they do not mean the predictions are misleading. Learning from mistakes and taking advantage of successes should rapidly improve the average productivity rates in ongoing studies. Concentrating on the best management techniques from the early studies should make later figures at least 125% higher. The results shown in Fig. 5.1 are based on a wide variety of sites, generally unimproved stock, and a wide variety of spacings, ages, fertilizer levels, and weed control regimes. All these factors offer ways to improve productivity or lower costs. Figure 5.2 geographically displays the productivity rates used to make Fig. 5.1 show regional differences. Figure 5.3 shows the projected productivity rates that species screening and stand management research indicate should be possible for a wide range of sites and species.

Fig. 5.1. SRIC productivity rates observed in the United States.

Fig. 5.2. Woody biomass productivity commonly achieved on sites of moderate quality.

Fig. 5.3. Possible productivity rates for large-scale short-rotation intensive silviculture, assuming improvements from genetics, species selection, and management practices.

Weed control in SRIC, as in agriculture, has proven critical for maximizing productivity per unit land. During the first few growing seasons, chemical or mechanical weed control appears mandatory and can improve productivity by as much as 100% over plots receiving only preplanting weed control. Lack of any weed control treatment often leads to the total failure of hardwood crops.

Fertilizers are also almost mandatory for achieving high productivity levels. Figure 5.4 shows the effect of fertilizer on productivity rates over a wide range of site types, climates, and management approaches. The figure suggests productivity can be more than doubled over the first 4 or 5 years, and results from specific experiments indicate that the increase levels off at rotation ages above 5 to 8 years.

Improvements in productivity can also be made through careful spacing of crops and timing of harvests. For the most efficient use of a site, both of these factors must be directly tied to the growth rate of the trees. Experimental results suggest that spacings of 2 m or more between trees, and harvests around 8 years apart yield the most biomass. Harvests of coppice regrowth (stump sprouts) are expected to yield 30% more biomass per year of growth than the first harvest, but data are so limited that generalizations are probably very inaccurate. Because information on coppice growth is important for evaluating SRIC, coppice regrowth cycles are the focus of much attention in current SRWCP research.

Fig. 5.4. Data from research projects in the Short Rotation Woody Crops Program. Effect of fertilizer on productivity rates.

Diseases and pests have been only minor problems in SRIC to date, but they are expected to become more common as hardwood plantations become larger, older, and more widespread. If not controlled, they could cause significant decreases in productivity. The SRWCP research projects are constantly monitoring for pest and disease problems, and integrated pest management research is expected to be a continuing part of program research.

6.0 ECONOMIC STUDIES

6.1 APPROACH

The major objective of the economic studies in the SRWCP is to increase the cost efficiencies of SRIC systems by integrating economic considerations into system design and research planning. Specific goals for this subject area include:

1. identifying and defining the expenses associated with SRIC,
2. determining the relative economic importance of the different components of SRIC systems,
3. defining the critical range of variation for each major economic component of SRIC, and
4. determining the site-specific revenue requirements for selected short-rotation woody biomass production systems.

This is the smallest and newest research area in the SRWCP. It was originally called "harvest, collection, transportation, and storage of biomass" and still includes studies that are not in themselves economic analyses but that are producing information needed to evaluate the economics of SRIC.

6.2 RESULTS AND IMPLICATIONS

Existing studies of SRIC economics have been specific to particular systems and sites and have been based on different sets of assumptions. However, some have included sensitivity analyses that help define the relative economic importance of the different components of SRIC systems. Because there have been very few studies to date, generalizations from the sensitivity analyses are probably more useful at this point than the specific projections of costs or profits.

The sensitivity analyses have consistently identified several factors as having the significant effects on the economic viability of the total system. In summary, the sensitivity analyses show the following.

1. The costs of the entire system are most sensitive to land costs, harvesting costs, and productivity rates.
2. The total cost of site preparation, planting, and management is significant, but changes in a single operation, except irrigation, generally make little difference in overall costs.

