IEA REPORT

SOUTHERN RESEARCH STATION
USDA FOREST SERVICE

AN ANNOTATED BIBLIOGRAPHY OF SHORT ROTATION WOODY CROPS OPERATIONS LITERATURE

by

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IEA BIOENERGY
TASK XII - BIOMASS PRODUCTION, HARVESTING, AND SUPPLY
ACTIVITY 2.1 - SHORT ROTATION FORESTRY

BIOENERGY AGREEMENT
INTERNATIONAL ENERGY AGENCY

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PROLOGUE

International Energy Agency-Bioenergy is a multi-national collaborative agreement to improve worldwide cooperation and information exchange concerning bioenergy. Currently, Task XII, Biomass Production and Harvesting, has as part of its mission to design and develop cost-effective and environmentally sound biomass production, harvesting, and supply systems for energy. One component of Task XII is Short Rotation Forestry Production Systems (Activity 2.1) which focuses on production systems, pests, and stock improvement and characterization. This bibliography was sponsored as part of the efforts of Activity 2.1 with the goal of improving information exchange among participating scientists.

This document primarily addresses the operational aspects of woody crops for energy. As interest continues to grow in short rotation forestry, the need for state-of-the-art research and technology information for intensively managed plantations is of great importance. Our hope is that this bibliography will prove useful to scientists and plantations managers in improving short rotation management.

An Annotated Bibliography of Short Rotation Woody Crops Operations Literature

1. Anon. 1996. Bioenergy in the Southeast: Status, Opportunities, and Challenges - Recommendations of the Southeast Bioenergy Roundtable. Muscle Shoals, AL: DOE Southeast Regional Biomass Energy Program; 83 p.

   The report is organized to provide a common base of understanding of: the context of bioenergy development, the Southeast's biomass resources and its bioenergy potential; and the environmental and market development issues, challenges; and opportunities associated with the development of this resource.

   bioenergy/ biomass/ residue/ genetics/ environmental impacts/ water quality/ pests.

2. Anon.1993-1996. Energy Crops Forum. Oak Ridge, Tennessee: Biofuels Feedstock Development Program, Environmental Sciences Division, Oak Ridge National Laboratory.Energy Crops Forum is published three times a year and contains short articles related to biofuels and energy plantations. Each edition contains a list of publications of interest.

   biofuels/ energy crops/ references.

3. Anon.1995. NC News. North Central Forest Experiment Station. 6 p.

   Contains several short articles about short rotation forestry: Short-Rotation Intensive Culture: A Research Success Story; SRIC Research: Then and Now; Agro-forestry: SRIC Research Success Realized; Dave Dawson: The Father of SRIC; Harshaw Farm: A Showplace for SRIC Research.

   short rotation intensive culture.

4. Anon.1994. Silva 3000. Sustainable Forest Systems. 4. 4 p.

   Contains two short articles: Exotic Tree Plantations and Their Impact on Diversity, and The Importance and Value of Diversity. Lists recommended readings.

   diversity/ plantations.

5. Ager, A.; Nordh, N. E.; Ledin, S.; Ostry, M. E.; Carlson M.; Ronnberg-Wastljung, A. 1990. International transfer of alnus, populus, and salix germplasm: Early test results. In: Mitchell, C. P.; Zsuffa, L.; Anderson, S.; Stevens, D. J., eds. Forestry, Forest Biomass and Biomass Conversion; The IEA Bioenergy Agreement (1986-1989) Summary Reports: 49-62.

   The interim results of a genetic testing program established within the IEA/FEA

are reported. The project was designed to compare the growth rates of selected genetic materials under a variety of growing environments, and identify germplasm with potential for biomass cultivation. The project was also designed to examine the limitations of long-distance international transfer of clones/provenances/species among national biomass programs. Genetic materials with superior growth potential in one or more of the test environments were indentified. Also identified were the maximum climatic tolerance of several previously untested species/provenances.

biomass/ energy

6. Akinyemiju, O. A.; Isebrands, J. G.; Nelson, N. D.; Dickman, D. I. 1982. Use of glyphosate in the establishment of Populus in short rotation intensive culture. In: Zavitkovski, J.; Hansen, E. A., eds. Proceedings of the North American Poplar Council Meeting; July 20-22, 1982; Rhinelander, Wisconsin. Manhattan, Kansas: Kansas State University: 161-169.

7. Anderson, H. W.; Papadopol, C. S.; Zsuffa, L. 1983. Wood energy plantations in temperate climates . Forest Ecology Management. 6:281-306.

8. Barnett, P. E.; Sirois, D. L. 1985. Roll splitting as an alternative intermediate process for wood fuel. Garpenburg, Sweden: SLU; 2 p.

In an effort to develop mobile equipment for harvesting and processing woody biomass from power line rights-of-ways and precommerial thinnings numerous alternative concepts were evaluated by Tennessee Valley Authority's Timber Harvesting Project.

short rotation woody crops/ storage.

9. Barron, W. F.; Perlack, R. D.; Kroll, P.; Cushman, J. H.; Ranney, J. W. 1983. Oak Ridge, TN: Oak Ridge National Laboratory; ORNL/TM-8566.

FIRSTCUT is an interactive simulation model which calculates the discounted average cost, net present value and rate of return for short-rotation intensive silvicultural biomass production. The model is intended for preliminary economic feasibility assessments in which the principal analytical objectives are (1) to analyze the variation in discounted average cost and net present value with respect to specific resource characteristics and economic conditions, (2) to identify the most attractive.

short rotation woody crops/ intensive culture/ models.

10. Bergez, Jacques-Eric; Bouvarel, Luc; Auclair, Daniel. 1991. Short-rotation forestry:

An agricultural case study of economic feasibility. In. Bioresource Technology. Oxford, England: Elsevier Science Publishers, Ltd.: 41-47.

The economic feasibility of short rotation forestry was studied assuming growth on agricultural land in central France. The annual discounted average gross margin was used as a criterion of comparison between short rotation forestry and traditional annual agricultural crops. Using average assumptions concerning cost, yield and selling price, short rotation forestry is not competitive with the other crops studied. In the present economic conditions, even if some of the inputs and initial assumptions are modified, the results remain unchanged. Some suggestions are made concerning agricultural policy at the state or community level.

biomass/ short rotation/ economics.

11. Berguson, W. E.; Hansen, E. A.; Johnson, W. C.; Borse, C. B.; Zimmerman, D. 1990. Short-rotation intensive culture tree production in Minnesota. In: Klass, D. L., ed. Energy from biomass and wastes XIII; Chicago, IL: Institute of Gas Technology: 275-294.

short rotation intensive culture/ plantation establishment/ poplars, hybrid/ Salix/ willows/ growth/ yields

12. Betters, D. R.; Wright, L. L.; Couto, L. 1991. Short rotation woody crop plantations in Brazil and the United States. Biomass and Bioenergy. 1:305-316.

short rotation woody crops/ Brazil/ economic analysis/ fiber content/ fuels/ commercialization

13. Bhat, Mahadev G.; English, Burton C. 1996. An Optimal Staggered Harvesting Strategy for Herbaceous Biomass Energy Crops. In: Carter, Mason C., ed. Growing Trees in a Greener World: Industrial Forestry in the 21st Century; 1996; Louisiana State University. Baton Rouge, LA: Louisiana State University School of Forestry: 265.

The biofuel research over the past two decades has revealed the lignocellulosic crops served as a reliable source of feedstock for alternative energy. However, under the current technology of producing, harvesting and converting biomass crops, the resulting biofuel is still not competitive with conventional biofuel in terms of cost. While a tremendous research effort is being spent on finding ways to produce low cost biofuel, this study looks into minimizing biofuel feedstock cost under the current technology. The study recognizes the fact that cost of harvesting biomass feedstock is a single largest component of feedstock cost. It is argued that there is a tremendous cost advantage in taking into account various techno-economic and institutional factors associated with current technology in designing a biomass harvesting system. The traditional system of farmer-initiated harvesting operation for biomass causes an over investment in agriculture. This over investment is nothing but a social cost to the society. Instead, this study developes a least-cost, time-distributed (staggered) harvesting system for switch grass, as an example, that calls for an effective coordination between farmers, processing plant and single third-party custom harvester. A linear programming model is developed to explicitly account for the trade-off between yield loss and benefit of reduced machinery overhead cost, associated with the staggered harvesting system.

14. BonneMann, A. 1978. Performance and properties of poplars as indicators of suitability for short rotations. Holzzucht. 32(1/2):4-10.

15. Booth, Calvin T. 1992. The farm wood fuel and energy project. Uppsala, Sweden: Swedish University of Agricultural Sciences Department of Forest Yield Research;

This project aims to provide information and break the 'no supply-no market:no market-no supply' cycle. Initial objectives include: 1) cultivation of arable energy coppice and development of integrated production and marketing systems, 2) integration of arable coppice into a variety of farming systems and maintenance of productivity records, 3) design and evaluation of an environmentally friendly cropping system, 4) replacement of herbicides with organic materials and good husbandry, 5) generation of added income through game management, 6) development of a training package for farmers, addressing arable coppice production.

coppice/ farm wood/ energy.

16. Bowersox, T. W.; Stover, L. R.; Blankenhorn, P. R.; Strauss, C. H. 1983. Biomass yields from dense plantations. Proceedings of the 7th International FPRS Industrial Wood Energy Forum; September 19-21, 1983; Nashville, TN. Madison, WI: FPRS: 129-133.

Biomass yield and energy data for dense plantations of a Populus hybrid, grown under four management strategies on two dissimilar sites, have been determined for ages 1 to 3 years. Management strategies were control, irrigation, fertilization, and irrigation/fertilization.

biomass/ short rotation/ bioenergy/ research/ yields

17. Bruce, Alan P. 1994. Short rotation forestry in loblolly pine. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry: Mechanization in SRIC Forestry; March 1-3, 1994; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 15-20.

The potential for developing and expanding SRIC forestry in the South is greater than ever before. Increased demand for wood across the South makes the high cost of SRIC forestry more favorable to wood products companies. Technological developments in herbicides, genetics, and mechanical treatments are making SRIC forestry more biologically and economically feasible. James River Corporation is currently practicing SRIC forestry on both their pine and hardwood timberlands in the South. Loblolly pine and eastern cottonwood are James River's primary SRIC species. Sycamore and sweetgum are being managed on a project basis.

costs/ economics/ genetics/ technology/ short rotation

18. Brumm, D. B.; Wehr, Michael A. 1986. A Forth-controlled tree harvester. Proceedings of the 1986 International Conference on Industrial Electronics, Control and Instrumentation; September 29-October 3, 1986; Milwaukee, WI. The Industrial Electronics Society of the Institute of Electrical and Electronics Engineers, Inc. and The Society of Instrument and Control Engineers of Japan: 851-855.

A hydraulically powered harvester moves continuously down a row of trees in an even-aged plantation, severing and collecting the trees under microprocessor control. The controller is based on Forth and permits the on-board generation, modification, and storage of source code in nonvolatile memory, permitting stand-alone program devlopment.

harvesting/ Forth/ microprocessor control

19. Burk, T. E.; Nelson, N. D.; Isebrands, J. G. 1983. Crown architecture of short-rotation, intensively cultured Populus: III. A model of first-order branch architecture. Canadian Journal of Forestry Research. 13(6):1107-1116.

20. Campbell, G. E. 1988. The economics of short-rotation intensive culture in Illinois and the Central States. Urbana, IL: Department of Forestry, University of Illinois at Urbana-Champaign; Forestry Research Report No. 88-12.

Estimates costs and returns for several alternative short-rotation management alternatives, for marginal farm land and reclaimed mined land. The species considered is silver maple, rotation age is five years, and five harvests are assumed from an initial planting. Breakeven prices are estimated.

economics/ short-rotation/ maple.

21. Cannell, M. G. R. ; Smith, R. I. 1980. Yields of minirotation closely spaced hardwoods in temperate regions: review and appraisal. Forest Science. 26(3):415-428.

Published data are reviewed on the yields of ovendry stems and branches (S and B) with bark, and the mean annual increments obtained from 1- to 5-year-old closely planted sycamore, Populus spp., and maple.

biomass/ productivity/ coppice

22. Chappelle, D. E. 1987. Regional economic impacts using input-output analysis. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 177-189.

Input-output analysis can be useful in forecasting economic impacts of various economic development strategies, including those of short rotation biomass energy systems. However, such measurements must be developed with clear recognition of the substitutability of one type of energy for another, the global energy situation, and probable impacts of new production and consumption technologies. A recent input - output analysis of economic impacts of the fuelwood sector in the Upper Great Lakes region is discussed as an application, although the above complications could not be recognized because of reliance on secondary data.

fuelwood/ regional/ economic growth/ biomass/ regional

23. Christopherson, N. S. 1989. Energy forestry production systems: Report on status of sourcebook. In: Ledin, Stig; Ohlsson, Agnetha., eds. Energy forestry production systems activity:IEA, Task 5: Workshop report; May 11-12; Herning,Denmark. Uppsala, Sweden: Swedish University of Agricultural Sciences, Department of Ecology and Environmental Research, Section of Short Rotation Forestry: 3-6.

IEA/ summaries

24. Christopherson, N. S.; Barkley, B. A.; Ledin, S.; Mitchell, C. P. 1989. Production technology for short rotation forestry. Bioenergy Agreement, International Energy Agency; 110 p.

This report is one in a series reporting on the Activities of Task II of the IEA/BA. Task II is concerned with biomass growth and production technology in short-rotation forestry.

IEA/ biomass/ growth/ production.

25. Christopherson, N. S.; Mattson, J. A. 1987. Engineering issues--The hidden challenges in SRIC forestry. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 190-196.

SRIC forestry is a promising source of renewable energy. As in agriculture, trees are grown on tilled land in evenly spaced rows with trees in each row spaced equal distances. Biologists and economists are trying to determine optimum inter-row spacing; intra-row spacing; single-stem rotations only or single-stem/coppice methods; final size, weight and form of trees; species; and other characteristics. Engineers must deal with these parameters before they can design proper and adequate machinery, making these the real engineering issues.

short rotation/ plantations/ forest engineering/ technology/ equipment/ mechanization

26. --- 1990. Mechanization of the operational aspects of short-rotation forestry. In: Mitchell, C. P.; Zsuffa, L.; Anderson, S.; Stevens, D. J., eds. Forestry, forest biomass and biomass conversion.; The IEA Bioenergy Agreement (1986-1989) Summary Reports: 123-134.

The IEA/BA that ended Dec. 31, 1988 expanded its involvement with mechanization by creating a separate Activity called 'Production Technology'. This Activity investigated the current state of technology for establishing, managing and harvesting SRIC forests or plantations. Five countries participated. Several workshops were held, and a final joint project evolved. As the final effort, a 'Sourcebook' of Production Technology will be made available. A summary of the main findings is provided here.

short rotation/ mechanization/ plantations/ growth/ technology

27. Christopherson, Nels S. 1989. Mechanization of fast-growing forests: worldwide progress. St. Joseph, MI: American Society of Agricultural Engineers; ASAE Paper 89-7604. 21 p.

Fast-growing forest produce energy wood or pulp fiber in 3 to 7 years. Trees are planted in rows and treated like agricultural crops. Planting is by hand or semi-mechanized. Prototype harvesting machines from different countries are discussed. Mechanization of the production cycle is needed for economic success.

forestry/ tree harvesters/ tree planters/ plantations/ intensive culture/ fast-growing/ energy forestry.

28. Christopherson, Nels S.; Mattson, James A. 1986. Perspectives on short-rotation production technology. In: Evers, R.; White, E.; Barkley, B.; Zsuffa, L., eds. Proceedings "Forest Crop Nutrition: Production, Prices and Pathways". IEA/BA Task II Workshop Production Technology, Economics and Nutrient Cycling; May 20-23; Kingston, Canada. IEA/BA Task II: 92-98.

One way to increase wood production for fiber and energy is short-rotation intensive culture(SRIC) forestry. Although using the principles of agriculture, SRIC forestry is able to employ little of agriculture's production equipment per se. With their high stocking and small trees, SRIC plantations have created a need for new equipment for planting, weed control, fertilizing, harvesting, and processing.

harvesting/ processing/ planting/ equipment

29. Colletti, Joe P.; Gan, Jianbang. 1987. A linear programming model of traditional farm crops, livestock and SRIC operations. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 108-114.

A linear programming (LP) model is presented that integrates traditional agronomic cropping and livestock production with short rotation, intensive culture (SRIC) tree plantations. SRIC activity budgets are incorporated into an existing data set developed by the Center for Agricultural and Rural Development (CARD) at Iowa State University. A farm level linear programming model similar to the CARD-Resources Conservation Act (RCA) assessment model is developed. Constraints considered include, but are not limited to, land, labor, capital, soil erosion and water quality. The model simultaneously allocates and schedules farming and SRIC activities over time. Once refined, the model can aid in such analyses as assessing the impact of future technological change on crop, livestock and SRIC production patterns, farm debt-load restructuring and efficacy of taxes on fertilizers or pesticides or other public policies to control water pollution and soil erosion.

water quality/ plantations/ biomass/ environmental impacts

30. Comerford, P. 1980. Harvesting of short rotation forestry. In: Neenan, M.; Lyons, G., eds. Production of Energy from Short Rotation Forestry. Dublin, Ireland: An Foras Taluntais: 68-72.

Briefly describes early harvesting developments in the US, Sweden, Finland, France, Canada, Northern Ireland and in the Irish Republic.

harvesting.

31. Couto, Laércio; Betters, David R. 1995. Short-rotation eucalypt plantations in Brazil: Social and environmental issues. Oak Ridge National Laboratory; ORNL/TM-12846. 34 p.

This report presents an overview of the historical and current legislative, social,

and environmental aspects of the establishment of large-scale eucalypt plantations in Brazil. The report consolidates the vast experience and knowledge relating to these forest plantation systems and highlights lessons learned and new trends. The overview should prove useful to those interested in comparing or beginning similar endeavors.

short-rotation/ eucalypt plantations/ Brazil.

32. Crist, J. B. 1987. Potential SRIC products and markets. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 253-257.

The material produced using short rotation intensive culture has different properties than that produced by typical forestry practices. Understanding these differences allows proper processing and allocation to products for which it is particularly well suited. The properties imparted by the high proportion of thin-walled early wood fibers, associated with rapid growth and young age, make the raw material desirable for some paper grades and composite panel products. Conversely, these same raw material properties make the material poorly suited for solid wood products. However, this situation follows the trend in markets for wood products in which the composite products are continuing to capture a larger percentage at the expense of solid wood products.

plantations/ short rotation/ products

33. Crist, J. B.; Isebrands, J. G.; Nelson, N. D. 1979. Suitability of intensively grown Populus raw material for industry. 16th Annual Meeting of North American Poplar Council; Thompsonville, Minnesota: North American Poplar Council: 65-74.

poplars/ short rotation intensive culture

34. Crist, John B.; Mattson, James A.; Winsauer, Sharon A. 1983. Effect of severing method and stump height on coppice growth. St. Paul, MN: USDA North Central Forest Experiment Station; GTR NC-91. 7 p.

In this study we evaluated the effect of stem severing method and stump height on coppice growth in a short-rotation intensively cultured Populus plantation 1,2, and 3 years after cutting. Initially, stumps 46 cm high had smaller and significantly more sprouts than either 8 or 15 cm high stumps. However, the dominant sprouts were not affected by the stump height. After subsequent growing seasons, the dominant sprouts were the only ones to survive, and no effect of stump height was present. Severing method-shearing or chain sawing-did not affect coppicing as long as the stumps were not excessively damaged during the original harvest.

coppice/ harvesting/ populus.

35. Culshaw, Damian. 1994. Mechanization of short rotation intensive culture forestry (in the UK). In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3, 1994; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: p. 145-156.

Wood as a fuel is currently used in the UK in the domestic sector and in the wood processing industry although there is now an incentive to generate electricity from it. Short rotation intensive forestry crops are being considered as an energy crop on land set aside from agriculture. A 2 to 5 year cycle coppicing system is being developed using willow and poplar. Agricultural techniques and machines will be used and the husbandry techniques will be similar to those employed in Sweden. Work on the development of mechanization of the crop is being funded by the UK Governments's Department of Trade and Industry under a program managed by ETSU. Work on harvesting machines has already started and work on transport and supply is due to start shortly. Modelling of the drying and storage of bulks of wood chips has already been advanced leading to some understanding of the processes involved. This work continues to be applied to short rotation crops.

electricity generation/ coppice/ harvesting/ equipment/ mechanization/ short rotation/ management

36. --- 1993. Short Rotation Forestry Crops in the UK & Development of Their Mechanisation. Status of Short Rotation Forestry Mechanisation Worldwide; March 2-4, 1993; Swedish University of Agricultural Sciences. Oxford, England: Harwell Laboratory: 9-20.

This report on short-rotation forestry in the UK is split into two. The first section deals with 'short rotation forestry in the UK' and the second on the plans for the future 'development of their mechanisation' which is of particular relevance to this activity of the IEA/BA.

37. Curtin, D. T.; Barnett, P. E. 1986. Development of forest harvesting technology: Applications in short rotation intensive culture (SRIC) woody biomass. Muscle Shoals, Alabama : Tennessee Valley Authority, Office of Agriculture and Chemical Development; TN B-58; TVA/ONRED/LER-86/7.

Available forest biomass harvesting systems, functions, and machines are briefly described. The relationships between timber stands and harvesting function productivity and costs are graphically presented. Current developments in short-rotation, intensive-culture (SRIC) biomass plantation harvesters are described and related to available information on stem size, stocking, and productivity information.

costs/ harvesting/ equipment/ production/ short rotation/ technology.

38. Cushman, J. H.; Wright, L. L.; Trimble, J. L. 1983. Oak Ridge, TN: Oak Ridge National Laboratory, Environmental Sciences Division.; ORNL-5973. 128 p.

Increasing demands for fuelwood and wood energy feedstocks has placed severe pressures on forest resources in many developed and developing countries. Energy plantations are one concept under investigation for increasing the size and productivity of the wood resource base. The BIOCUT model described in this report is designed to facilitate the systematic investigation of a wide range of potential wood energy plantation applications and to provide reasonable estimates of net returns and minimum required product prices. The BIOCUT model is coded in PASCAL and operates on IBM personal computers and compatibles with 256K memory using the DOS 2.0 operating system.

39. Dawson, D. H. ; Zavitkovski, J. 1978. Intensively cultured plantations. TAPPI Journal. 61:6.

New silvicultural practices will have to be introduced into United States forests to respond to the demand for fiber that is expected to double by the year 2000. The Maximum Yield and Intensive Culture Project was established at the Institute of Forest Genetics in Rhinelander, Wisconsin, with the misson to study a short-rotation intensive culture (SRIC) system. In the SRIC system, agrotechniques, which greatly increased production of agricultural crops, are applied to forestry. Selected or improved tree species are planted at close spacings and grown on short rotations under intensive care including site preparation, weed control, fertilization, and irrigation. Results of previous *Populus* hybrids indicate that biomass production in SRIC plantations can be significantly increased in comparison to the production achieved in plantations or natural stands tended in the traditional way.

plantation/ production

40. Dawson, W. M. 1991. Short rotation coppice willow: The Northern Ireland experience. In: Aldhous. J. R., ed. Wood for energy: The implications for harvesting, utilization and marketing.; April 5-7; Heriot-Watt University, Edinburgh. Institute of Chartered Foresters: 235-247.

The background of a short-rotation willow coppice system is described. Problems with a foliar rust disease were encountered and alternative disease control strategies are being developed.

energy/ biomass/ proceedings/ short rotation

41. DeBell, D. S.; Strand, R. F.; Reukeman, D. L. 1978. Short-rotation production of red alder: some options for future forest management. Utilization and Management of Alder; Olympia, Washington: U.S. Forest Service, PNW Forest and Range Experiment Station: 231-244.

short rotation woody crops/ production/ red alder/ management/ forests/ pulpwood

42. Debell, Dean S.; Whitesell, Craig D.; Schubert, Thomas H. 1985. Mixed plantations o Eucalyptus and Leguminous trees enhance biomass production . Berkeley, California: Pacific Southwest Forest and Range Experiment Station; PSW-175. 6 p.

Two species of Eucalyptus are especially favored for their wood because of quick growth and high yields. Their growth is limited on many sites by low levels of soil nitrogen. This study tested the effects of planting leguminous trees .

Eucalyptus/ legumes/ species trials/ plantations/ Hawaii.

43. Dinus, R. J.; Dimmel, D. R.; Feirer, R. P.; Johnson, M. A.; Malcolm, E. W. 1990. Modifying woody plants for efficient conversion to liquid and gaseous fuels. Oak Ridge, TN: Oak Ridge National Laboratory; ORNL/Sub/88-SC006/1.

The Short Rotation Woody Crop Program, U.S. Department of Energy, is using conventional tree breeding and intensive cultural practices to increase growth and yield of "energy plantations" of selected hardwood tree species. Large increases in productivity are being achieved. In view of these accomplishments, the agency is now evaluating opportunities for altering physical and chemical properties of biomass. Such research would seek to improve efficiencies of processes for converting lignocellulosic materials to ethanol and gaseous or other liquid fuels.

conversion/ application/ energy.

44. Dippon, D. R.; Rockwood, D. L.; Comer, C. W. 1986. Cost sensitivity analysis of Eucalyptus grandis woody biomass systems. In. Biomass Energy Development. New York: Plenum Publishing Corp.: 143-156.

Eucalyptus grandis/ intensive culture/ economic analysis/ short rotation woody crops/ planting density/ coppice/ harvesting.

45. Dippon, Duane R. 1985. Slash and sand pine intensive short rotation culture: Economic energy feedstock. In: Rockwood, Donald L., ed. Proceedings of the 1985 Southern Forest Biomass Workshop; June 11-14; Gainesville, Florida.

Institute of Food and Agricultural Sciences: 52.

Before intensive short-rotation slash or sand pine plantations are commercially planted for energy conversion facilities, the cost/dry tonne must be known. Production costs depend on land, labor,capital and the productivity of the system. To determine the lowest cost per tonne, planting density and rotation must be estimated. This study evaluates the first five years of growth for slash and sand pine at simulated plantation densities ranging from 4800 to 43300 trees per hectare. The analysis found that the optimal rotation length for either species or density has yet to be reached. Projected growth and yields along with estimated cost data indicate that slash pine plantations could produce biomass for less than $35/dry tonne, or under $2/gJ. Sand pine intensive culture systems currently appear less attractive because of higher average costs per tonne of material produced.

costs/ economics/ short rotation/ production

46. Downing, M. E.; Graham, R. L. 1993. Evaluating a biomass resource: the TVA region-wide biomass resource assessment model. Proceedings of the First Biomass Conference of the Americas: Energy, Environment, Agriculture, and Industry; Golden, Colorado. National Renewable Energy Laboratory: 54-63.

The economic and supply structure of short rotation woody crop (SRWC) markets have not been established. Establishing the likely price and supply of SRWC biomass in a region is a complex task because biomass is not an established commodity as are oil, natural gas, and coal. In this study we project the cost and supply of short rotation woody biomass for the TVA region - a 276 county area that includes all of Tennessee and portions of 10 contiguous states in the southeastern United States are projected. Projected prices and quantities of SRWC are assumed to be a function of the amount and quality of crop and pasture land available in a region, expected SRWC yields and production costs on differing soils and land types, and the profit that could be obtained from current conventional crop production on these same lands. Results include the supply curve of SRWC biomass that is projected to be available from the entire region, the amount and location of crop and pasture land that would be used, and the conventional agricultural crops that would be displaced as a function of SRWC production.

biomass resources/ models/ short rotation woody crops

47. Downing, M. E.; Tuskan, G. A. 1995. Is there a need for site productivity functions for short-rotation woody crop plantings? Second Biomass Conference of the Americas: Golden, Colorado: National Renewable Energy Laboratory: 207-215.

site characteristics/ short rotation woody crops/ Populus/ poplars/ hybrids/

hardwoods

48. Downing, Mark; Langseth, Dan: Stoffel, Ron; Kroll, Tom. 1996. Large-scale Hybrid Poplar Production Economics . BIOENERGY '96 - The Seventh National Bioenergy Conference: Partnerships to Develop and Apply Biomass Technologies; September 15-20, 1996; Nashville, Tennessee. Oak Ridge, TN: Oak Ridge National Laboratory: 467-471.

The Minnesota Wood Energy Scale-Up Project planning began in late 1993. Cooperators include the WesMin Resource Conservation and Developement Council, the U.S. Department of Energy's Biofuels Feedstock Developement Program at Oak Ridge National Laboratory, the Electric Power Research Institute, the U.S. Forest Service in Rhinelander, Wisconsin, and the Minnesota Department of Natural Resources-Forestry. In spring 1994, Phase I, established 1,000 acres of trees. Phase II, documented here, includes plantings established on 870 acres by June 1995. The purpose is to track and monitor economic costs of planting, maintaining, and monitoring larger-scale commercial plantings.

hybrid poplar/ production economics/ wood energy

49. Downing, Mark; Pierce, Rick; Kroll, Thomas. 1996. Minnesota wood energy scale-up project 1994 establishment cost data. Oak Ridge, TN: Oak Ridge National Laboratory; ORNL/TM-12914.

The purpose of the Minnesota Wood Energy Scale-up Project is to track and monitor economic costs of planting, maintaining and monitoring larger scale commercial plantings. 1000 acres of hybrid poplar trees were planted on Conservation Reserve Program (CRP) land near Alexandria, Minnesota in 1994. The fourteen landowners involved re-contracted with the CRP for five-year extensions of their existing 10-year contracts.

Minnesota/ poplars.

50. Drennen, T. E.; Ostlie, L. D. 1987. The whole tree burner: A new technology in power generation. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 74-81.

This new technology in burning wood consists of an innovative approach where the wood is harvested, transported, dried, and burned in whole tree form. Fuel for the plant can come from either natural stands or from energy plantations utilizing SRIC technology. Trees arriving at the plant are dried by utilizing turbine cycle waste heat before being combusted in a deep pile configuration. The whole tree burner is economically competitive with fossil fuel alternatives.

energy/ technology/ proceedings

51. Durst, Patrick B. 1987. Wood-fired power plants in the Phillipines:Where will the wood come from? In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 322-341.

The economic costs of producing captive wood supplies currently exceed the costs of open-market wood at 10 of the 14 Philippine wood-energy sites recently evaluated. Plantation establishment and wood transport are the most costly activities associated with producing fuel for power plants. Total unit costs of captive wood are influenced most by plantation yields and materials costs; wage rates have little impact on total wood costs. The economic viability of plantations can be improved at several sites by enlarging the size of tree farms. At sites where wood is being purchased from the open market, precautions must be made to guard against adverse social and environmental effects.

energy/ short rotation/ economics/ electricity generation/ dendrothermal power

52. Dutrow, G. F.; Saucier, Joseph R. 1976. Economics of short-rotation sycamore. New Orleans, LA: USDA Forest Service Southern Forest Experiment Station; Research Paper SO-114. 16 p.

Short-rotation sycamore was most profitable with good sites, wide spacings, and cutting cycles of 4 or 5 years. Unless costs can be substantially reduced and markets expanded, the system appears to be economically feasible for industrial landowners only. In most cases, annual income from sycamore did not compare favorably with income form agricultural crops.

Platanus occidentalis, simulation, yields, costs, returns, fertilization, genetic improvement.

53. Dutrow, George F. 1971. Economic implications of silage sycamore. USDA Forest Service, Southern Forest Experiment Station; Research Paper SO-66. 9 p.

Best estimates of costs and returns indicate that some wood processors would find the growing of silage sycamore profitable. Success, however, requires substantial expenditures for heavy equipment and allocation of 4,000 to 8,000 acres to the project. Unless establishment costs can be substantially reduced and a market created, the system will not be economically feasible for nonindustrial landowners.

silage sycamore/ economics.

54. Earley, S. B.; Rose, D. W.; Blinn, C. 1987. Database management system for investment analysis of short rotation, intensive culture forestry. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 151-159.

The research project that is introduced in this paper could result in better cost/benefit analyses and more accurate systems modelling. Decisions on forestry investments could be improved by becoming more organized in the business of information management. Decisions could also be made more confidently when sufficient information is easily available. Basic guidelines for the development of a database are explained.

costs

55. Ehrenshaft, A. R. 1989. Short rotation woody crops program publications and presentations. Oak Ridge, TN: Oak Ridge National Laboratory; ORNL/TM-10848.

The Department of Energy's Short Rotation Woody Crops Program was initiated in 1978, with technical management and sub contract administration transferred to the Biomass Production Program of Oak Ridge National Laboratory in 1981. This bibliography was compiled to document the information dissemination activities of the researchers funded by the SRWCP. The following materials have been included: book chapters, papers published in conference proceedings, unpublished conference papers, symposium abstracts, Forest Service technical reports, dissertations and theses, and unpublished draft reports. The publications and presentations are arranged into separate sections for each research institution and each section is arranged alphabetically by author.

short rotation woody crops/ information resources.

56. Ehrenshaft, A. R. ; Wright, L. L. 1993. ORNL's biofuels feedstock information resources. Biologue. 11:35-38.

biofuels/ feedstocks/ information resources/ herbaceous energy crops/ short rotation woody crops

57. --- 1991. Short rotation woody crops program data base. Bioresource Technology. Oxford, Great Britain: Elsevier Science Publishers: 241-245.

A large amount of information on short rotation woody crops has been assembled at Oak Ridge National Laboratory, the technical manager for the US Department of Energy's SRWCP. A data base management system was developed to manage this information; it contains detailed information about test design, yearly climate conditions, site descriptions, planting stock, test maintenance, and biomass yields. The data base can be queried to produce species-specific biomass yields, comparisons of annual growth on the state and regional levels, biomass yields by planting density, and graphic representations of cultural treatment differences over time. The SRWCP data base is unique beccause it contains growth and yield data from more than 25 different species along with the associated cultural and climatic conditions of more than 100 sites within the United States. It is certainly the most complete dataset available documenting the early growth patterns of many species of trees.

short rotation/ biomass/ yields/ growth/ management/ models/ site characteristics.

58. -- 1989. The SRWCP database management system: users guide, data definitions, and source code. Oak Ridge, TN: Oak Ridge National Laboratory; ORNL/TM-10820.

short rotation woody crops/ information resources.

59. Ek, A. R. ; Brodie, J. D. 1975. A preliminary analysis of short rotation aspen management. Canadian Journal of Forestry Research. 5:245-258.

Stand-yield models were developed for stem and branch wood, stem wood and conventional utilization standards for various sites and initial densities. A model of sucker reproduction following harvesting is also presented. These models were then subjected to conventional economic analysis and long-term simulation comparisons. Results indicate that aspen rotations may be moderately shortened, with substantial increases in yields if utilization standards are increased. Greatest potential lies with the best sites, but more complete utilization standards may also allow operations on site currently considered marginal. Rotations based on the usual soil-expectation value criteria could be reduced from the current 35 to 45 range (at 5% discount rate) down to 20-30 years. Extremely short rotations (e.g., 15 years) appear undesirable due to sustained rapid volume and value growth rates well into the third decade.

60. Evans, R. S. 1974. Energy plantations-should we grow trees for power plant fuel? Vancouver, British Columbia: Canadian Forestry Service; 15 p.

The concept of sustained-yield management of a forest strictly to fuel a thermal-electric generation plant has been advanced. This report examines the viability of the concept in general and in relation to an actual power requirement situation on Vancouver Island, British Columbia. The report is critical of the "solar-energy conversion efficiency" approach to estimation of viability. It advocates assessment by direct use of available forest productivity (biomass) data. In the Canadian Boreal forest zones, land areas in excess of 1000 square miles would be required to sustain a modest 150-megawatt power plant. Data from the

Pacific Northwest suggest that red alder (*Alnus rubra*) has exceptional productivity and that a power plant of the above size might be sustained by a plantation of 65 square miles in area.

Forest biomass, solar radiation, productivity, thermal-electrical plant, *Alnus rubra*, plantation area, Vancouver Island, fuel wood.

61. Farnham, R. S.; Garton, S.; Reed, P. E.; Louis, K. A. 1982. Propagation and establishment of bioenergy plantations. Proceedings of the Second International Seminar of Energy Conservation and the Use of Renewable Energies in the Bio-industries; 1982;

62. Fege, A. S. 1986. Research evaluation techniques applied to a case study of short-rotation forestry. Radnor, PA: USDA Forest Service Northeastern Forest Experiment Station; 9 p.

63. Felker, P. 1984. Economic, environmental, and social advantages of intensively managed short rotation mesquite (Prosopis spp) biomass energy farms. Biomass. 5:65-77.

    mesquite/ Prosopis/ short rotation woody crops

64. Ferguson, K. D.; Rose, D. W.; Lothner, D. C.; Zavitkovski, J. 1981. Hybrid poplar plantations in the Lake States - A financial analysis. Journal of Forestry. 79(10):664-667.

    Hybrid poplar plantations in the Lake States may be a low-cost alternative to conventional sources of wood fiber for industrial users in some areas, but in most areas at this time they are high-risk, low-return investments. On the basis of our specific assumptions and 1979 prices, the return on investment of nonirrigated plantations is projected to be 8 percent. Irrigated plantations have a slightly negative rate of return. Rates differ little between short (5 to 10 years) and long (15 years) rotations. Investment performance measures are most sensitive to estimates of product sale value, yields, irrigation costs, and harvesting costs.