Table 6.1, derived from Mittelhauser Corporation's preliminary studies for the SRWCP, shows the results of a typical sensitivity analysis. Doubling management and equipment costs has little effect on the final price of the biomass product, assuming all other items remain unchanged. Irrigation, on the other hand, is prohibitively expensive and requires that the price be raised 38% to cover its costs. Even if irrigation increased productivity by 20%, the price of biomass would have to be raised. Under these circumstances irrigation would not pay for itself; however, if productivity could be increased by 20% by doubling management costs, the price of the biomass could be reduced by roughly 5%. This change would be advantageous. SRWCP stand management research is now defining the relationships between investments in management (costs) and productivity (returns). Cost analysis, including extensive sensitivity analysis, will be used to develop economically efficient systems for using the available management practices in SRIC.

Table 6.1. A typical sensitivity analysis showing the effects of changing individual components of a proposed SRIC system

Change from base case	Price impact (% change)
Doubling management costs	+3.5
Doubling equipment investment	+2.5
Adding irrigation system	+38.0
Changing land price from \$815/ha	
to \$2500/ha	+25.4
to \$250/ha	-7.8
Increasing yield by 20%	-9.2
Decreasing yield by 20%	+13.7

Existing cost studies underscore the limits of our current ability to make forecasts about SRIC. Our estimates for some of the most important factors are quite tentative, and we have almost no information about their variability. Land costs and product values can be estimated for specific situations with a degree of certainty, but they change across the country, and they become more uncertain when projected into the future. Harvesting costs are very important but remain uncertain because short-rotation harvesting systems have been proposed but none has yet been fully developed. Finally, the productivity rates achieved under an array of management systems are still variable and somewhat unclear, and we have very little information about productivity rates in coppice growth. More extensive data on coppice growth are

still several years away; yet coppice regrowth is essential to the SRIC concept and must be considered in calculating SRIC costs.

We are now also beginning to estimate the risks associated with SRIC. Disease losses are being quantified for some species, but many of the species being considered for SRIC have never been grown under intensive management, and levels of possible loss to drought, temporary defoliation by insects, intermediate levels of plantlet survival, and poor sprouting success are completely unknown. These risks carry with them costs that must be incorporated into product prices but that at this point can only be estimated.

In summary, the economic feasibility of short-rotation intensive culture depends on factors that are either very site specific or largely undefined, or both. If SRIC systems could be depended on to produce biomass at the levels now predicted by some experimental results, they would now be economically feasible in a number of places for a number of uses. However, many critical questions still remain. Those related to productivity and harvesting costs can be answered only with agricultural or silvicultural research of the type now found in the SRWCP. Others, particularly those related to end uses and product prices, will depend on technological developments in energy conversion and on future wood and energy markets.

7.0 PROJECT SUMMARIES

7.1 SPECIES SELECTION PROJECT SUMMARIES

The University of Alaska is evaluating selected hardwood species for intensive biomass production on a range of sites in interior Alaska. Six native species, chosen in 1981, will be established on four sites throughout the state in 1982, and species/site interactions will be addressed. Genetic variation within a species will be examined to identify potential production improvements. In addition, selected species will be evaluated for chemical defenses against browsing by small mammals.

The University of Arizona is preparing a comprehensive literature review on woody plants in the semiarid Southwest to identify the most promising species for biomass production in this region. These species will be tested and selection will be based on productivity, site adaptability, ability to coppice, and resistance to pests and diseases. Field tests are being established in 1982 at three sites using Prosopis spp. and Acacia spp.

Michigan State University has been evaluating over 20 species for maximum biomass production on a range of sites since 1979. To date, several promising species (European black alder, hybrid poplar, and hybrid pine) have been identified and species/site interactions have been investigated. Guidelines for plantation establishment and management are being developed for cutover sites and old fields. Additional project emphasis is on genetic improvement and economic analyses.