65. Ferm, Ari; Kauppi, Anneli. 1990. Coppicing as a means for increasing hardwood biomass production . In: Mitchell, C. P.; Zsuffa, L.; Anderson, S.; Stevens, D. J., eds. Forestry, forest biomass and biomass conversion - The IEA Bioenergy Agreement (1986-1989) Summary Reports. London: Elsevier Applied Science: 107-121.

    Summarizes work done under the IEA Activity entitled 'Developing the coppicing potential of selected hardwoods'. Altogether, 26 papers and publications have been prepared under this project, discussing a large number of coppicing mechanisms and factors of many important short-rotation hardwood tree species, the main emphasis being on birch, poplar, alder and willow. Coppicing research is reviewed briefly on the basis of two inquiries. There were 20 research projects and a total of 39 researchers dealing with coppicing in the various participating countries. A survey of coppicing problems indicates a need for scientific projects in ecophysiology, anatomy and stand dynamics.

biomass/ production/ coppice.

66. Ferrell, J. E.; Wright, L. L.; Tuskan, G. A. 1995. Research to develop improved production methods for woody and herbaceous biomass crops. Second Biomass Conference of the Americas Energy, Environment, Agricultural, and Industry; Golden Colorado: National Renewable Energy Laboratory: 197-206.

production/ biomass/ short rotation woody crops/ herbaceous energy crops/ renewable energy/ hybrids/ willows/ poplars

67. Ford-Robertson, J. B.; Watters, M. P.; Mitchell, C. P. 1991. Short rotation coppice willows for energy. In: Aldhous, J. R., ed. Wood for energy: The implications for harvesting, utilization and marketing.; April 5-7; Heriot-Watt University, Edinburgh. Institute of Chartered Foresters: 218-234.

Short rotation crops provide alternatives to fossil fuels and a use for surplus agricultural land. The Loughry Coppice Harvester has performed well in field trials, reducing overall costs and highlighting the importance of mechanization to the economics of the system.

biomass/ energy/ proceedings/ short rotation

68. Francis, J. K. 1982. Fallowing for cottonwood plantations: Benefits carry to rotation's end. Proceedings of the 19th Annual North American Poplar Council Meeting; July 20-22, 1982; Rhinelander, Wisconsin. 1-7.

69. Frederick, Douglas J.; Stokes, Bryce J.; Curtin, Dennis T. 1986. Field trials of a Canadian biomass feller buncher. In: Rockwood, Donald L., ed. Proceedings of the 1985 Southern Forest Biomass Workshop; June 11-14, 1985; Gainesville, Florida. Gainesville, FL: Institute of Food and Agricultural Sciences - University of Florida: 17-22.

A prototype, continuous felling and bunching machine was evaluated in harvesting a three year old sycamore short rotation energy plantation in Alabama. Prediction equations, production rates, and costs were developed for the harvester.

biomass/ equipment/ mechanization/ short rotation/ harvesting

70. Gamble, G. G.; Betters, D. R. 1995. Farmer and Rancher Receptiveness to Short Rotation Tree Plantations in East-Central Colorado. Ft. Collins, Colorado: Colorado State University; TR95-3.

short rotation woody crops/ Colorado.

71. Geimer, R. L. ; Crist, J. B. 1980. Structural flakeboard from short-rotation, intensively cultured hybrid Populus clones. Forest Products Journal. 30:42-48.

structural flakeboard/ short rotation intensive culture/ poplars, hybrid

72. Geyer, W. A. 1992. Great Plains Energy Forest: Final Report. Oak Ridge, TN: Oak Ridge National Laboratory; ORNL/Sub/80-07934/7.

short rotation woody crops / yields/ Kansas/ wood.

73. --- 1981. Growth, yield, and woody biomass characteristics of seven short-rotation hardwoods. Wood Science. 13:209-213.

growth/ yields/ short rotation woody crops/ hardwoods/ fiber

74. --- 1993. Influence of environmental factors on woody biomass productivity in the Central Great Plains, U.S.A. Biomass and Bioenergy. 4:333-337.

biomass/ fuelwood/ short rotation woody crops/ energy crops/ environmental impacts/ climate

75. Geyer, W. A.; Melichar, M. W. 1982. Energy cost budgets for short rotation forest systems. In: Baldwin, V. C. Jr.; Lohrey, R. E., eds. Southern Forest Biomass Working Group Workshop; June 16-18, 1982; Alexandria, LA. New Orleans, LA: US Forest Serviee Southern Forest Experiment Station: 53-56.

76. --- 1986. Short rotation forestry research in the United States. Biomass. 9:125-133.

short rotation woody crops/ biomass

77. Geyer, W. A.; Naughton, G. G. 1980. Biomass yield and cost analysis of various tree species grown under a short-rotation management scheme in eastern Kansas. Proceedings, Central Hardwood Forest Conference III ; Columbia, Missouri: University of Missouri, Forestry Department: 315-329.

biomass/ agroforestry/ fuelwood/ short rotation woody crops/ forestry/ rotation length/ economic analysis

78. --- 1981. Short rotation forestry biomass yields and cost analysis in Eastern Kansas. In: Baldwin, V. C. Jr.; Lohrey, R. E., eds. Proceedings of the 1981 Southern Forest Biomass Workshop.; 7-19.

79. Geyer, Wayne A. 1978. Spacing and cutting cycle influence on short rotation Silver maple yield. Tree Planters' Notes. 29(1):5-7, and 26.

Field studies showed that silver maple trees grown at close spacings produced annual dry-weight-wood yields of 4 tons/acre, even after numerous coppice cuttings over an 8-year period. Annual yields were higher with a longer cutting cycle.

Silver maple/ spacing/ harvesting/ short rotation woody crops/ maple/ biomass/ silage

80. Gibson, Harry G.; Pope, Philip E. 1984. Design parameters for a biomass harvester for short-rotation hardwood stands. St. Joseph, Michigan: American Society of Agricultural Engineers; ASAE 84-1610. 12 p.

Design parameters for a short-rotation hardwood biomass harvester were developed from field tests and mathematical simulations methods. Severing methods, tires versus tracks, and compaction were evaluated from field tests. Power, weight, tractive effort and speed requirements were determined from simulation methods.

short rotation/ proceedings/ harvesting/ equipment.

81. Golob, T. B. 1986. Analysis of short rotation forest operations. Ottawa, Canada: Division of Energy, National Research Council of Canada; NRCC No. 26014. 127 p.

This analysis studied short rotation forest operations with the goal of establishing the optimum level of mechanization of SRF operations related to the 1985 cost of wood chips delivered to pulp mills, and to the cost of heating oil based on relative heating values of wood and oil. The biomass grown in SRF plantations is competitive on the open market with prices of wood and fiber used in pulp mills, and with the price of oil used in direct combustion. The SRF plantations are normally planted on low grade abandoned agricultural land, thus potentially providing a cash crop in most depressed farm areas.

costs.

82. Gordon, Mary; Roberts, Bernelda. 1981. 1981 Energy Bibliography. Madison, Wisconsin: Forest Products Research Society; Bibliography No. B1. 110 p.

A bibliography of material contained in the AIDS information retrieval file listing of energy related citations through 1979. Also contains ordering information for copies.

bibliography.

83. Graham, R. L. 1994. An analysis of the potential land base for energy crops in the conterminous United States. Biomass and Bioenergy. 6(3):175-189.

This paper defines the land suitable for energy crop production and estimates the yield potential of that land. Analyses of the relative economics of energy crop and alternative agricultural land uses will be required before the land base potentially available for energy crop production can be defined.

energy crops/ short-rotation woody crops/ herbaceous energy crops

84. Graham, R. L.; Downing, M. E. 1995. Potential supply and cost of biomass from energy crops in the TVA region. Oak Ridge, TN: Oak Ridge National Laboratory; ORNL-6858. 41 p.

Establishing the likely price and supply of energy crop biomass in a region is a complex task because biomass is not an established commodity as are oil, natural gas, and coal. In this study, the cost and supply of short-rotation woody crop (SRWC) and switchgrass biomass for the Tennessee Valley Authority (TVA) region are projected. Projected prices and quantities of biomass are assumed to be a function of the amount and quality of crop and pasture land available in a region, expected energy crop yields and production costs on differing soils and land types, and the profit that could be obtained from current conventional crop production on these same lands. Results include the supply curves of SRWC and switchgrass biomass that are projected to be available from the entire region, the amount and location of crop and pasture land that would be used, and the conventional agricultural crops that would be displaced as a function of energy crop production. Also, the separate impacts of varying energy crop production costs and yields, and interest rates are examined.

short-rotation woody crops/ biomass.

85. Graham, R. L.; English, B. C.; Alexander, R. R.; Bhat, M. G. 1992. Biomass fuel costs prediction for East Tennessee power plant. Biologue. 10:23-26.

biomass/ economic analysis/ Tennessee/ power plant/ short rotation woody crops/

fuels/ feedstocks

86. Graham, R. L.; Liu, M.; Noon, C.; Daly, M.; Moore, A. 1995. The effect of location and facility demand on the marginal cost of delivered wood chips from energy crops: a case study of the State of Tennessee. Second Biomass Conference of the Americas; Golden, Colorado: National Renewable Energy Laboratory : 1324-1333.

site productivity/ short rotation woody crops/ populus/ hybrid poplar/ hardwoods

87. Hakkila, P.; Leikola, M.; Salakari, M. 1979. Production, harvesting, and utilization of small-sized trees: final report on the research project on the production and utilization of short-rotation wood. Helsinki, Finland: Finnish National Fund for Research and Development; 162 p.

88. Hansen, E. A. 1991. Energy plantations in North Central United States: Status of research and development plantations . Energy Sources. 13:105-110.

89. --- 1987. SRIC yields: A look to the future. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. IEA/BA Task II Workshop - Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. Madison, WI: Forest Product Laboratory: 197-207.

Current SRIC record small plot yields are 4-7 times that of average field yields. SRIC yields necessary for marginal profitability have not yet been attained in field yields, but appear achievable when viewed from the perspective of present and projected SRIC field yields and small plot yields. Further SRIC yield increases will probably be forthcoming. However, the rate of future yield increases and the potential size of yield gains are uncertain. Whether the large yield gains achieved recently in agricultural crops can be duplicated in SRIC within a reasonable amount of time will depend on a number of factors including the future investment in cultural and breeding research and the realization of the biotechnology promise.

energy/ plantations/ economics/ biomass/ yields/ short rotation

90. Hansen, E. A.; Dawson, D. H.; Tolsted, D. N. Irrigation of intensively cultured plantations with paper mill effluent . TAPPI Journal. 63:5.

pines/ larch/ plantation management/ conifers/ short rotation woody crops

91. Hansen. E. A.; Madgwick, H. A. I. 1986. Short-rotation plantation management technology for coniferous species. In: Mitchell, C. P.; Nilsson, P. O; Zsuffa, L., eds. Proceedings of the Joint International Energy Agency/Forestry Energy Programme and Food and Agricultural Organization/Cooperative Network on Rural Energy Forest Energy Conference and Workshps on Research in Forestry for

Energy; Garpenberg, Sweden: Swedish University of Agricultural Sciences: 212-229.

conifers/ short rotation woody crops/ plantation management/ intensive culture

92. Hansen, E. A.; McLaughlin, R. A.; Pope, P. E. 1988. Biomass and nitrogen dynamics of hybrid poplar on two different soils: implications for fertilization strategy. Canadian Journal of Forestry Research. 18(2):223-230.

93. Hansen, E. A.; McNeel, H. A.; Netzer, D. A.; Phipps, H. M.; Roberts, P. S.; Strong, T. F.; Tolsted, D. N.; Zavitkovski, J. 1979. Short-rotation intensive culture practices for northern Wisconsin. Proceedings, 16th Annual Meeting, North American Poplar Council, Joint Meeting of the United States and the Canadian Chapters; August 14-17, 1979; Thomasville, Michigan. Filer City, Michigan: North American Poplar Council: 47-63.

short rotation intensive culture/ poplars, hybrid/ site preparation/ irrigation/ Wisconsin/ poplars

94. Hansen, E. A.; Morin, M. J. 1983. Short rotation plantation tending: Biological needs and mechanization. In: Nilsson, P. O.; Zsuffa, L., eds. Short Rotation Forest Biomass Production Technology and Mechanization: Proceedings of a workshop held by the IEA Forest Energy Programme; Garpenburg, Sweden: Swedish University of Agricultural Sciences, Department of Operational Efficiency: 37-42.

plantation management/ short rotation woody crops

95. Hansen, E. A.; Netzer, D. A.; Rietveld, W. J. 1984. Site preparation for intensively cultured hybrid poplar plantations. St. Paul, MN: USDA Forest Service North Central Experiment Station ; Research Note NC-320. 4 p.

Five site preparation treatments consisting of combinations of tillage, contact herbicide (glyphosate), and pre-emergent herbicide (linuron) were tested for their effects on tree survival and growth. Treatments had little effect on tree survival, but effects on second-year tree height were significant and additive - i.e., tree height increased as the number of types and repetitions of site preparation increased. Best growth was obtained with a summer fallow-with-herbicide treatment consisting of two applications of glyphosate followed by plowing and repeated disking, plus spring disking and application of linuron at planting time. A comparable growth response was obtained from the less intensive fall-plow treatment consisting of one application of glyphosate followed by plowing and disking, plus spring disking and application of linuron at planting time. The least effective treatment was no-till, presumably because of lowered soil temperatures.

Intensive culture/ weed control/ glyphosate/ linuron/ no-till/ tillage/ fallowing/ plantation establishment.

96. Hansen, Edward A.; Baker, James B. 1979. Biomass and nutrient removal in short rotation intensively cultured plantations. Symposium on Impact of Intensive Harvesting on Forest Nutrient Cycling; Syracuse, NY: State University of New York: 130-151.

Reported dry matter production of wood plus bark in short rotation intensive culture plantations ranges up to 20,000 kg/ha/yr, 3 to 5 times that reported for some natural stands. Mean annual uptake of nitrogen ranged from 20- to 80-kg/ha/yr and generally decreased with increasing plantation age. Maximum total nitrogen content ranges from 100 kg/ha in young plantations up to 400 kg/ha in 20 year old plantations. Nutrient concentration is not noticeably different in older short rotation intensive culture plantations than in natural stands. However, because of higher biomass production in SRIC, both total nutrient content and the annual uptake rate are also higher. Possible approaches for increasing nutrient utilization efficiency are (1) avoid harvesting young (< 7 yrs) plantations, (2) leave high nutrient components distributed on the site, (3) select efficient nutrient utilization species or clones, and (4) select harvesting season to coincide with low nutrient concentrations in wood and bark.

coppice/ biomass/ genetics

97. Hartsough, B. R. 1992. Product/harvesting options in agroforestry plantations in the San Joaquin Valley, California. St. Joesph, MI: American Society of Agricultural Engineers; ASAE paper 90-7549. 23 p.

Harvesting costs and annual worths of stumpage were calculated for product/harvesting combinations. Optimal rotation ages were near 10 years. Production of firewood for local consumption had higher worth than fuel chip, pulp chip, or firewood production for urban markets. Methods using whole tree transport were not competitive with systems that produced firewood or chips on site.

plantations/ harvesting/ costs/ analysis.

98. Hartsough, B. R.; Stokes, B. J.; Kaiser, C. 1991. Short rotation poplar: a harvesting trial. Forest Products Journal. 42(10):59-64.

A study of components of two systems for harvesting short-rotation poplar, one utilizing a tracked skidder and the other based on cable yarding, was carried out in Oregon. The terrain was flat, and dry enough to allow the use of tractive equipment. The skidder system appeared to be a viable alternative for producing pulp chips during dry weather. Several problems need to be addressed to make the yarding system physically and economically feasible. If trees were prebunched, the production rate for the yarder would be half that of the flail delimber/debarker. Some of the crop trees used as intermediate supports broke while yarding unbunched turns; stronger supports would be needed to handle the larger prebunched turns.

harvesting/ mechanization/ short rotation/ economics

99. Hartsough, Bruce R. ; Nakamura, Gary. 1990. Harvesting Eucalyptus for fuel chips. California Agriculture. 44(1):7-8.

Six year old eucalytus trees were harvested, chipped, and delivered to an electric power plant. Costs exceeded the value of the chips. Expenses could be reduced if bigger trees were harvested, more acres were cut, and the stand were closer to the power plant.

costs/ Eucalyptus/ harvesting

100. Hartsough, Bruce R.; Richter, Randall. 1994. Mechanization potential for industrial-scale fiber and energy plantations. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3, 1994; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 65-78.

Current costs for all activities on an irrigated, short rotation, pulpwood and energy plantation in California were compared with estimated minimum costs for the same activities if high levels of effort were put into mechanization. The plantation, 4000 ha, is operating on an eight year rotation, with 500 ha in each age class. At this scale, move-in costs are insignificant and can be ignored; most of the specialized equipment can be utlized throughout the dry operating season, about eight months. Because the plantation has equal areas in each age class, costs for activities on each age class are incurred each year. The differential cost between current and minimum was derived for each activity, and yearly benefits were calculated. For the California plantation, further mechanization efforts were estimated to provide benefits of up to half a million dollars per year. The majority of this would come from an improved method of delimbing and debarking. Other large gains were projected for a continuous-travel felling machine, lighter chip vans and a better method of handling drip irrigation lines. Minor benefits would accrue from further mechanization of some cultural operations: planting, stump removal and thinning of coppice sprouts.

costs/ economics/ equipment/ management/ short rotation/ plantations/

mechanization

101. Hasselgren, Kenth. 1996. Municipal Wastewater Recycling in Energy Forestry. In: Chartier, P.; Ferrero, G. L.; Henius, U. M.; Hultberg, S.; Sachau, J.; Wiinbald, M., eds. Biomass for energy and the environment - Proceeding of the ninth European bioenergy conference; June 24-27, 1996; Copenhagen, Denmark. Oxford, England: Elsevier Science Limited: 90-95.

Irrigation of short rotation energy forestry (willow plantations) with pre-treated municipal wastewater (secondary effluent) is being tested at the Kagerod Wastewater Treatment Plant, Svalov Municipality, Sweden. The main objectives are: i) to evaluate potentials of biomass productivity and tertiary wastewater treatment efficiency in willow plantations after application of pre-treated wastewater and ii) to demonstrate alternatives or complements to conventional wastewater treatment methods where also wastewater resources are being recycled or reused. The project was established in 1992 and concerns mainly measurements of biomass growth and removal of various wastewater constituents (eg nitrogen, phosphorus, organic matter, metals) in the soil-plant system. Wastewater is being applied during the growth period (May-October) using a solid-set spray irrigation system. Wastewater irrigation up to a rate of 12 mm/d during three growth periods has not affected superficial groundwater quality. The results indicate wastewater treatment efficiencies at similar or higher rates compared with traditional techniques. The willow plants developed better in parcels applied with wastewater than in control parcels. Irrigated willows with 3-year-old shoots on 4-year-old roots yielded between 22 and 37 tonnes of dry matter per hectare or four times more than control plants.