Mississippi State University has measured genetic variation in biomass yields and disease resistance for sycamore in the Mid-South. Genetically superior seed sources and progenies have been identified for both biomass production and disease resistance. Productivity rates for seed sources planted at 9 m^2 (94 ft^2) per plant have been estimated at $5.5 \text{ dry Mg ha}^{-1} \text{ year}^{-1}$ ($2.4 \text{ dry tons acre}^{-1} \text{ year}^{-1}$). Regression equations for predicting biomass from standing tree measurements have been developed and are being verified. A final report, due in June 1982, will summarize the 3 years of research in this project.

The USDA-Forest Service, Pacific Northwest Forest and Range Experiment Station is evaluating the response of red alder, a promising species for biomass production in the Pacific Northwest, to a variety of cultural practices. The genetic variability of the species, including broad geographic differences and variation in natural populations will be examined in this project, which started in 1981. Data will be collected on soil/site and productivity relationships to aid in site selection and prediction of relative yield for short-rotation alder plantations.

Utah State University, in a project now in its final year of research, has studied six native shrubs for biomass production on arid and semiarid lands of the Southwest. Biotypes from a variety of native shrub populations were selected, propagated, and established on dry-land sites. The following conclusions have resulted from this research: (1) biotypes of shrub species must be grown in areas where they are adapted; (2) further study is needed to determine the optimum rotation length; and (3) substantial productivity rates may be achieved

(5.2 dry Mg ha⁻¹ year⁻¹ or 2.3 dry tons acre⁻¹ year⁻¹) from shrubs grown at close spacings and with minimal management on dry-land sites.

The University of Vermont is evaluating the feasibility of short-rotation intensive culture of selected hardwood species on marginal agricultural lands in the Northeast. Since this project began in 1979, 15 species of trees and seven clones of hybrid poplar have been screened for biomass production on a variety of sites throughout Vermont and New York. Various weed control methods, fertilizer levels, and management techniques are being evaluated. To date, the most promising species are hybrid poplar and black locust, with productivity rates of 10.4 dry Mg ha⁻¹ year⁻¹ (4.6 dry tons acre⁻¹ year⁻¹) and 10.8 dry Mg ha⁻¹ year⁻¹ (4.8 dry tons acre⁻¹ year⁻¹), respectively. Additional tasks include an assessment of land availability for biomass plantations and a study of the economic feasibility of short-rotation silviculture in the Northeast.

The University of Washington, in conjunction with Washington State University, is studying the genetic improvement of black cottonwood for biomass production. Fifty-five clones, 10,500 open-pollinated seedlings, and 3,414 black cottonwood hybrids are being evaluated for rapid growth, disease resistance, and site adaptability. To date, a hybrid black cottonwood with eastern cottonwood is the most promising for short-rotation silviculture. After two growing seasons a productivity rate of 14.4 dry Mg ha⁻¹ year⁻¹ (6.3 dry tons acre⁻¹ year⁻¹) was achieved.

7.2 STAND MANAGEMENT PROJECT SUMMARIES

The University of Arkansas, in a cooperative study with the USDA-Forest Service and Georgia Pacific Corporation, has characterized and quantified understory wood biomass in natural southern pine stands. Forty plots were established in two forest types (pine and pine-hardwood), two density classes (high and low), and two site classes (good and poor) in southern Arkansas and northern Louisiana. All sites have been harvested and the data have been collected. The average understory biomass production for all sites is $23.4 \text{ dry Mg ha}^{-1}$ ($10.3 \text{ dry tons acre}^{-1}$) with a range of 2.2 to $57.6 \text{ dry Mg ha}^{-1}$ ($0.97 \text{ to } 25.3 \text{ dry tons acre}^{-1}$). The highest average yield, $32.1 \text{ dry Mg ha}^{-1}$ ($14.1 \text{ dry tons acre}^{-1}$), was harvested from a poor, high density, predominantly pine site. The forthcoming final report will summarize project results and will address the long-term impact of periodic harvests of understory biomass on site productivity.