Muncipal wastewater/ land treatment/ slow rate treatment/ spray irrigation/ soil-plant system/ natural system/ nutrients/ nitrogen/ phosphorus/ energy forestry/ willow/ Sweden

102. Heilman, P. E. ; Fu-Guang, X. 1993. Influence of nitrogen on growth and productivity of short-rotation Populus trichocarpa x Populus deltoides hybrids. Canadian Journal of Forestry Research. 23:1863-1869.

nitrogen/ growth/ productivity/ Populus tichocarpa/ Populus deltoides/ hybrids/ short rotation woody crops

103. Heilman, P. E.; Peabody, D. V.; Debell, D. S.; Strand, R. S. 1972. A test of close-spaced short-rotation culture of black cottonwood. Canadian Journal of Forestry Research. 2:465-459.

104. Heilman, Paul E. ; Stettler, R. F. 1990. Genetic variation and productivity of Populus trichocarpa and its hybrids. IV. Performance in short rotation coppice. Canadian

Journal of Forestry Research . 20(9):1257-1264.

Resprouting after harvest and rapid growth of sprouts are often considered essential for success of close-spaced, short rotation cultural systems. This study examined resprouting, subsequent growth, and dry weight production following the initial 4-year harvest of a 'common garden' trial of 50 clones of populus trichocarpa. The clones were selected from 10 populations from major river drainages from western British Columbia, Washington, and Oregon. The clone identified as superior in coppicing in this experiment represent potential parents for new hybrids intended for short rotation systems involving coppicing.

coppice/ genetics/ growth/ yields/ short rotation

105. Heilman, Paul E.; Stettler, R. F.; Hanley, Donald P.; Carkner, Richard W. 1990. High yield hybrid poplar plantations in the Pacific Northwest. Pullman, WA: Washington State University; PNW356. 32 p.

This bulletin presents a system for "domestication" of wood and fiber production called short rotation intensive culture, and describes the newly developed hybrid poplars recommended for that culture. In culture and in harvesting the system is closer to agriculture than to forestry. Success of the system depends on having good soil, appropriate cultural practices and trees bred and selected specifically for high productivity. Trees that make the system work best in the Pacific Northwest (PNW) are hybrid poplars. The most productive derive from crosses of native black cottonwood (Populus trichocarpa) and eastern cottonwood (P. deltoides).

short rotation intensive culture/ poplars/ Pacific Northwest.

106. Hodges, J. W. 1986. The Short Rotation Woody Crops Program Computerized Technical Data Base System. Oak Ridge, TN: Oak Ridge National Laboratory; ONL/TM-9959.

Short rotation woody crops/ information resources.

107. Hoffman, Wayne; Cook, James H.; Beyea, Jan. 1996. Some ecological guidelines for large-scale biomass plantations. In: Carter, Mason C., ed. Growing Trees in a Greener World: Industrial Forestry in the 21st Century; 1996; Louisiana State University. Baton Rouge, LA: Louisiana State University School of Forestry: 33-42.

The National Audubon Society sees biomass as an appropriate and necessary source of energy to help replace fossil fuels in the near future, but is concerned that large-scale biomass plantations could displace significant natural vegetation and wildlife habitat, and reduce national and global biodiversity. We support the

development of an industry large enough to provide significant portions of our energy budget, but we see a critical need to ensure that plantations are designed and sited in ways that minimize ecological disruption, or even provide environmental benefits. We have been studying the habitat value of intensively managed short-rotation tree plantations. Our results show that these plantations support large populations of some birds, but not all species using the surrounding landscape, and indicate that their value as habitat can be increased greatly by including small areas of mature trees within them. We believe short-rotation plantations can benefit regional biodiversity if they can be deployed as buffers for natural forests, or as corridors connecting tree tracts. To realize these benefits, and to avoid habitat degradation, regional biomass plantation complexes (e.g. the plantations supplying all the fuel for a powerplant) need to be planned, sited, and developed as large-scale units in the context of the regional landscape mosaic.

108. Hoganson, H. M.; Lothner, D. C. 1987. Short-rotation intensive culture systems as part of a forest-wide production system. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 160-176.

Short-rotation intensive culture (SRIC) systems are a potential new management tool in forestry. The value of SRIC systems is difficult to measure because of the uncertainty surrounding future product prices. Results from harvest scheduling models can be used to help understand how SRIC systems can best be integrated into an existing forest. Results from an analysis of the forested region in northeastern Minnesota indicate that SRIC systems offer some potential, especially if the product produced is not limited to fuelwood use.

harvesting/ linear programming/ joint production/ management/ proceedings

109. Hohenstein, William G. ; Wright, Lynn L. 1994. Biomass energy production in the United States: An overview. Biomass and Bioenergy. 6(3):161-173.

This paper summarizes reports prepared for the U.S. Environmental Protection Agency (EPA) by researchers at the U.S. Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL). It also presents conclusions from a Biomass Energy Strategies Workshop conducted at ORNL. The Biofuels Feedstock Development Program (BFDP) has largely concentrated on the development of dedicated biomass feedstocks, referred to as energy crops. Two general types of energy crops have received the most attention--short-rotation woody crops (SRWC) and herbaceous energy crops (HEC). These cropping systems use traditional food production technologies as a means of maximizing the production of biomass per unit of land. Research focuses on the development of new crops and cropping technologies. The reports prepared for EPA and summarized by this article include discussions of crop production technologies, available land, economic considerations and environmental trade-offs. The discussion of other sources of biomass occurs only in the context of the workshop on biomass energy strategies.

biomass energy/ herbaceous energy crops/ short-rotation woody crops/ environmental impacts/ economics/ biomass feedstocks/ biomass strategies

110. Host, G. E. ; Isebrands, J. G. 1994. An interregional validation of ECOPHYS, a growth process model of juvenile poplar clones. Tree Physiology. 14:933-945.

photosynthesis/ poplars/ short rotation woody crops/ models/ ECOPHYS

111. Host, G. E.; Rauscher, H. M.; Isebrands, J. G.; Dickmann, D. I.; Dickson, R. E.; Crow, T. R.; Michael, D. A. 1990. St. Paul, Minnesota: North Central Forest Experiment Station; NC-141. 22 p.

poplars/ whole-tree/ short rotation intensive culture/ photosynthesis/ carbon allocation/ ECOPHYS.

112. Howe, D. L. 1994. The application of a skyline yarding technique in the harvesting of ecologically sensitive flat terrain sites. In: Sessions, John; Kellogg, Loren., eds. Proceedings of the Meeting on Advanced Technology in Forest Operations: Applied Ecology in Action.; July 24-29, 1994; Corvallis, Oregon USA. Oregon State University: 124-134.

The logging technique consists of a skyline yarder extracting cut-to-length Eucalyptus grandis poles, presented by a tree harvester, on moderate sloping terrain. This unusual combination of equipment is due to the results of research showing that short-rotation sites are sensitive to compaction and erosion, mainly as a result of harvesting occurances and improper harvesting techniques previoulsy utilized. Productivity measurement and cost analysis proved this combination to be a viable option which would satisfy many of the needs of flat terrain harvesting.

harvesting/ short rotation/ plantations/ cable-yarder/ slopes/ sensitive sites

113. Hubbes, M. 1990. Development of biotechnology programmes for energy forestry. In: Mitchell, C. P.; Zsuffa, L.; Anderson, S.; Stevens, D. J., eds. Forestry, forest biomass and biomass conversion. The IEA Bioenergy Agreement (1986-1989) Summary Reports: 75-89.

Dramatic gains in tree growth can be achieved by today's breeding techniques. However, much of these gains may be lost due to pathogen-caused diseases and insect attack. Conventional breeding programs, geared to produce pest-resistant trees, are slow and require a large number of plants and space. Therefore,

alternative techniques which use more powerful tools have to be employed to accelerate the processes that produce effective methods of pest control. Biotechnology, employing cell and tissue culture, cell fusion, recombinant DNA technology for cell cloning, and genetic engineering, is a new and rapidly developing field/science. Moreover, it seems ideally suited for the development of pest-resistant plant material for energy plantations. This paper summarizes the results of several workshops held by the representatives of the IEA member countries on this topic.

plantations/ energy/ pests/ tolerance/ genetics.

114. Hudson, J. B.; Mitchell, C. P. 1992. Integrated harvesting systems. In: Mitchell, C. P.; Zsuffa, L.; Andersson, S.; Stevens, D. J., eds. Biomass and Bioenergy Special Issue. IEA Bioenergy Agreement Progress and Achievement 1989-1991. April 2-3, 1992; Edinburgh, UK. Oxford, United Kingdom: Pergamon Press Ltd, 121-130.

The evolution of integrated harvesting systems is examined and progress recorded from early systems studies, through development of optimal allocation models to the uptake of integrated systems in commercial harvesting operations. The progress that has been made in the introduction of integrated harvesting systems has been as a result of technological improvements to the harvesting equipment, and to supply incentives which have raised delivered wood fuel prices. The introduction of integrated harvesting operations has realised benefits to the forest stand in terms of stand health and reduced fire hazard.

integrated harvesting/ bioenergy

115. Inman, R. E.; Salo, D. J.; McGurk, B. J. 1977. Silvicultural biomass farms, Volume IV: site-specific production studies and cost analysis. The MITRE Corporation/METREK Division; MITRE Technical Report IV. 123 p.

The costs of producing silvicultural biomass on intensively managed, short-rotation farms at ten study sites are estimated. Cost estimates are derived by means of a computerized financial model, based on a conceptual production design that identifies the sequence of operations and activities for the farm and the materials and labor required. Site-specific characteristics, requirements and limitations, including biomass yields, are reflected in the design and in the estimated costs. An energy budget for biomass production and a preliminary examination of environmental impacts, are also presented.

costs/ yields/ short rotation.

116. Insley, H. 1987. The economics of coppice as an alternative farm crop in Great Britain.

In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 293-302.

The economic returns from conventional and short rotation coppice under British conditions are examined. Establishment cost models are given for both types of coppice regime. Internal rates of return from conventional coppice are calculated for a range of species, income levels and for different assumptions on planting grants, tax incentives and land costs.

economics/ economic analysis/ short rotation

117. Isebrands, J. G. 1981. Reaction wood anatomy and its effect on kraft paper from short rotation intensively cultured trees. International Association of Wood Anatomists (IAWA) Bulletin. 2:57-58.

wood anatomy/ kraft pulp/ short rotation intensive culture/ poplars

118. --- 1982. Toward a physiological basis of intensive culture of poplar. 1982 TAPPI Research and Development Conference; August 29-September 1, 1982; Asheville, NC. TAPPI Press, Atlanta, GA: 81-90.

Recommendations for silvicultural practices are made based on morphological and physiological patterns for poplar, including crown morphology, photosynthesis, and photosynthate production.

silviculture/ poplars

119. Isebrands, J. G. ; Nelson, N. D. 1983. Crown architecture of short-rotation, intensively cultured Populus: II. Branch morphology and distribution of leaves within the crown of Populus "Tristis"as related to biomass production. Canadian Journal of Forestry Research. 12:853-864.

photosynthetic efficiency/ crown architecture/ short rotation woody crops/ poplars/ branch characteristics/ Populus tristis/ biomass production/ Wisconsin/ leaf composition

120. --- 1980. Photosynthate distribution within short-rotation, intensively cultured populus clones during the establishment year. Procedings of the 6th North American Forest Biology Workshop; August 11-13, 1980; Edmonton, Alberta. University of Alberta: 150.

121. Isebrands, J. G.; Nelson, N. D.; Dickman, D. I.; Michael, D. A. 1983. Yield physiology of SRIC poplars. St. Paul, Minnesota: USDA Forest Service North

Central Experiment Station;

122. Isebrands, J. G.; Sturos, J. A.; Crist, J. B. 1979. Alternatives for the integrated utilization of short rotation intensively cultured Populus raw material. Proceedings, 1979 TAPPI Annual Meeting; TAPPI Press: 181-187.

short rotation intensive culture/ biomass/ Populus/ by-products

123. --- 1979. Integrated utilization of biomass: A case study of short rotation intensively cultured Populus raw material. TAPPI Journal. 62(7):67.

A case study is presented for the integrated utilization of the total above ground biomass prodced by a 5-year-old SRIC Populus plantation grown at a 1.2-m spacing. Vacuum airlift segregation was employed and four alternative systems for utilization were explored including:(I) pulp only, (II) fuel only, (III) pulp and fuel, and (IV) pulp, fuel, and animal feed supplement. The SRIC Populus produced more than 42 metric ton/ha (oven-dry) raw material for pulp in System I, 200 Mkcal/ha energy equivalent in System II, 27 metric ton/ha of raw material for pulp plus 68 Mkcal/ha energy equivalent in System III, and 27 metric ton/ha for pulp, 48 Mkcal/ha energy equivalent, plus 5 metric ton/ha for high-value animal feed supplement in System IV. The VAS process provides the manager with several integrated utilization alternatives; we believe analyses such as presented in this case study facilitate the economic evaluation of these alternatives.

short rotation woody crops/ poplars/ biomass/ kraft pulp

124. Jen, I-an. 1987. An economic analysis on planting Leucaena in Taiwan. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 280-292.

This paper evaluates recent capital investments in first rotation Leucaena leucocephala plantations in Tawain. The internal rate of return is determined by Hertz's method. There is some potential for making a profit from planting leucaena in Taiwan.

plantations/ short rotation/ economic analysis

125. Johnson, J. E.; Pope, P. E.; Mroz, G. D.; Payne, N. F. 1987. Environmental impacts of harvesting wood for energy. Great Lakes Regional Biomass Program; 169 p.

An overview of the environmental impacts of timber harvesting in forests within the Great Lakes Region. Specific impact areas include soil erosion, sedimentation and stream water quality, forest regeneration, nutrient cycling and depletion, and wildlife habitat. The book concludes with management practice suggestions for the harvesting of wood energy.

126. Jones, P. C.; Shen, S-Y. 1982. A framework for evaluating the economics of short-rotation forestry research and development. U.S. Department of Energy,Argonne National Laboratory; ANL/CNSV-35. 56 p.

This report provides an introductory review of short-rotation forestry and presents a framework for economic evaluation of short-rotation forestry research and development. This framework is based on a consumer surplus approach to cost-benefit analysis, and the report presents a procedure for estimating supply curves for wood from short-rotation forestry. An important part of the procedure for deriving supply curves is a linear complementary model of short-rotation forestry, which is used to maximize the net present value of employed resources. This model can be used to calculate optimal sustainable harvests from short-rotation forests.

127. Joshlin, J. D.; Schoenholtz, S. E. 1995. Measuring the Environmental Effects of Converting Cropland to Short-Rotation Woody Crops: A Research Approach. Proceeding of the Internation Energy Agency Workshop, "Environmental Guidelines for Developing Sustainable Energy Output from Biomass"; September 17-23, 1995; Sault Ste Marie, Michigan. New Zealand Journal of Forestry Research: 33.

Conversion of cropland to short-rotation woody biomass crops (SRWC) has received increasing interest as biomass utilization technologies have improved and concerns for effects of fossil fuel emissions on global climate have developed. Effects of this conversion on erosion, hydrology, water quality, and soil productivity may be significant. A large cooperative research project began in the spring of 1995 at three sites representative of the lower Tennessee Valley to compare the environmental effects of growing traditional crops to the production of SRWC's over 3- to 5-year rotations. This paper presents the research approach that will be used to evaluate these effects and a few preliminary results from the initial three months of the study. Small watersheds cultivated in row crops - corn (*Zea mays* L.) or cotton (*Gossypium hirsutum*) are being compared to small watersheds in tree crops - sycamore (*Platanus occidentalis* L.), sweetgum (*Liquidambar styraciflua* L.), or eastern cottonwood (*Populus deltoides* Bartr.) with respect to: 1) erosion, 2) runoff quality (nutrients, pesticides) and quantity, 3) groundwater quality, 4) soil chemical changes (carbon, nutrients, pesticides), 5) soil physical changes (infiltration, bulk density, aggregate stability), 6) soil biological changes, and 7) wildlife populations. During the spring and summer of the first growing season, few differences in runoff quantity and erosion were observed between treatments. One exception was a tendency towards higher

erosion under cotton than cottonwood. Larger differences are expected in later years as trees become established and a litter layer developes. At two sites during the first growing season, differences between row crops and SRWC's were observed in both the runoff and leaching of NO3-N, NH4-N, P, Ca, Mg, and K in spring following fertilization of the row crops only at two sites. Wildlife studies on small mammals and bird populations, as well as microfauna, are just getting under way.

short-rotation woody biomass crops/ *Platanus occidentalis*/ *Liquidambar styraciflua*/ *Populus deltoides*/ environmental impacts/ erosion/ water quality/ soil quality

128. Kaiser, Charles E.; Rice, Donald E.; Wallace, Krik R. 1994. Stand establishment and culture of hybrid poplar. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3, 1994; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 25-30.

Fueled by the energy crisis of the mid 1970's and a simultaneous increase in domestic demand for communication grade paper products for the computer age and world demand for tissue and towel grades, technicians turned to short rotation intensive culture research for biomass and pulp fiber supplies. An overview of all management practices developed to successfully establish, maintain and harvest short rotation hybrid cottonwood in the Pacific Northwest by James River Corporation is presented.

energy/ management/ short rotation/ genetics

129. Kennedy, H. E.; Henderson, W. H. 1976. Cultivation in cottonwood plantations-practices and equipment. In: Thiegles, B. A.; Land, S. B. Jr., eds. Proceedings of the Symposium on East Cottonwood and Related Species.; LSU, Baton Rouge, LA. Baton Rouge, LA: North American Poplar Council: 379-384.

130. Kenney, W. A.; Gambles, R. L.; Sennerby-Forsse, L. 1992. Feedstock characteristic and quality. In: Mitchell, C. P.; Ford-Robertson, J. B.; Hinkley, T. M.; Sennerby-Forsse, L., eds. Ecophysiology of Short Rotation Forest Crops. New York: Elsevier Science Publishers Ltd.: 267-284.

feedstocks/ short rotation woody crops/ short rotation intensive culture/ yields.