The BioEnergy Development Corporation in Hilo, Hawaii, is evaluating Eucalyptus as a source of biomass fuel. BioEnergy has planted over 500 acres of Eucalyptus on the island of Hawaii. Approximately 30% of the acreage [60 ha (150 acres)] is being utilized for plantation establishment studies including fertilizer, herbicide, and spacing trials. The remaining acreage is being monitored for economic analysis and for future large-scale harvesting trials. The greatest growth, over 6.0 m (19.7 ft) in one year, has been achieved on fertilized sites. Productivity rates are being estimated at $40 \text{ dry Mg ha}^{-1} \text{ year}^{-1}$ ($17.6 \text{ dry tons acre}^{-1} \text{ year}^{-1}$). This project is scheduled for completion at the end of 1983.

The University of Florida is evaluating seven native and exotic woody species for biomass production. This interdisciplinary research effort, which started in 1979 and is scheduled to end in 1983, includes: assessment of land availability, intraspecific genetic selection, species screening, evaluation of cultural treatments and management regimes, and economic analysis of short-rotation intensive silviculture. A statewide survey of land availability and quality has been completed. To date, eight sites have been planted throughout the state, and data on genetic improvement, fertilizer responses, growth rates, and water use are being collected. Preliminary estimates of biomass productivity by selected Eucalyptus progenies exceed 13.0 dry Mg ha⁻¹ year⁻¹ (5.7 dry tons acre⁻¹ year⁻¹), and with the addition of high nitrogen fertilizers productivity may exceed 20.0 dry Mg ha⁻¹ year⁻¹ (8.8 dry tons acre⁻¹ year⁻¹) on selected sites.

The University of Georgia (W. L. Nutter, Principal Investigator) is evaluating biomass production of five hardwood species in short-rotation plantations irrigated with municipal sewage effluent. This project is a cooperative effort between the university and the Clayton County (Georgia) Water Authority, which operates the largest land treatment system in the United States devoted to forest production. The goal of this project is to provide information regarding species establishment and suitability for large-scale plantations at land treatment sites. The project began in 1981 and is scheduled to end in 1986.

The University of Georgia (K. Steinbeck, Principal Investigator) is investigating means of increasing the biomass production in short-rotation intensive systems through species admixtures, fertilization,

and cultural practices. In addition, techniques for cloning genetically superior hardwoods are being developed. Two plantations of 20 ha (50 acres) each have been established, one in the Coastal Plain and one in the Piedmont of Georgia. Height growth of 6.0 m (19.7 ft) has been achieved after three growing seasons. The mass cloning program using tissue culture techniques has produced fully rooted plantlets with survival rates of over 90%. Harvesting equipment was obtained and 4-year-old stands were harvested in the winter of 1981-1982.

The University of Houston is evaluating the Chinese tallow tree as a species for intensive silviculture along the Gulf Coast. Stand establishment and cultural practices such as spacing, fertilization, and weed control are being studied. After 3 years of study it may be concluded that fertilizer application is critical to the rate of growth of young trees and that trees planted at closer spacings (0.3 m^2 or 4 ft^2 per tree) accumulated about two to four times the biomass of wider spacings (1.4 m^2 or 16 ft^2 per tree). Productivity in closely spaced, fertilized plots is $8.06 \text{ dry Mg ha}^{-1} \text{ year}^{-1}$ ($3.5 \text{ dry tons acre}^{-1} \text{ year}^{-1}$). Additional studies are emphasizing direct seeding techniques and coppicing practices. Genetic variability is being studied, and superior individuals are being selected from natural populations for propagation and field planting.

The University of Illinois is evaluating the feasibility of using marginal agricultural lands for short-rotation woody biomass production. This project emphasizes sites typical of marginal agricultural lands that are currently nonproductive. Seven hardwood species are being evaluated under a variety of spacings, rotation lengths, and

cultural treatments. Results to date include preliminary information on growth under a variety of techniques for establishment and management of biomass plantations. This information will be incorporated into an economic analysis of biomass production systems when the experimental plantings have matured enough to produce the necessary data. Extensive herbicide trials have been conducted, and appropriate treatments have been identified for various species and site types. This project will be completed in 1984.