131. Kermse, R. D. ; Fisher, J. T. 1989. Species screening and biomass trials of woody plants in the semi-arid southwest United States. Biomass. 18:15.

short rotation intensive culture/ biomass/ coppice/ atriplex/ Leucaena/ Prosopis/

shrubs/ species selection

132. Kerr, S. N.; Sopper, W. E. 1982. Utilization of municipal sludge for woody biomass production in mined land. Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation; Lexington, Kentucky: University of Kentucky: 313-317.

municipal sludge/ short rotation woody crops/ mined land

133. Keville, B. J.; Devenish, E. J. 1983. Harvesting developments for short rotation forest crops. Proceedings of the 7th International FPRS Industrial Wood Energy Forum; September 19-21, 1983; Nashville, TN. Madison, WI: Forest Product Research Society: 51-58.

The harvester developments, for short rotation forest crops at present can be broadly classified into two types, namely self-propelled and towed units. The design and development approach varies in the different countries.This is desirable to allow for the different conditions, terrain etc. encountered in the differing climates of the participating countries.

harvesting/ equipment/ research

134. Knutell, Hans. 1992. Economics of wood energy supply systems. In: Mitchell, C. P.; Zsuffa, L.; Anderson, L.; Stevens, D. J., eds. Biomass and Bioenergy Special Issue. IEA Bioenergy Agreement Progress and Achievement 1989-1991. April 2-3, 1992; Edinburg, UK. Oxford, United Kingdom: Pergamon Press Ltd.: 193-209.

Summaries of papers presented at a conference on Bioenergy Supply systems are presented.

bioenergy/ economics/ coppice/ harvesting/ energy

135. Kofman, Pieter D. 1996. Storage trials with willow from short rotation. In: Chartier, P.; Ferrero, G. L.; Henius, U. M.; Hultberg, S.; Sachau, J.; Wiinbald, M., eds. Biomass for energy and the environment - Proceedings of the ninth European bioenergy conference; June 24-27, 1996; Copenhagen, Denmark. Oxford, England: Elsevier Science Limited: 863-866.

The storage trial is being conducted to see the influence of piece size and the method of covering the storage losses of willow from short rotation.

136. Kolster, H. W. 1982. The production of poplar wood with short rotation. Busbouwtijdschrift. 54(7/8):214-220.

137. Kormanik, P. P.; Tyre, G. L.; Belanger, R. P. 1973. A case history of two short-rotation coppice plantations of sycamore on Southern Piedmont bottomlands. Orono, Maine: College of Life Science and Agriculture, University of Maine; 10 p.

138. Koski, V.; Dickman, D. I. 1992. Tree ideotype. In: Mitchell, C. P.; Zsuffa, L.; Anderson, S.; Stevens, D. J., eds. Biomass and Bioenergy Special Issue. IEA Bioenergy Agreement Progress and Achievement 1989-1991. April 2-3, 1992; Edinburg, UK. Oxford, United Kingdom: Pergamon Press Ltd, 71-75.

Application of the ideotype concept for short rotation biomass production species was studied using a modelling approach. A verbal model which includes a list of desirable traits is given. Two mathematical models are introduced. The first one, ECOPHYS, simulates the growth of young trees, and the other one, a Finnish model, WILLOW, the growth and production of willow stands. Results are encouraging and continued work with the ideotype models is recommended.

production/ morphology/ physiology/ ideotype/ ECOPHYS/ WILLOW

139. Kuiper, L. C.; Kolster, H. W. 1996. Twenty years of research on poplar biomass production in the Netherlands. In: Chartier, P.; Ferrero, G. L.; Henius, U. M.; Hultberg, S.; Sachau, J.; Wiinbald, M., eds. Biomass for energy and the environment - Proceedings of the ninth European bioenergy conference; June 24-27, 1996; Copenhagen, Denmark. Oxford, England: Elsevier Science Limited: 96-102.

Research on optimization of biomass production systems for energy purposes is a time consuming and costly affair. Many lessons can be learned from long term research trials, such as the ones presented here. Poplar crops spaced somewhat wider than commonly adopted for energy plantations (1600 to 3200 trees per hectare) may significantly reduce stand establishment costs while maintaining high production levels over a long period of time. As a result larger sized stems are produced which yield biomass for pulp and energy purposes simultaneously, allowing the tree farmer greater flexibility towards the market of wood chips.

Biomass/ short rotation forestry/ coppice/ poplar/ clones/ rotation/ yield/ economics

140. Laarman, J. G.; Vasievich, J. M.; Durst, P. B. 1986. Technologies to harvest fast-growing energy plantations in Hawaii and the Philpppines. In: Div. 3, IUFRO World Congress. 18 IUFRO World Congress, Div. 3, Forest Operations and Techniques; September 7-13, 1986; Ljubljana, Yugoslavia. 256-267.

Harvesting technologies are still in early stages of development. Many observers envision a highly mechanized approach in Hawaii, where energy plantations may be harvested with feller-bunchers, grapple skidders, and large chippers. In the Philippines, in contrast, current labor-intensive technologies include cutting with hand tools, and forwarding manually or with draft animals. Some experimentation has been conducted with more capital-intensive methods, e.g. European cable systems to move wood to power plants.

141. Land, S. B. Jr. 1982. Genetic selection of American sycamore for biomass production in the mid-south. Oak Ridge, TN: Oak Ridge National Laboratory,, Environmental Sciences Division.; ORNL/Sub/81-9051/1.

142. Land, S. B. Jr.; Ezell, A. W.; Schoenholtz, S. H.; Tuskan, G. A.; Tschaplinski, T. J.; Stine, M.; Bradshaw, H. D.; Kellison, R. C.; Portwood, J. 1996. Intensive Culture of Cottonwood and Hybrid Populars. In: Carter, Mason C., ed. Growing Trees in a Greener World: Industrial Forestry in the 21st Century; 1996; Louisiana State University. Baton Rouge, LA: Louisiana State University School of Forestry: 167-189.

143. Ledin, Stig. 1992. The energy forestry production systems. In: Mitchell, C. P.; Zsuffa, L.; Anderson, S.; Stevens, D. J., eds. Biomass and Bioenergy Special Issue. IEA Bioenergy Agreement Progress and Achievement 1989-1991. April 2-3, 1992; Edinburg, UK. Oxford, United Kingdom: Pergamon Press Ltd, 17-24.

The economics of energy forestry must be improved to make the whole concept viable. Although the economics need strengthening, it has been agreed that energy forestry is one of the most promising alternatives to cereal crops on farm land. There are two main ways to improve the economics: to increase production of stemwood per area and time, and to lower the costs of production. Good achievements along these routes have been reached over the last three years. Improving each step in growing is being achieved gradually. Lowering the costs is a more stepwise process, for example as was the case when a modified maize harvester proved to work surprisingly well as an energy forestry harvester. Introductory work during the three-year period indicates that expert systems or decision support systems may play an important role to share and use the knowledge on energy forestry production systems. For immediate use, a handbook on how to grow short rotation forests has been published.

short rotation/ economics/ environmental impacts/ production

144. --- 1987. The use of woody biomass for energy in Scandanavia. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 40-47.

In Sweden, the use of wood for energy is more extensive than in other Scandanavian countries. In all Scandanavian countries the actual energy policy is aiming at systems where as much as possible of the energy used is based on sustainable, preferably renewable and indigenous energy sources.The development of short-rotation energy forest systems in Sweden will to a large extent be dependent on the market, which in turn will be very much dependent on national and local political decisions.

energy/ proceedings/ short rotation

145. Ledin, Stig and Alriksson, Agnetha. 1992. Handbook on How to Grow Short Rotation Forests. Uppsala, Sweden: IEA/BA Task V, Swedish University of Agricultural Sciences. 330 p.

This handbook deals with how to grow short rotation forests and the economics of the system. The book represents a joint effort of people working with intensively grown woody crops in the following countries: Austria, Canada, Denmark, Italy, Sweden, UK, and USA. These are members of the International Energy Agency Bioenergy Agreement, Activity 1: Energy Forestry Production System. An online updated report is available at http://www.abda.ac.ulc/ieabioenergy/srfhbook/srfhb.hti.

short-rotation woody crops.

146. Lichty, R. W.; Bradley, D. P. 1987. Measuring regional ecomomic impact of SRIC programs using input-output analysis. Duluth, MN: IEA/BA; 11 p.

Describes an enhancement to traditional Input-Output analysis which can examine inter-institutional transfers. Such transfers are common to most government subsidy programs yet the various impacts are seldom obvious. In a specific case, the new Conservation Reserve Program is designed to both reduce price supports as well as the need for expensive soil erosion preventatives. Yet, in their place is a ten year transfer payment program as well as an initial cost sharing program. The net efects on government costs and social welfare are obscure.

cost-benefit analysis/ IMPLAN/ regional .

147. Linval, F.; Lothner, D. C. Economic evaluations of short rotation biomass energy systems-An annotated bibliography. Duluth, Minnesota: North Central Forest Experiment Station USDA Forest Service; Information Report 88:3.

List of bibliographies with brief abstract.

bibliography/ costs/ economics/ short rotation.

148. Liu, W.; Merriam, R. A.; Phillips, V. D.; Singh, D. 1993. Estimating short-rotation Eucalyptus saligna production in Hawaii: An integrated yield and economic model. Bioresource Technology. 45:167-176.

short rotation woody crops/ Hawaii/ Eucalyptus saligna

149. Lortz, D. A.; Betters, D. R.; Wright, L. L. 1994. Production function for short-rotation woody-crop Populus spp. plantations. Canadian Journal of Forestry Research. 24:180-184.

production/ short rotation woody crops/ poplars/ biomass

150. Lothner, D. C. 1988. Economic evaluations for short rotation biomass production systems. In: Mitchell, C. P.; Zsuffa, L.; Anderson, S.; Stevens, D. J., eds. Forestry, forest biomass and biomass conversion.; Duluth, MN: The IEA Bioenergy Agreement (1986-1989) Summary Reports: 135-144.

Economics were added for the first time, as a formal 'Activity' in the 1986 IEA/BA Task II. The objective of the 'Activity' was to economically evaluate the state of the art for short-rotation biomass production systems. This was done through three significant economic workshops, a comprehensive annotated bibliography, the development and testing of a standardized cost accounting spreadsheet for reporting cost information, and the publishing of numerous technical papers. Given the economic climate during 1986-88, short-rotation woody crop systems for energy appeared marginal in most instances without government incentives.

biomass/ production/ short rotation/ economics

151. --- 1990. Economic evaluations for short-rotation biomass production systems. Biomass. 22:135-144.

biomass production/ short rotation intensive culture/ economic analysis

152. --- 1987. A framework for evaluating short-rotation biomass projects from the perspective of society and the individual firm. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13; Duluth, Minnesota. IEA/BA: 3-10.

A cost-benefit analysis is often prescribed to evaluate short-rotation biomass projects. Such an analysis in the broad sense should include a series of appraisals that evaluate financial efficiency, economic efficiency, economic impacts, social impacts, and environmental impacts. The appraisal process of a project should include the following steps: defining the problem, designing the analysis, collecting the data, performing the analysis, comparing the results, and presenting the results.

cost-benefit analysis/ project appraisal/ economics

153. --- 1991. Short-rotation energy plantations in North Central United States: an economic analysis. Energy Sources. 13:111-117.

154. Lothner, D. C.; Hansen, E. A.; Netzer, D. A. 1988. Growing and utilizing intensively cultured woody crops for energy: Some recent economic evidence from the north central United States. In: Lonner, G.; Tornquist, A., eds. Proceedings from the Workshop: Economic Evaluations of Biomass Oriented Systems for Fuel - International Energy Agency Bioenergy Task III, Activity 4 (Applications of Systems Analysis); Garpenberg, Sweden: Swedish University of Agricultural Sciences, Department of Forest - Industry - Market Studies: 92-102.

yields/ short rotation woody crops/ short rotation intensive culture/ economic analysis

155. Lothner, D. C.; Hoganson, H. M.; Rubin, P. A. 1986. Examining short-rotation hybrid poplar investments by using stochastic simulation. Canadian Journal of Forestry Research. 16(6):1202-1207.

We examined and compared short rotation hybrid poplar investments using standard discounted cash flow and stochastic simulation. With stochastic simulation, triangular probability density functions were used to describe the values for three important uncertain factors: product price, product yield, and harvest and transport costs. We found that the net present value per acre could range from a minus $310 to a positive $1010 with a mean value of about $140, using a 4% discount rate. Based on the assumptions used, product price uncertainty was found to be the major cause of uncertainty surrounding the financial returns from a short rotation system. Because information on future prices is limited, decisions about short rotation systems should be made carefully. Thinking through the uncertainties and collecting information should help investors make better choices.

economic analysis/ cost-benefit analysis/ economics

156. Lowe, Hamish T.; Sims, Ralph E. H.; Cooper, Jim A. 1994. Utilization of short rotation forestry for fuelwood from an effluent disposal scheme. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: p.

107-114.

A 100 ha plantation of short rotation Eucalyptus trees grown in combination with a land treatment scheme for the plant's effluent disposal. It is intended that a cyclic renewable system will be created where the biomass grown to treat the irrigated waste water will be used for boiler fuel, thereby substituting for some of the current coal demand. A utilization system to harvest, handle, store, dry, comminute and combust the tree crop is now under development. Major limitations in harvesting and drying have been identified. Mechanized systems are being evaluated options for each component are being evaluated and incorporated into a computer model to identify the optimum cost effective system. Harvest dates and quantities will be determined in order to provide a continuous stream of biomass feed-stock for the boiler.

bioenergy/ biomass/ energy/ drying/ comminution

157. Lunnan, Anders; Moen, Knut Johannes. 1987. Analyses of different strategies for production of biomass for energy purposes in agriculture and forestry in Norway. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 342-346.

Market saturation has been achieved for most agricultural products in Norway. A report from the Ministry of Agriculture in 1984 shows that the return to marginal investment in agriculture is lower than the costs. Bioenergy is mentioned as one of the possible expansion fields for agriculture. Possible bioenergy strategies in agriculture are short-rotation forestry, utilization of straw, different energy crops and more intensive utilization of traditional forest biomass. A cost-benefit analysis will be used as a tool for strategic agricultural policy decisions.

energy/ biomass/ cost-benefit analysis

158. Lyons, G. 1980. Transportation of short rotation forest biomass--a review. Neenan, M.; Lyons, G., eds. Production of Energy from Short Rotation Forestry. Dublin, Ireland: An Foras Taluntais: 73-82.

Reviews transportation options--truck, rail or pipeline--for short rotation biomass. Factors considered are material characteristics and form (chips, logs or whole trees), quantity of material and geographic distribution, transport distances and type of terrain. Centralized chipping may be feasible where transport distances are short. The transport scheme must be part of the overall design.

159. Lyons, Gerard J. 1987. Economic evaluation of short-rotation forestry in the European community and a national woody biomass summary. In: Lothner, D. C.; Bradley,

D. P.; Gambles. R. L.. eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth. Minnesota. IEA/BA: 48-57.

The main obstacles to near term commercialisation of forest biomass plantations are 1) absence of established fuelwood markets, 2) liquidity and cash-flow problems in the 'waiting' years to first harvest, 3) currently low commercial fuel prices in the industrial sector, 5) land-owner attitudes.

biomass/ economics/ costs/ short rotation

160. Malik, R. K; Green, T. H.: Mays, D.; Bock, B. R.; Joslin, J. D.; Thornton, F. C.; Tolbert, V. R.; Brown, G. F.; Sistani, K. 1996. Cover Crops for Erosion Control in Bioenergy Hardwood Plantations. BIOENERGY '96 - The Seventh National Bioenergy Conference: Partnerships to Develope and Apply Biomass Technologies; September 15-20, 1996; Nashville, Tennessee. 1996: Oak Ridge National Laboratory: 6.

The use of cover crops between rows has been suggested as a means of reducing soil erosion in short-rotation woody crops (SRWC) plantations for bioenergy production. This study is designed to test whether cover crops could reduce soil erosion without significantly reducing the growth and biomass yield of sweetgum (*Liquidambar styraciflua* L.) planted as the SRWC at a 1.5 X 3.0 m spacing. Four cover crops, winter rye grass (*Lolium multigeonum* L., a winter annual grass); tall fescue (*Fescuta eliator* L., a winter perennial grass); crimson clove (*Trifolium incarnatum* L., a winter annual legume); and interstate sericea (*Lespedeza ameata* L., a growing season perennial legume), are tested at two different strip widths (1.22 and 2.44 m) as well as a control with complete competition control. Small berms were built to direct runoff to a sediment fence installed at the down slope ends of each plot. Soil erosion is measured by sediment accumulation near the fence. Height, ground-line diameter, and crown width of trees were measured on a monthly basis. During the first growing season all cover crops reduced the growth of trees. There were some significant differences among cover crop regimes. Slight differences in soil erosion were detected during the first growing season. The control plots lost more soil per hectacre than cover crops, however, strip widths and cover crops did not show any significant difference.

bioenergy/ cover crop/ erosion/ hardwood

161. Markovic. J.; Roncevic. S.; Pudar, Z. 1996. Possibility of poplar biomass production as raw material for bioenergy production. In: Chartier, P; Ferrero, G. L.; Henius. U. M.: Hultberg, S.; Sachau, S.; Wiinbald, M., eds. Biomass for energy and the environment - Proceedings of the ninth European bioenergy conference; June 24-27. 1996; Copenhagen, Denmark. Oxford, England: Elsevier Science Limited: 739-745.

This paper presents the results of the research of potential biomass production of small-sized poplars that can be used for the production of bioenergy. The possibility of biomass production was researched in one-year, two-year, three-year, four-year and five-year rotations, and plantations established by poplar rooted cuttings, roots and seedlings, regenerated by coppice vigor after felling. In this way, the production process during 8 - 10 years and from two to nine rotations lasting from one to five years, produces annually on the average between 14.8 and 19.8 tons (of oven-dry mass) of wood and bark per ha, which can provide heat energy from 216 to 285 GJ.
The paper presents the main elements of the technology of plantation establishment, tending and protection, with the main characteristics regarding the number and size of average trees, as well as the structural percentage of wood and bark in the total produced biomass.

poplar/ clone/ average tree/ volume/ bark/ wood/ mass/ energy value

162. Marley, D. S. 1982. An evaluation of existing and conceptual short rotation energy plantation/harvesting machinery and systems. Blacksburg, VA: School of Forestry and Wildlife Resources, Virginia Ploytechnical Institute and State University;

163. Martin, S. A; Cooper, L. S.; Ehrenshaft, A. R. 1995 Mar. Biofuels feedstock development program: Bibliography 1978-1994. Oak Ridge, TN: Oak Ridge National Laboratory; ORNL/M-4073.

The U.S. Department of Energy's Biofuels Feedstock Development Program (BFDP) is a mission-oriented program of research and analysis to develop and demonstrate environmentally acceptable crops and cropping systems for producing large quantities of low-cost, high-quality biomass feedstocks. Over 1000 reports, articles, papers, and books by BFDP-sponsored researchers were published between 1978 and 1994. This bibliography was compiled to assist researchers and the interested public in locating biofuels-related resources.

bibliography/ biofuels.

164. Maryan, P. S. 1991. The potential for short rotation fuel wood crops. In: Aldhous, J. R., ed. Wood for energy: The implications for harvesting, utilization and marketing.; April 5-7, 1991; Heriot-Watt University, Edinburgh. Institute of Chartered Foresters: 178-182.

Wood as a substitute for fossil fuel.Energy forestry is the growth of willow or poplar coppice at close spacing on short rotation. The potential for energy from this crop is almost ten times that from conventional forestry at 10 million tonnes coal equivalent per year.

biomass/ energy/ proceedings/ short rotation

165. Matthews, J. D. 1980. An experimental study of short rotation forestry for energy. Energy in the rural communities of Third World Countries.; May 5-10, 1980; CEGET-Bordeaux. 30-34.

166. Mattson, J. A. 1980. Harvesting forest residues for energy - potentials and problems. Proceedings of the joint IEA/IUFRO forestry energy workshop and study tour.; October 2; Garpenberg, Sweden. Garpenberg, Sweden: Swedish University of Agricultural Sciences, Department of Operational Efficiency: 74-81.

Residues from conventional harvesting operations, small trees considered unmerchantable by current utilization standards, and stumps are an immediate potential source of wood for energy. The removal of these materials from the forest can also have significant positive silvicultural and economic effects. The categories of the forest resource that are the most likely candidates for use as an energy source are typically also the most difficult to harvest and transport. Therefore, new and imaginative systems are needed to effectively utilize these materials as a source of energy. This paper summarizes the cooperative work being undertaken by nine of the participating countries in the IEA Forest Energy Project to characterize significant wood energy operations, identify areas in need of further research and development work, and establish multinational projects to solve major harvesting and transportation problems associated with wood fuels.

167. Mattson, J. A.; Miyata, E. S. 1982. A time study of planting a short-rotation intensively cultured plantation. St. Paul, MN: USDA Forest Service, North Central Forest Experiment Station; Research Note NC-278.

Time study of mechanical planting of a 3 ha short-rotation plantation on a 1- by 1-m spacing found a productivity of 0.52 ha/hour and planting cost of $98/ha. Four continuous-furrow planters were attached to a common tool bar on a tractor, and planting crew included the tractor driver and four planter operators.

machine rates/ Populus/ energy plantation/ biomass/ tree planting.

168. Mattson, J. A.; Wehr, M. A. 1983. A prototype harvester for short rotation plantations. St Paul, MN: USDA Forest Service, North Central Forest Experiment Station; GTR NC-91. 6 p.

A promising approach to increasing the supply of wood fiber for pulp and energy is short-rotation intensively cultured forestry. To apply the principles of agriculture to the growing of wood fiber, designers of harvesting equipment must consider a unique set of operating criteria. This paper summarizes the design criteria relevant to the SRIC concept and describes the results of initial trials with a prototype short-rotation harvester.

short rotation/ harvesting/ equipment.

169. Mattson, James A. 1983. Harvesting developments for short rotation intensively cultured forests. Forest Products Journal. 33(3):31-38.

Short rotation intensively cultured forestry is a promising approach for increasing the supply of fiber for pulp and energy uses. Applying the principles of agriculture to growing wood fiber presents equipment designers with a unique set of operating criteria for developing harvesting equipment for SRIC forests. Because of the unique operating conditions encountered, new and innovative approaches are needed to develop efficient harvesting systems for this potential fiber resource. This paper summarizes the design criteria relevant to the SRIC concept and reviews several design approaches being investigated around the world in an effort to develop new equipment concepts for harvesting the wood fiber grown in SRIC forests.

bioenergy/ costs/ equipment/ harvesting

170. --- 1982. The potential application of auger cutters to biomass harvesting. The Sixth International FPRS Industrial Wood Energy Froum '82; March 8-10, 1982; Washington, D.C. Madison, WI: Forest Products Reseach Society: 95-99.

Small tree and brush species commonly called puckerbrush, woody plants grown under intensively cultured conditions on biomass farms, and residues from conventional harvesting operations are all potential fiber sources for the future. Each of these fiber sources consists of many small or irregularly shaped pieces. Harvesting this material will require new and imaginative equipment and methods. This paper discusses the potential application of auger cutters, or peripheral milling cutters, as a severing mean in biomass harvesting equipment. Basic design information on the auger cutting process is presented along with several possible applications of auger cutters to unique harvesting problems.

bioenergy/ harvesting

171. Mattson, James A.; Christopherson, Nels S. 1987. Harvesting system developments for biomass plantations . In: Klass, Donald L., ed. Biomass and Wastes X; April 7-10, 1987: Washington, DC. London & Chicago: Elsevier Aplied Science Publishers (London) & Institute of Gas Technology (Chicago): 187-204.

Promising research results on the agro-forestry concept of growing trees in short-rotation, intensively cultured biomass plantations have led to continuing interest in this concept as a renewable source of energy supplies. The close spacings and short-rotation ages in biomass plantations produce trees that are small by conventional forestry standards. Economics requires the harvesting of many of these small trees per unit of time. Research has begun in the United States, Canada, Sweden and Ireland to develop appropriate harvesting equipment. Several new machine concepts, in prototype stage, have demonstrated several-fold increases in productivity over conventional forestry harvesting equipment. This new technology could also apply to small-tree harvesting problems in conventional forest operations, such as early thinnings in conifers.

short-rotation/ biomass plantations

172. McAlpine, R. G.; Brown, C. L.; Herrick, W. M.; Ruark, H. E. 1966. 'Silage' sycamore. Forest Farmer. 26(1):6-7,16.

173. McDonald, Timothy P.; Stokes, Bryce J. 1994. Status of short rotation forestry in the USA. In: Culshaw, Damian., ed. Status of short rotation forestry mechanization worldwide. IEA/BA Task IX Activity 3; March 2-4, 1993; Sweden. 22-44.

Summary of research on species, cultural practices, harvesting methods, expected yields. Emphasizes felling technology for harvesting operations. Interest in the US has turned from using SRIC exclusively for energy, to fiber production with secondary energy use.

mechanization/ harvesting/ short rotation/ environmental impacts

174. McLaughlin, Robert A.; Felker, Peter. 1994. Development of a flail harvester for small diameter brush and coppiced trees to produce energy/chemical feedstock. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 31-42.

The design, fabrication and field testing is described for a harvester to produce shredded woody biomass from small diameter natural brush stands and coppiced energy plantations. These small diameter stems have not been economically harvested-to-date because the brush is too small to be handled by conventional forestry equipment, yet too woody for conventional agricultural equipment. A harvester was built on a John Deere 210 kw forage harvester. A flail shredder and auger conveyance system was used to sever the trees, shred them and blow them behind the harvester in a vehicle pulled behind the harvester. Economical operation of the harvester will require both a silvicultural need for thinning and an energy market for the chips. The current version of the harvester is not suited to typical forestry terrain. A team of forestry companies, equipment manufacturers, universities and government would be best suited to develop this harvester.

costs/ equipment/ harvesting/ mechanization/ short rotation

175. McNabb Jr., H. S.; Hall, R. B.; Ostry, M. E. 1982. Biological and physical modifications of the environment and the resulting effect upon the host-parasite interactions in short-rotation tree crops. In: Heybroek, H. M.; Stephan, B. R.; Von Weissenberg, K., ed. Proceedings of the Third International Workshop on the Genetics of Host-Parasite Interactions in Forestry: Resistance to Diseases and Pests in Forest Trees; Wangeningen, The Netherlands: Centre for Agricultural Publishing and Documentation: 60-71.

parasites/ short rotation woody crops/ environmental impacts

176. McNabb, Ken. 1994. Silvicultural techniques for short rotation Eucalyptus plantations in Brazil. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3, 1994; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 89-97.

Brazil has established several millions of ha of Eucalyptus plantations primarily on abandoned agricultural lands. Genetics programs have produced superior genotypes routinely used in plantation establishment. Rooted clonal cuttings are hand planted to a site prepared using machinery or a chemical/machine combination. Nitrogen and phosphorous fertilizers are used. Herbaceous weeds are controlled with preemergent herbicide, manual weeding, and mechanical weeding. Clonal selection and silvicultural treatments have limited insect and disease problems. The vast majority of Eucalyptus plantations are managed to maximize raw material production for fiber or energy industries and are therefore not thinned. Clearcut harvesting usually occurs at age 6 to 8 years.

Eucalyptus/ genetics/ management/ pests/ disease/ short rotation/ plantations

177. Meridian Corporation. 1986. Falls Church, Virginia:

Intro and guide to SRIC of woody crops for energy. Discusses species and site selection, available planting stock, site preparation practices and planting options, plantation management and cultural requirements and options. Also examines environmental considerations, current wood harvesting and handling options, and the economics of SRIC systems operation.

short rotation/ Great Lakes/ environmental impacts.

178. Merriam, Robert A.; Phillips, Victor D. 1996. Space/age forestry: implications of

planting density and rotation age on SRIC management decisions. In: Carter. Manson C., ed. Growing Trees in a Greener World: Industrial Forestry in the 21st Century; 1996; Louisiana State University. Baton Rouge, LA: Louisiana State University School of Forestry: 260-264.

Short-rotation intensive-culture (SRIC) of promising tree crops is being evaluated worldwide for the production of methanol, ethanol, and electricity from renewable biomass resources. Planting density and rotation age are fundamental management decisions associated with SRIC energy plantations. Most studies of these variables have been conducted without the benefit of a unifying theory of the effects of growing space and rotation age on individual tree growth and stand level productivity. A modeling procedure based on field trials of *Eucalyptus* spp. is presented that evaluated the growth potential of a tree in the absence and presence of competition of neighboring trees in a stand. The results of this analysis are useful in clarifying economic implications of different growing space and rotation age decisions that tree plantation managers must take. The procedure is readily applicable to other species under consideration for SRIC plantations at any location.

179. Miller, R. O.; Hanover, J. W.; Howe, G. T. 1983. Species and genotype screening for biomass production in Michigan: A survey of field performance for 28 species. Proceedings of the 7th international FPRS industrial wood energy forum; September 19-21, 1983; Nashville, Tennessee. Madison, WI: FPRS: 116-121.

The growing economic and social pressures on current energy sources have recently created increased interest in woody plant biomass as an alternative source of fuel. Michigan currently has one wood-fired, electrical generating plant and more are in the planning stages. Forest products industries in the state also use biomass in the form of mill residues for power generation. A research program was initiated at Michigan State in 1979 to identify the best system for producing woody plant biomass in energy plantations in Michigan. This paper summarizes the progress to date, with respect to species and genotype screening trials and yield projection investigations.

bioenergy/ fuelwood/ electricity generation/ yields

180. Mitchell, C. P. 1992. Ecophysiology of short rotation forestry crops. In: Mitchell, C. P.; Zsuffa. L.; Anderson. S.; Stevens, D. J., eds. Biomass and Bioenergy Special Issue. IEA Bioenergy Agreement Progress and Achievement 1989-1991. April 2-3; Edinburgh. UK. Oxford. United Kingdom: Pergamon Press Ltd: 25-37.

An understanding of ecophysiology of the crop is critical to the effective management of short rotation forest crops. There are many interacting ecophysiological factors such as canopy structure and development, water and

nutrient use efficiency, root architecture and function, sustainability of coppicing, which, through a deeper understanding, can be manipulated through genetic improvement and silvicultural practice. These complex factors are discussed, and areas requiring further research to elucidate the nature of the process are highlighted.

ecophysiology/ short rotation/ water quality/ models/ nutrients/ coppice/ pests/ disease/ feedstock quality/ genetics

181. --- 1990. Nutrients and growth relations in short-rotation forestry. In: Mitchell, C. P.; Zsuffa, L.; Anderson, S.; Stevens, D. J., eds. Forestry, forest biomass and biomass conversion.; The IEA Bioenergy Agreement (1986-1989) Summary Reports: 91-105.

Ongoing research into the nutrient and water relations in short-rotation forestry within the IEA/BA participating countries is discussed. The physiological and forestry approaches to tree nutrition are discussed in relation to a practical solution to fertiliser prescriptions. Coppice stool physiology is identified as the main unknown in the system and is thought to be the key to the future management regimes for short-rotation coppice production.

short rotation/ nutrients/ water quality/ ecophysiology

182. --- 1987. United Kingdom and EEC work on the production and feasibility of short-rotation forestry. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 58-73.

The potential for short-rotation forestry in the United Kingdom is reviewed and information given on current RD&D. EEC work on short rotation forestry is outlined. The yields and production costs necessary for short rotation forestry to be economically viable are discussed.

economics/ proceedings/ short rotation/ production

183. Mittlehauser Corporation. 1982. Standard economic analysis methodology for short rotation woody crops. Downers Grove, Illinois: ORNL/SUB-81//69788/1 MC 410-W.

184. Molenaar, J. A.; Huisman, W.; Venturi, P. 1996. Energy consumption and costs of the production chains of *Miscanthus x giganteus*. In: Chartier, P.; Ferrero, G. L.; Henius, U. M.; Hultberg, S.; Sachau, J.; Wiinblad, M., eds. Biomass for energy and the environment - Proceeding of the Ninth European Bioenergy Conference; June 24-27, 1996; Copenhagen, Denmark. Oxford, England: Elsevier Science Limited:

867-872.

The efficiency of energy production of *Miscanthus x giganteus* is made visible by the energy balance of the production chain. The energy input and energy output is calculated for different harvest methods and type of power stations. The efficiency of energy production depends highly of the scale of the power station under consideration.

crop production/ electricity/ energy/ energy efficiency/ energy input / output ratio/ harvest/ input energy/ output energy/ *Miscanthus x giganteus*/ power station/ storage/ transport

185. Moran, L. A; Nautiyal, J. C. 1985. Present and future feasibility of short-rotation energy farms in Ontario., Forest Ecology Management. 323-338.

The economic feasibility of energy farming based on P. x euramericana (clone I45/51) in eastern Ontario has been evaluated for two potential energy end-uses: direct combustion and methanol production. Optimal management regime and the time when energy farming should begin to be economically most desiravle have been determined. Three year rotations with 16 to 35 thousand stumps/ha planted and coppiced for 5 to 6 rotations could be an attractive enterprise in about 15 years. Farming for methanol production could be feasible only about 35 years from now.

186. Morgan, Thomas H. Jr. 1994. Industrial short rotation intensive cultural operations. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 1-4.

Brief history of Scott Paper Co. in Mobile, AL. And an outline of their work with short rotation intensive hardwood culture.

187. Myers, Gary C. ; Crist, John B. 1986. Feasibility of manufacturing hardboard from short-rotation intensively cultured Populus. Forest Products Journal. 36(1):37-44.

A hybrid poplar, Populus "Tristis No. 1," grown under short-rotation intensive culture, was investigated as a possible raw material source for the manufacture of hardboard. All aboveground material was chipped, and a portion of the chips was upgraded with vacuum airlift segregation to remove some fines and bark. Debarked aspen stemwood was used as a control. All chips were fiberized in a small presurized single disk refiner, and medium-and high-density hardboards were made from the pulps by both the wet- and dry-forming processes. Two resin contents were used in each type of hardboard manufactured. Hardboards were evaluated for

strength properties and dimension change, and test results were analyzed statistically. Results indicate that intensively cultured Populus raw material is suitable for manufacturing hardboards.

short rotation intensive culture/ Populus/ hardboard,short rotation intensive culture/ Populus/ hardboard

188. Naughton, G. G. 1985. Production and harvesting cost of an 8-year old energy plantation. June 25-27, 1985; Lawrence, Kansas. 22nd Annual Meeting of the Poplar Council of the United States: 84-89.

Costs of growing and harvesting silver maple and Siberian elm are reported. Harvest, at age 8, was conducted with a small feller-buncher, tricycle skidder, grapple-equipped farm tractor, and small chipper. Skidding cost was less with the farm tractor than with the tricycle skidder. Growing, harvesting and transportation cost averaged $5/MMBTU.

189. Neenan, M. 1980. Cost of establishment of plantations. Production of Energy from Short Rotation Forestry. Dublin, Ireland: An Foras Taluntais: 64-67.

Briefly describes the costs of land preparation, drainage and planting, and presents costs for five sites in Ireland.

190. Netzer, D. A. ; Hansen, E. A. 1981. Crown architecture of short rotation, intensively cultured Populus: I. effects of clone and spacing on first-order branch characteristics. Canadian Journal of Forestry Research. 11:73-81.

branch characteristics/ crown architecture/ poplars/ clonal propagation/ short rotation intensive culture/ spacing

191. Netzer, Daniel; Hansen, Edward A. 1994. Establishing and tending poplar plantations in the North-Central U.S. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3, 1994; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 79-87.

Cultural methods and equipment are described for successful establishment of poplar plantations in the north-central United States. Methods use both ground and aerial equipment including standard farm machinery, newer style compact tractors, 'four-wheelers', and helicopters.

equipment/ management/ mechanization/ plantations/ short rotation/ technology/ poplars/ establishment methods

192. Nurmi, Juha; Hytönen, Jyrki. 1994. The effect of whole tree harvesting on fuel quality and coppicing ability of SRIC willow crops. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3, 1994; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 97-106.

A seven-year-old stand of willow was manually felled by using chain saw and a clearing saw. Uncomminuted stems were piled and stored for 18 months. Heating value and basic density of the material remained unchanged. Moisture content dropped from the initial 54 percent to 20% by the end of the second summer of storage. Bark content dropped from 24.1% to 14.9%. Stool damage caused by forwarding did not have a significant effect on the height growth or biomass production of the following crop.

coppice/ moisture content/ storage

193. Nutter, Wade L. 1986. Short rotation hardwood energy plantations irrigated with municipal sewage effluent. In: Rockwood, Donald L., ed. Proceedings of the 1985 Southern Forest Biomass Workshop; June 11-14, 1985; Gainesville, Florida. Gainesville, Florida: Instituteof Food and Agricultural Sciences, University of Florida: 40-41.

energy/ proceedings/ short rotation/ wastewater

194. Paquin, D.; Singh, D.; Liang, T. 1989. Development of a biomass harvester . Quebec, Canada: ASAE; 14 p.

A low-cost biomass harvesting/handling system for short rotation intensively cultivated trees has been developed. The harvester is a 2-row continuously moving cutter. It stands the trees up in a flat bed trailer which is hitched to the harvester. Full trailers are towed to a conversion plant.

Biomass, cutting, harvesting machinery, self-propelled implements, tree harvester.

195. Pari, Luigi. 1996. Harvesting, storage, and logistics of short rotation forestry for fuel production. In: Chartier, P.; Ferrero, G. L.; Henius, U. M.; Hultberg, S.; Sachau, J.; Wiinblad, M., eds. Biomass for energy and the environment - Proceedings of the Ninth European Bioenergy Conference; June 24-27, 1996; Copenhagen, Denmark. Oxford, England: Elsevier Science Limited: 901-906.