Kansas State University is determining the biomass yields, financial and energy balances, and herbicide sensitivity of selected hardwood species in short-rotation intensive systems. After three growing seasons, black locust, cottonwood, silver maple, and Siberian elm show rapid growth and a high rate of survival. From preliminary results it appears that a rotation length of 5 or more years and spacings of 1.8 to 2.4 m (6.0 to 8.0 ft) are desirable for short-rotation culture in this region. Several herbicides are effective in controlling the weed populations, but mechanical cultivation resulted in less tree mortality.

Michigan Technological University is determining the feasibility of converting existing pole-size maple stands (sugar maple and red maple) to short-rotation plantations using black locust as an interplanted species. Three forested sites, representing high, medium, and low productivity levels, were clear-cut commercially. Plots were interplanted with black locust and fertilized with nitrogen, phosphorus, and potassium. Significant differences have been identified in stump sprout productivity by site, species, time of fertilizer application,

and tree diameter. The symbiotic association of black locust with Rhizobium, the nitrogen-fixing bacterium, is being studied. Selected strains of the bacterium may enhance the productivity of black locust.

The University of Minnesota is evaluating the potential of peatland areas for woody biomass production. The principal objectives of this project are as follows: (1) evaluate the productivity of natural stands, (2) develop propagation techniques for exotic and native willows and alders, (3) establish a nursery on wetland soils, (4) establish biomass plantations on wetland soils to evaluate the yield of selected clones, and (5) determine the potential of wetland soils for woody biomass production. Two objectives have been completed: the determination of natural stand productivity and the evaluation of wetland potential for woody biomass production. Over 60,000 willow plantlets have been propagated via tissue culture. An additional 15,000 willows have been propagated by cuttings, including several species that have been very productive in European studies. A 1-ha (2.5-acre) nursery and 5 ha (12.5 acres) of field plots have been established using promising willow and alder varieties.

North Carolina State University is screening hardwood tree species and evaluating silvicultural systems for woody biomass production in the Southeast. This research project has been greatly enhanced by cooperative efforts within the North Carolina State University Hardwood Research Cooperative, which is composed of state agencies and 18 forest industries. The cooperative members provide land for field sites, technical support, and equipment. Four plantations have been established to evaluate species/site relationships, spacing, coppicing, and

rotation age. Conclusions to date are as follows: (1) sweetgum is the most adaptable hardwood tested, (2) hardwoods must receive intensive care until well established for acceptable growth and development, and (3) species/site interactions must be considered.

The Packaging Corporation of America (PCA), a forest products company in Filer City, Michigan, is evaluating woody biomass production of large-scale hybrid poplar plantations. To date, PCA is the only large-scale planter of intensive-cultured hardwoods in the Great Lakes region. Over 1.5 million hybrid poplars have been planted on 1200 ha (3000 acres) for intensive forest management. The existing plantations will be used to determine the economics and productivity rates of large-scale short-rotation plantations. This project will also emphasize the following areas of research: (1) development of soil/site/yield guidelines; (2) evaluation of plantation establishment techniques, including herbicide application; (3) evaluation of plantation management strategies, including pest management; (4) evaluation of poplar nursery management techniques; and (5) evaluation of the economics of plantation establishment and management techniques.

The Pennsylvania State University (P. R. Blankenhorn, Principal Investigator) is evaluating the productivity of short-rotation hybrid poplar under four management strategies (control, irrigation, fertilization, and irrigation/fertilization). After two growing seasons a maximum height of 2.9 m (9.7 ft) was achieved under the irrigation/fertilization treatment. Data are being collected on the energy and economic inputs needed to operate and maintain the plantation under each management strategy. These data will be analyzed using

a linear programming model that will identify the most efficient management strategies for attaining a maximum net energy or financial output.

The Pennsylvania State University (W. E. Sopper, Principal Investigator) project, now in its final year, has evaluated the effect of municipal wastewater irrigation on biomass production in hybrid poplar plantations. An economic analysis of using wastewater as a substitute for inorganic fertilizer is under way. Results obtained to date indicate that wastewater irrigation significantly increased diameter and total height growth of hybrid poplar. Furthermore, total woody biomass production was more than doubled by wastewater irrigation after 3 years of growth. A forthcoming final report will summarize the 4 years of research from this project.

Seattle City Light, a municipal utility in Seattle, Washington, is evaluating various cultural treatments of red alder and black cottonwood for optimum woody biomass production in the Pacific Northwest. Two research plantations, 4 ha (10 acres) each, were established in 1979. Data are being collected on growth response to spacing, irrigation, fertilization, cultivation, and species mixture. Technical experts are being consulted on equipment, economics, planting stock procurement, and environmental impacts. This project will be completed in 1983.

Texas A&I University in Kingsville, Texas, is investigating production of woody biofuels from mesquite. Mesquite is a leguminous woody shrub indigenous to tropical and subtropical arid and semiarid regions. This project is using clonal stock from 20 shrubs that were

previously identified as promising for woody biomass production. The goal of this project is to utilize these high-producing strains for cost-effective commercial biomass farms. Research efforts include determination of biomass production, collection of additional plant material from unusual sources and origins, and refinement of tissue culture techniques and propagation methods.

USDA-Forest Service, North Central Forest Experiment Station, in the final project year, has developed a management program for establishment of large-scale poplar plantations. The establishment period, defined as the first three growing seasons, is the most critical period for large-scale plantations. Investigators in this project have identified optimal methods for site preparation, planting, and weed control. Selection of planting materials and initiation of pest management strategies are also being studied. The percentage of successful plantations (those with greater than 75% survival) has risen from 15% in 1977 to 95% in 1980. A forthcoming final report will summarize the 5 years of research from this project.

7.3 ECONOMIC STUDIES PROJECT SUMMARIES

The Biosys Corporation of McLean, Virginia, is evaluating the availability of land for short-rotation biomass plantations in the Western Great Lakes region. This project will address the following issues: (1) the potential land resource available for biomass plantations, (2) major issues in land competition, (3) the types of sites available for biomass plantations, and (4) the location of potential sites. A final report describing the results of this project will be compiled by July 1982.

Mathtech, Inc., of Princeton, New Jersey, has analyzed and applied ten scenarios to an optimization harvesting model previously developed for the Biomass Energy Systems Division. The model accounts for the processes of shearing, chipping, collecting, transporting, storing, and processing of woody biomass. The ten scenarios involved mode of operation and terrain configuration. Drying characteristics of the harvested biomass was incorporated into the model. A final report describing the analyses of the biomass harvesting model was completed early in 1982.

Mittelhauser Corporation of Downers Grove, Illinois, has developed an integrated computer program that will measure woody biomass product price sensitivities to various modes and intensities of silvicultural management practices. The model incorporates the costs of all relevant aspects of short-rotation woody biomass production including: land purchase or lease, establishment, development, harvesting, and storage operations. A report that describes the model and a series of sensitivity analyses was completed in March 1982.

Virginia Polytechnic Institute and State University, Blacksburg, Virginia, is completing the conceptual design of a harvesting system to sever, collect, transport, and process woody material from short-rotation energy plantations. The harvesting system will offer flexibility in harvestable tree size, operable terrain, and road spacing. The system will be able to handle single stems from a seedling planting and multiple stems from coppice development. In addition, the harvester will use base carriers that may be readily adaptable to spraying, fertilization, site preparation, and other stand management activities. Research efforts to date include the

evaluation of severance devices and the design of a "tree grabber." An existing skidder is being modified to serve as a base machine for the harvesting system.

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