In this paper the results of tests carried out in Italy with a Claas Jaguar 665 equipped with a SRF head on the harvesting of poplar and robinia are reported and commented. Consideration on the adaptibility of the machineries developed in North Europe for SRF harvesting to the Italian pedo-climatic conditions and

different growing systems are reported.

SRF harvesting/ biomass crops mechanization

196. Parikka, Matti. 1987. An economic analysis of small-scale intensively cultivated energy forests in Sweden. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 303-321.

An economic simulator of small-scale intensively cultivated energy forests is presented. Major attention in this economic simulation is given to the effects of different production levels, interest rates, prices of fuel chips and government subsidies. The analysis is seen from the cultivators point of view, and the same methods are used to compare energy forests with other crops.

economics/ analysis/ short rotation

197. Parker, J. Kathy. 1987. Woody biomass in the global economy. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 11-22.

Increasing deficits in some regions suggest the magnitude of demand for woody biomass and existing and potential problems with supply. Any solution or set of solutions actually involves millions of urban and rural dwellers using woody biomass for commercial and domestic purposes. The complexity of local, regional and national systems suggest that a wide range of technological, economic, social, and institutional opportunities and constraints must be addressed in energy programs that focus on the sustainable production, transformation, distribution, and consumption of short-rotation woody biomass.

economics/ energy/ proceedings/ production/ short rotation

198. Parkham, R. A.; Robinson, K. W.; Isebrands, J. G. 1977. Effects of tension wood on kraft paper from a short rotation hardwood (Populus 'Tristis #1'). Wood Science and Technology. 11:291-303.

199. Perala, D. A. 1976. Regeneration and productivity of aspen grown on repeated short rotations. St. Paul, MN: USDA Forest Service North Central Experiment Station; Research Paper No. NC 176. 7 p.

200. Pereira, H.; Pardos, A. M.; Mitchell, P.; Mughini, G.; Kyritsis, S.; Dalianis, C. 1996. Eucalypt plantations for production of raw-material for industry and energy in Europe. In: Chartier, P.; Ferrero, G. L.; Hultberg, S.; Sachau, J.; Wiinblad, M., eds.

Biomass for energy and the environment - Proceeding of the Ninth European Bioenergy Conference; June 24-27, 1996 ; Copenhagen, Denmark. Oxford, England: Elsevier Science Limited: 84-89.

In Europe, eucalypt plantations are an important raw-material for the pulp industry, especially in Portugal and Spain, with approx. 1 million ha. At present one species is used exclusively, *Eucalyptus globulus* Labill., which combines a rapid growth with a very good tree and wood quality. Growth of *Eucalyptus globulus* is known to respond strongly to climatic, even micro-climatic, conditions. Water has been considered as one of the most important parameters in reducing growth. *Eucalyptus globulus* is also a cold sensitive eucalypt species and this may cause serious reductions in growth. An on-going European project deals with some of the factors impacting growth and quality. Some results are summarised here relating to cold tolerance, to water stress and to growth under high competition conditions in biomass short-rotation forestry.

Eucalypts/ *Eucalyptus globulus*/ cold tolerance/ water stress/ growth/ biomass production/ competition/ raw-material quality

201. Perlack, R. D.; Das, S.; Ranney, J. W. 1986. The economic evaluation of SRIC energy plantations. In: Rockwood, Donald L., ed. Proceedings of the 1985 Southern Forest Biomass Workshop; June 11-14, 1985; Gainesville, Florida. Gainesville, FL: Institute of Food and Agricultural Sciences: 58-61.

Evaluation of the economics of a representative SRIC energy plantation is demonstrated using a microcomputer-based cost simulation model. The model is described and then is used to conduct sensitivity analysis on the rotation age, plantation costs, and first coppice rotation productivity. By specifying interval estimates for uncertain activities the model is used to conduct an expedient risk analysis.

models/ economics/ production/ short rotation/ proceedings

202. Perlack, R. D. ; Geyer, W. A. 1987. Wood energy plantation economics in the Great Plains . Journal of Energy Engineering. 113:92-101.

wood energy/ plantations/ economic analysis/ Great Plains/ short rotation intensive culture/ feedstocks/ Kansas/ maplesilver/ harvesting/ planting density

203. Perlack. R. D.; Ranney, J. W. 1987. Cost objective overview for short rotation woody crops. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. IEA/BA Task II Workshop:Economic Evaluations of Short-rotation Biomass Energy Systems.; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 224-229.

The costs of SRIC feedstocks are evaluated under present state-of-the-art conditions and under two sets of assumptions about anticipated advances in the technology. The results indicate that delivered SRIC feedstock costs using available technology are likely to range between $3.00 and $4.10/GJ depending on the region where grown. Based on esimates of technological advances in genetics. cultural management, and harvesting, delivered costs could be lowered to under $2.00/GJ by the year 2000.

costs/ economic analysis/ short rotation woody crops/ feedstocks/ genetics/ management/ harvesting

204. --- 1987. Economics of short-rotation intensive culture for production of wood energy feedstocks. Energy. 12:1217-1226.

short rotation intensive culture/ economic analysis/ regional analysis

205. Perlack, R. D.; Ranney, J. W.; Barron, W. F.; Cushman, J. H.; Trimble, J. L. 1986. Short-rotation intensive culture for the production of energy feedstocks in the US: A review of experimental results and remaining obstacles to commercialization. Biomass. 9(2):145-159.

SRIC research has demonstrated that biomass yields can be substatntially increased over those for conventional forestry by species sreening and genetic selection, and stand management; the concept is technically feasible; and costs of production are potentially competetive. The main outstanding question is to identify uncertanties and financial risks of large scale monocultural plantations.

commercialization/ short rotation intensive culture/ biomass feedstocks

206. Perlack, R. D. ; Wright, L. L. 1995. Technical and economic status of wood energy feedstock production. Energy. 20:279-284.

economic analysis/ wood energy/ feedstocks/ production/ short rotation woody crops

207. Perlack, Robert D.; Walsh, Marie E.; Wright, Lynn L.; Ostlie, L. David. 1996. The economic potential of whole-tree feedstock production. Bioresource Technology. 16(22):1-7.

This paper summarizes an economic evaluation of whole-tree feedstock production. Our analysis indicates that wood feedstocks have the potential to be grown, harvested and delivered at costs approximating $1.80 GJ-1 on good cropland. However, attaining this cost requires that special consideration be given to selecting the land base, carefully matching appropriate clones to sites and using

whole-tree direct load harvesting concepts. The direct load system significantly reduces harvest and handling costs by eliminating skidding and minimizing in-field handling, using high-speed continuous cutting principles and harvesting all year round for better equipment utilization and reduced biomass losses from handling and storage. Our estimate is also based on regenerating new stands by replacing cut trees with improved clones rather than by coppice regrowth.

short-rotation woody crops/ harvesting/ whole-tree/ economics

208. Perlack, Robert D.; Wright, Lynn L.; Huston, Michael A.; Schramm, William E. 1995. Biomass fuel from woody crops for electric power generation. Oak Ridge, TN: Oak Ridge National Laboratory; ORNL-6871. 65 p.

This report discusses the biological, environmental, economical, and operational issues associated with growing woody crops in managed plantations. Information on plantation productivity, environmental issues and impacts and costs is drawn from DOE's Biofuels Foodstock Development as well as commercial operations in the U.S. and elsewhere. The particular experiences from three countries - Brazil, the Philippines, and U.S. (Hawaii) - are discussed in considerable detail.

short-rotation/ biomass.

209. Phelps, J. E.; Isebrands, J. G.; Einspahr, D. W.; Crist, J. B.; Sturos, J. A. 1985. Wood and paper properties of vacuum airlift segregated juvenile poplar whole-tree chips. Wood and Fiber Science. 17:529-539.

Whole tree chips from a hybrid poplar clone grown under short rotation intensive culture were sparated into three fractions using vacuum airlift segregation. The fractions were, accepts, which was predominantly a woody fraction, rejects, which contained less wood and more bark and twigs, and fines, which consisted mostly of bark particles. The raw material quality was evaluated and kraft pulp and paper properties were determined by the whole-tree chips and each VAS fraction as well as on a 50:50 mixture of the accepts:rejects fractions. A 50:50 mixture of VAS accepts and 55-yr-old mill-run jack pine was also studied. Pulp and paper properties of the whole tree chips, the VAS accepts and rejects, and a 50:50 mixture of accepts:rejects were similar and were only slightly lower in quality than those of mature aspen chips. The 50:50 mixture od VAS accepts and mill-run jack pine was acceptable by industrial standards. These results suggest that whole-tree chips from SRIC poplar stands can be mixed with conifer chips to supplement furnishes for kraft pulping.

Populus tristis/ short rotation intensive culture/ beneficiation/ kraft pulp/ biomass quality/ whole-tree/ scanning electron microscopy/ vacuum airlift segregation

210. Pimental, D. ; Krummel, J. R. 1987. Biomass energy and soil erosion: Assessment of resource costs. Biomass. 14:15-33.

erosion/ water availability/ corn stover/ herbaceous energy crops/ short rotation woody crops/ energetics

211. Portwood, C. Jeffrey. 1994. Utilization of cottonwood plantations. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3, 1994; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 21-23.

The majority of this land is located in the flood prone batture areas along the river. Soil types are all of the alluvial classification. They contain high levels of nutrients and are well supplied with moisture. They range from well to poorly drained. Much progress has been accomplished in cottonwood plantation management over the past 20 years, although there is much more to be learned about cottonwood culture.

plantations/ short rotation/ site preparation/ management

212. Potter, C. J.; Tabbush, P. M. 1991. The cultivation of poplar as an energy crop. In: Aldhous, J. R., ed. Wood for energy: The implications for harvesting, utilization and marketing.; April 5-7, 1991; Heriot-Watt University, Edinburgh. Institute of Chartered Foresters: 206-216.

Poplar proved to be the most successful biomass production crop over ten years of research in Southern England. More detailed studies are currently under way.

biomass/ energy/ proceedings/ short rotation

213. Radcliffe, R. C.; Matson, E. D.; Mattson, J. A. 1981. Tree-planting interval indicator. Tree Planters' Notes. 32:13-14.

planting/ short rotation intensive culture

214. Ranney, J. W.; Barkley, B. A.; Turhollow, A. F.; Granger, C. 1987. The economics of short rotation intensive culture for producing energy feedstocks in North America. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 23-39.

Private industry has shown interest in the concept of SRIC. Private and public sector research results in Canada and the United States identified a range of costs, silvucultural prescriptions, productivity rates, and other concerns that define the progress still needed in the concept of SRIC. International economics is expected to play an increasing role in the viability of SRIC for producing energy feedstocks in North America.

economics/ energy/ harvesting/ proceedings

215. Ranney, J. W.; Cushman, J. H. 1982. Short-rotation woody crops as a source of energy. In: Hill, R. F., ed. Proceeding, Ninth Energy Technology Conference. Energy Efficiency in the Eighties.; Rockville, Maryland: Government Institutes, Inc.: 1391-1399.

short rotation woody crops/ biomass/ feedstocks/ short rotation intensive culture/ genetics

216. -- 1982. Short Rotation Woody Crops Program: Annual Progress Report for 1981. Oak Ridge, Tennessee : Oak Ridge National Laboratory; ORNL/TM-8120.

short rotation woody crops/ species selection/ economic analysis/ environmental impacts.

217. Ranney, J. W.; Ehrenshaft, A. R.; Layton, P. A.; McNabb, W. A.; Wright, L. L. 1988. Short Rotation Woody Crops Program: Progress Report for 1987. Oak Ridge, Tennessee: Oak Ridge National Laboratory; ORNL-6440.

species selection/ growth/ productivity/ poplars/ economic analysis/ clonal variations/ short rotation woody crops/ environmental impacts.

218. Ranney, J. W. ; Mann, L. K. 1994. Environmental considerations in energy crop production. Biomass and Bioenergy. 6(3): 211-228.

Biomass energy has the potential to be a significant source of electric or liquid fuel energy in selected regions of the United States. This paper is a preliminary attempt to provide information on the probable environmental effects of energy crop production relative to other potential uses of the land. While dedicated energy crop production is anticipated to occur primarily on land currently in agricultural production, some pastureland and forestland may be utilized. Experimental results suggest that chemical use on energy crops will be lower than on most row crops and that land producing energy crops should experience less erosion than land producing row crops. Long-term site productivity should not be a major issue if macro- and micro-fertilizers are added as needed and nutrient-conserving production techniques are used. Biodiversity effects, as with most environmental issues, will depend greatly on how energy crop production is integrated into existing agricultural landscapes, how much land total becomes dedicated to energy crops, and what alternative uses for the land might exist.

biomass energy/ energy crops

219. Ranney, J. W.; Trimble, J. L. 1982. Short Rotation Woody Crops Program: 1982 Program Summary . Oak Ridge, Tennessee: Oak Ridge National Laboratory; ORNL-5916.

short rotation woody crops/ environmental impacts/ species selection/ economic analysis.

220. Ranney, J. W.; Trimble, J. L.; Wright, L. L.; Cushman, J. H.; Wenzel, C. R. 1984. Short Rotation Woody Crops Program: Annual Progress Report for 1983. Oak Ridge,Tennessee: Oak Ridge National Laboratory; ORNL-6085.

Environmental impacts/ short rotation woody crops/ species selection/ economic analysis.

221. Ranney, J. W.; Trimble, J. L.; Wright, L. L.; Layton, P. A.; Perlack, R. D.; Wenzel, C. R.; Curtin, D. T. 1986. Short Rotation Woody Crops Program: Annual Progress Report for 1985. Oak Ridge, Tennessee: Oak Ridge National Laboratory; ORNL-6254.

environmental impacts/ short rotation woody crops/ species selection/ economic analysis.

222. Ranney, J. W.; Wright, L. L.; Layton, P. A. 1987. Hardwood energy crops: the technology of intensive culture. Journal of Forestry. 85:17-28.

Studies indicate that the optimum management scheme for SRIC energy plantations includes improved clones, intensive site preparation and weed control, some fertilization, planting densities of 2500 to 4000 trees/ha, and coppice rotations of 5 to 8 years, depending on region productivities must be increased to make biomass energy feasible on a large scale; increases of 50 to 100 percent over present levels may be obtainable.

223. Ranney, J. W.; Wright, L. L.; Layton, P. A.; Trimble, J. L.; Perlack, R. D. 1985. Short rotation woody crops program. In: Rockwood, Donald L., ed. Proceedings of the 1985 Southern Forest Biomass Workshop; June 11-14, 1985; Gainesville, Florida. Gainesville, FL: Institute of Food and Agricultural Sciences: 69.

The SRWCP is an integrated research program designed to improve the productivity and economic efficiency of growing woody plants for energy. Future research will (1) Emphasize genetic improvements to increase productivity and site adaptability and to reduce planting costs, (2) Establish and monitor larger monocultural plantations with industry participation, (3) Evaluate and improve nutrient utilization, (4) Assess coppice growth on previously established plantations, (5) Test and refine available prototype harvesting equipment in order to reduce costs, (6) Assess the environmental impacts of SRIC.

economics/ production/ energy/ research

224. Ranney, J. W.; Wright, L. L.; Trimble, J. L.; Perlack, R. D.; Dawson, D. H.; Wenzel, C. R.; Curtin, D. T. 1985. Short Rotation Woody Crops Program: Annual Progress Report for 1984. Oak Ridge, Tennessee: Oak Ridge National Laboratory, Environmental Sciences Division ; ORNL-2541.

Describes the evaluations and accomplishments in the SRWC program for the year ending September 30, 1984.The SRWCP is an integrated program of research and development devoted to a single objective: improving the productivity and economic efficiency of short-rotation intensive culture of hardwood trees and shrubs for energy. This report offers evidence suggesting that the technology may currently be economically competitive under specific regional or local conditions, but in most areas of the United States further technological improvements are required. New information is reported on cost analysis on a range of sites, genetic improvement research, and coppice productivity. The current status of harvesting technology is described, and areas of risk associated with SRIC systems are discussed. This report provides information on future programmatic research priorities as well as some general conclusions about SRIC systems emerging from research in several parts of the US.

short rotation/ economics/ production/ technology.

225. Rhodes, J. D.; Felker, P.; Klass, S.; Reyes, J.; Smith, D. 1983. Development of field management techniques and selection of mesquite phenotypes for biomass farming on semi-arid lands. Proceedings of the 7th International FPRS Industrial Wood Energy Forum: September 19-21, 1983; Nashville, Tennessee. Madison, WI: FPRS: 134-139.

Physiological and morphological attributes of mesquite aid this plant in becoming a valuable biomass producer in areas of low annual precipitation. The goals of the project at Texas A&I are to produce acceptable biomass plantations on non-irrigated, economically marginal lands. We are presently developing techniques for clonal propogation of mesquite so as to be able to produce rapidly superior plants. We are also engaged in developing field techniques for planting, maintaining, and assessing growth potentials of various Prosopis spp. under non-irrigated conditions in south Texas.

biomass/ short rotation/ genetics

226. Ribe, J. H. 1974. A review of short rotation forestry with comments on the prospect of meeting future demands for forest products. University of Maine: Life Sciences and Agriculture Experiment Station; Miscellaneous Report # 160. 52 p.

This paper reviews work presently being conducted concerning the growth and development of genetically improved trees grown under short rotation, intensive management. It explores prospects for meeting future demands in the forest products industry. It includes an assessment of the present and projected supply-demand functions; a review of alternatives to be taken to forestall possible fiber shortages; yield predictions from existing intensively managed, stands of a short rotation nature; and cost estimates and expected rates of return on investments for cultural and genetic treatments. This report concludes with a discussion of the possible impact of intensively managed short rotation forest crops upon the future supply of fiber and its effect upon land requirements of the pulp and paper industry.

genetics/ short rotation/ yields.

227. Riddell-Black, D. M.; Rowlands, C.; Snelson, A. 1996. Short rotation forest productivity using sewage sludge as a nutrient source. In: Chartier, P.; Ferrero, G. L.; Henius, U. M.; Hultberg, S.; Sachau, J.; Wiinbald, M., eds. Biomass for energy and the environment - Proceedings of the Ninth European Bioenergy Conference; June 24-27, 1996; Copenhagen, Denmark. Oxford, England: Elsevier Science Limited: 103-108.

Two trials commenced in 1991 to investigate the fertiliser value of sewage sludge to short rotation forestry (SRF) of willow and poplar. Liquid digest sewage sludge was surface applied at rates which delivered 40 - 370 kg ha available N, 20 - 170 kg ha P and 6 - 55 kg ha K. Yield increases of between 16 and 26% were observed from the annually harvested willow trial, depending on variety and sludge application rate. Yield increases in the poplar ranged from 5 to 34% but were not statistically significant. Nutritional status as indicated by poplar tissue concentrations and stool survival appear to be higher in plots which have received sewage sludge. Data indicate that yield benefits in willow may be derived from sludge applications of 50 m ha (126 kg total N ha) as plantations mature. A site maintenance application of sewage sludge may be appropriate to replace N and P removed in harvested crop.

short rotation forestry/ sewage sludge/ fertiliser application/ crop yield/ nutrient export

228. Riddell-Black, D. M.; Sims, R. E. H.; Roygard, R.; Clothier, B.; Green, S.; Edwards,

R. 1996. Water and nutrient use by fuelwood species: Preliminary results from an intensively monitored lysimeter study. In: Chartier, P.; Ferrero, G. L.; Henius, U. M.; Hultberg, S.; Sachau, J.; Wiinblad, M., eds. Biomass for energy and the environment - Proceeding of the Ninth European Bioenergy Conference; June 24-27, 1996; Copenhagen, Denmark. Oxford, England: Elsevier Science Limited: 775-780.

Knowledge of the water and nutrient demands of short rotation intensive forestry grown for fuel is required for a number of crop management reasons. A study has been undertaken to provide detailed information on the water and nutrient use of three short rotation tree species, and to investigate their capacity to renovate nutrient rich aqueous wastes. Twelve 1.78m diameter pots were instrumented to monitor all systems inputs and outputs. Individuals of one deciduous and two evergreen species were planted in each pot. Their influence on the quantity and quality of dairy shed effluent, applied weekly, was compared with unplanted soil control pots. Some preliminary data from one growth season is presented and discussed.

fuelwood species/ lysimeters/ water use/ nutrient use/ effluent treatment

229. Riekerk, H.; Hendrickson, J. C. 1986. The effect of tree planting density on soil water. In: Rockwood, Donald L., ed. Proceedings of the 1985 Southern Forest Biomass Workshop; June 11-14, 1985; Gainesville, Florida. Gainesville, FL: Institute of Food and Agricultural Sciences, University of Florida: 47-51.

Soil moisture content was studied under young trees planted at very high density and high density in trials throughout Florida.The effects may be important in areas with extensive dense natural stands, such as occur in South Florida and in areas where high density plantations have been established in North Florida.

growth/ proceedings

230. Rockwood, D. L.; Dippon, D. R. 1988. Biological and economic potentials of eucalyptus grandis and slash pine as biomass energy crops. In: McCaskey, T. A.; Lockaby. B. G., eds. Southern Biomass Conference; July 26-28, 1988; Auburn University, AL. Auburn, AL: 50.

Preliminary results from SRIC research initiated in 1979 suggested that eucalyptus grandis and slash pine were suitable as biomass energy crops for southern and northern Florida, respectively. Recent results have further substantiated the suitability of these species when various cultural amendment, planting density, and genetic options are utilized to maximize yields. The economic potentials of e. grandis and slash pine under these scenarios have been updated.

Eucalyptus/ short rotation/ analysis

231. Rockwood, D. L.; Dippon, D. R.; Lesney, M. S. 1988. Woody species for biomass production in Florida. Gainesville, FL: Institute of Food and Agricultural Sciences, University of Florida; Final Report. 153 p.

From 1983 to 1988, this project's short rotation woody crop research enhanced the potential of Eucalyptus species in Florida. A fourth generation E. grandis seed orchard could produce over 100 million seedlings annually for use in southern Florida. Seed from the 50 best trees in the orchard may double the average productivity in the preceding genetic base population. Three frost resilient and rapid-growing E. grandis clones are being commercially propagated by tissue culture, and over 250 additional clonal candidates are under test. While rooted cuttings of selected clones could be mass produced in less than seven months, micropropagation may reduce the cost of vegetative propagation. Eucalyptus tereticornis and E. camaldulensis demonstrated vigor and frost-hardiness and may be suitable for sandhills sites in central Florida and wetter sites farther south. For northen Florida, E. amplifolia had good frost-resilience and remained vigorous through four coppice rotations. Coppicing of other eucalyptus, notably E. grandis, is very dependent on climatic factors. Biomass properties of the eucalyptus vary due to genetics and age but appear suitable for certain fermentation and pulping proceses. Economic analyses suggest that E. grandis and E. amplifolia may be profitably grown and that short rotation culture appears feasible for slash pine but cannot yet be advised for sand pine.

eucalyptus/ genetics/ profitability.

232. Roeder, K. R.; Hansen, G. D. 1986. Season of harvest influences on Sycamore coppice productivity. In: Rockwood, Donald L., ed. Proceedings of the 1985 Southern Forest Biomass Workshop; June 11-14, 1986; Gainesville, Florida. Gainesville, FL: Institute of Food and Agricultural Sciences, University of Florida: 41-46.

A 12-year old sycamore plantation in North Carolina was harvested at five times during the year to evaluate coppicing response.

harvesting/ proceedings/ yields

233. Rose, Dietmar W. 1987. Economic evaluations of short rotation biomass energy systems discounted cash flow models including risk assessment. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 82-91.

Addresses some of the key problems that often are inadequately dealt with in

project analysis. These include the source of data and information to carry out such analyses, the uncertainty surrounding this data and the associated need to carry out appropriate sensitivity analyses, and finally the proper monitoring of projects through-out their life. The interrelation of these three elements emphasizes the need for better ways to organize, store and retrieve information relevent for analyzing SRIC systems.

economics/ economic analysis

234. Rose, Dietmar W. ; DeBell, Dean S. 1978. Economic assessment of intensive culture of short-rotation hardwood crops. Journal of Forestry. 11:706-707.

Hardwood crops coppices on 4- and 10-year cycles at spacings of 1.22 by 1.22 meters and 3.66 by 3.66 meters, respectively, appear economically feasible, while two-year coppice rotations do not. Short-rotation culture merits serious consideration and operational testing by industrial land managers.

short-rotation intensive culture/ coppice

235. Rose, Dietmar W.; Ferguson, Karen; Lothner, David C.; Zavitkovski, J. 1981. An economic and energy analysis of Poplar intensive cultures in the Lake States. St. Paul, MN: USDA Forest Service, North Central Forest Experiment Station; Research Paper NC-196.

Short- (5 to 10 years) and long- (15 years) rotation, irrigated and nonirrigated intensive cultures of hybrid poplar were analyzed economically via cash flow analysis. Energy balances were also calculated for each alternative. Nonirrigated systems offer reasonable economic returns whereas irrigated systems do not. All systems produce more energy than they use as production inputs.

236. Royle, D. J.; Hubbes, M. 1992. Diseases and pests in energy crop plantations. In: Mitchell, C. P.; Zsuffa, L.; Anderson, S.; Stevens, D. J., eds. Biomass and Bioenergy Special Issue. IEA Bioenergy Agreement Progress and Achievement 1989-1991. April 2-3, 1992; Edinburg, UK. Oxford, United Kingdom: Pergamon Press Ltd, 45-54.

The Pest and Disease Management Activity was established in response to an awareness of the potential importance of pests and diseases in woody biomass production systems. Annual surveys in several countries from 1987-91 confirmed that rust disease is currently the most serious problem in willow biomass production in Europe. Increasing clonal susceptibility to rust and an increasing association of premature defoliation with lower rust severity levels have occured over the period. A network of field experiments has been established, in collaboration with the Joint Trials Activity, to enable the rust pathotype composition to be compared between five countries. It also aims to identify an international set of standard willow clones to be utilized for characterizing rust pathotypes globally.

disease/ pests/ bioenergy/ technology

237. Rydelius, James A. 1994. Growing Eucalyptus for pulp and energy. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3, 1994; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 53-56.

The purpose of this paper is to describe the processes of site preparation, irrigation system design and installation, planting, and subsequent management of the subject plantations which have come to be known as the Tehama Fiber Farm.

plantations/ short rotation/ management

238. Säll, H. 1980. Optimizing establishment, management and harvesting energy crops from a technical standpoint. Proceedings of the joint IEA/IUFRO forestry energy workshop and study tour.; October 2, 1980; Garpenberg, Sweden. Garpenberg, Sweden: Swedish University of Agricultural Sciences, Department of Operational Efficiency: 64-73.

Discusses the costs for planting an energy crop.

economic analysis/ economics/ technology

239. Säll, H-O ; Nilsson, P. O. 1984. Harvesting a short rotation forest. Ecology and Management of Forest Biomass. 15:589-607.

Willow and Sallow present new problems in harvesting. Traditional harvesting techniques offer few elements of equipment or methods. If the harvester produced billets it would require less energy for its operation and it may be used for other purposes such as pre-commercial thinning or row thinning during the growing season. A few groups of designers have worked on analyses of requirements and possible solutions. Test rigs for severing and bundling were built and evaluated. Public funding was made available for design work on harvesters. Five groups were selected to produce layout designs of large and small harvesters. An evaluation procedure was performed., leading to selection of two concepts, slightly reworked from their original shapes. One is a large self-propelled front-cutting harvester, the other is a harvsting unit to be mounted on a suitable farm tractor.

harvesting/ equipment/ sheaves/ bundles/ billets

240. Saksa, T. 1996. Large-scale production of wood chips form forest for energy. In: Chartier, P.; Ferrero, G. L.; Henius, U. M.; Hultburg, S.; Sachau, J.; Wiinblad, M., eds. Biomass for energy and the environment - Proceeding of the Ninth European Bioenergy Conference; June 24-27, 1996; Copenhagen, Denmark. Oxford, England: Elsevier Science Limited: 873-877.

The aim of this demonstration project was to start a large-scale use of wood chips from forest in energy production in the Mikkeli region in Central Finland. This project belonged to the national Bioenergy Research Programme. The possibilities to use wood chip in energy production were studied from the point of view of local raw material resources, economy of wood chip production and everyday logisitics in wood chip delivery. Also the economical effects of the use of wood chip in energy production on the whole Mikkeli region's economy were estimated. The local raw material resources, energy wood from young thinning stands and logging residuals from regeneration cutting areas, were estimated to be large enough in the area nearer than 40 km from the heating plant to maintain a sustainable large-scale wood chip production (over 100,000 cubic meters of wood chips per year) for decades. The economical calculations showed that the wood chip production from logging residuals was economically possible in large-scale use. The wood chip production from young thinning stands needed some subsidies for instance from the communal sector in order to function. However these subsidies seemed to be smaller than the positive effects of wood chip production on the employment and on the whole regional economy.

bioenergy/ wood fuels/ chips/ delivery chain/ forests/ costs

241. Sampson, R. Neil; Wright, Lynn L.; Winjum, Jack K.; Kinsman, John D.; Benneman, John; Kürsten, Ernst; Scurlock, J. M. O. 1993. Biomass management and energy. Water, Air, and Soil Pollution. Netherlands: Kluwer Academic Publishers: 139-159.

The impact of managing biomass specifically for the conservation or production of enery can become a significant factor in the global management of atmospheric CO2 over the next century. This paper evaluates the global potential for:1) conserving energy by using trees and wood for shading, shelterbelts, windbreaks, and construction material; and 2) increasing the use of biomass and improving its conversion efficiency for producing heat, electricity, and liquid biofuels. Also addressed in the paper, but not quantified, were establishment of new forests, increasing the productivity of existing forests, or protecting forests to sequester C as an offset against CO2 emissions from burning fossil fuels of forest destruction.

conservation/ energy/ energy crops/ policy.

242. Saucier, J. R.; Clark, A. III.: McAlpine, R. G. 1972. Above ground biomass yields of short rotation sycamore. Wood Sciences . 5(1):1-6.

243. Schonoau, A. P. G. 1982. The planned production period for short rotation Eucalyptis Grandis. South African Forestry Journal. 122:10-13.

244. Semenov, M. A.; Evans, L. G.; Jamieson, P. D.; Eckersten, H. 1996. LARS-Willow: A model of short rotation forest with responses to water and nitrogen limitation. In: Chartier, P.; Ferrero, G. L.; Henius, U. M.; Hultberg, S.; Sachau, J.; Wiinbald. M., eds. Biomass for energy and the environment - Proceedings of the Ninth European Bioenergy Conference; June 24-27, 1996; Copenhagen, Denmark. Oxford, England: Elsevier Science Limited: 763-768.

A simulation model, LARS-willow, of short rotation forest is described. The idea behind the model development was to implement a generic mechanistic model for short rotation forest with responses to water and nitrogen stress which could be used on different spatial scales, from site-specific to the regional level. Results from the model calibration in Sweden are discussed.

simulation model/ short rotation forest/ energy crop/ nitrogen/ water limitation

245. Shen, S-Y; Jones, P. C.; Vyas, A. D. 1982. Economic analysis of short rotation forestry. Argonne National Laboratory: U.S. Department of Energy; 23 p.

The principles and the technology of short-rotation forestry are described, with some emphasis on the concept of wood-grass, an annually harvested tree crop, production. The model used for the economic analysis is described and the analysis and findings are presented. Wood-grass technology is identified as having substantial economic as well as technological benefit.

246. Sheppard, Lucy. 1991. Some early observations on the growth of red alder provenances on ex arable soil. In: Aldhous, J. R., ed. Wood for energy: The implications for harvesting, utilization and marketing.; April 5-7, 1991; Heriot-Watt University, Edinburgh. Institute of Chartered Foresters: 184-204.

Early experiments with restricted provenances sound the performance of red alder on upland forest sites to be disappointing. This paper reports on recent findings with a wider range of provenances established in 1984 on an agricultural site which had been under cereals. Twenty four provenances originating in North America between latitudes 58 and 46 were examined for growth, survival, frost hardiness and ability to form nodules with differing strains of Frankia in the range of soils used. Two local provenances of native common alder were included for

comparison. Additional work, conducted as pot experiments, indicated the importance of P for good growth and confirmed the unsuitability of peat as a growth medium.

biomass/ energy/ proceedings/ short rotation

7. Siegel, W. C. 1987. The financial implications of the 1986 tax reform act for short rotation forest plantations. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 268-279.

The federal income tax treatment of income and expenditures associated with short-rotation, intensive culture fuel wood plantations is an important factor in determining the economic feasibility of such ventures. The new Tax Reform Act's provisions have completely changed the federal income tax treatment of timber income and expenditures, including those associated with short-rotation plantations. This paper analyzes the changes and discusses their economic implications for fuel wood culture.

economics/ short rotation

18. Sims, R. E. H.; Riddell-Black, D. M. 1996. The practical and economic feasibility of fuelwood production and use in a municipal sewage management system. In: Chartier, P.; Ferrero, G. L.; Henius, U. M.; Hultberg, S.; Sachau, J.; Wiinbald, M., eds. Biomass for energy and the environment - Proceedings of the Ninth European Bioenergy Conference; June 24-27, 1996; Copenhagen, Sweden. Oxford, England: Elsevier Sciece Limited: 769-774.

The integration of bioenergy production with sewage and solid waste management using land treatment and incineration technologies could be a useful approach for local authorities. Based on New Zealand experience, the potential for a small town to benefit from such an approach is explored. The local authority has the opprotunity to create the conditions necessary to encourage a local bioenergy industry to develop, and to reach the critical mass necessary for biofuels to become competitive with traditional fossil fuels. At present the economics of energy recovery from MSW incineration and sewage using land treatment versus conventional muncipal waste disposal methods are marginal due to the low comparative energy costs for electricity, coal and gas and the minimum value placed on their environmental impacts. This may change in the future as environmental regulations become more stringent and energy costs rise.

fuelwood production/ sewage sludge and effluent/ muncipal solid waste/ heat and power generation

249. Staaf, H.; Bjorkroth, G. 1980. Complete tree utilization and soil fertility in Swedish Forests. Proceedings of the joint IEA/IUFRO forestry energy workshop and study tour.; October 2, 1980; Garpenberg, Sweden. Garpenberg, Sweden: Swedish University of Agricultural Sciences, Department of Operational Efficiency: 82-101.

250. Standiford, R. B.; Ledig, F. T. 1983. Economic evaluation of Eucalypt energy plantations. In: USDA Forest Service, Pacific Southwest Forest and Range Experiment Station. Proceedings of a Workshop on Eucalyptus in California: 1983; Berkeley, California: 42-48.

Cash flow analyses of two possible management scenarios for Eucalyptus for energy are presented, and breakeven prices are calculated. A benefit-cost analysis of an actual commercial planting using actual cost and return data from earlier trials is also described. Benefit-cost ratios were all greater than one for discount rates of 10 percent or less, for lower planting densities, i.e. 435 trees/ha.

251. Steenackers, V.; Hall, R.; Steenackers, M.; Smets, P. 1992. Exchange of genetic material. In: Mitchell C.P.; Zsuffa, L.; Anderson, S.; Stevens, D. J., eds. Biomass and Bioenergy Special Issue. IEA Bioenergy Agreement Progress and Achievement 1989-1991. April 2-3, 1991; Edinburg, UK. Oxford, United Kingdom: Pergamon Press Ltd.: 77-83.

The exchange of genetic material activity of the IEA/BA involved three countries in the period 1986-1988 and seven in the 1989-91. During this time, many poplar clones and seed, obtained from the Belgian breeding program and demonstrating a potential use for biomass production, were sent to other counties. Willow seed has also been exchanged among participants. The emphasis has gradually shifted from the exchange of clones which could be of immediate use in the new environment to the collection of informations about the exchanged clones in their new environment to permit enhanced exchanges in the future and subsequently to the exchange of seed and pollen which could be of use in breeding programs of the particiants.

biomass/ production/ genetics

252. Steenackers, V.; Stroble, S.; Steenackers, M. 1988. Collection and distribution of poplar species, hybrids, and clones. In: Mitchell, C. P.; Zsuffa, L.; Anderson, S.; Stevens, D. J., eds. Forestry, forest biomass and biomass conversion.; The IEA Bioenergy Agreement (1986-1989) Summary Reports: 1-20.

Three countries participated in the Poplar Exchange activity of the 3-year programme of Task 2 of the IEA/BA. The objectives of this activity were to exchange clones and/or seeds for immediate use in new environments and to collect information on clonal reactions to various diseases in different environments. Discussed in this paper are the poplar breeding programme in Belgium, biomass production possibilities, clones exchanged, current outstanding problems, and provisional results.

biomass/ production/ genetics

253. Steenari, B. M.; Lindqvist, O.; Tomsic, A. 1996. Wood ash recycling to forest soil - chemical aspects. In: Chartier, P.; Ferrero, G. L.; Henius. U.M.; Hultberg, S.; Sachau, J.; Wiinbald, M., eds. Biomass for energy and the environment - Proceedings of the ninth European bioevergy conference; June 24-27, 1996; Copenhagen, Denmark. Oxford, England: Elsevier Science Limited: 757-762.

Recycling of wood ash will be necessary in sustainable forestry. The main objective is to prevent depletion of accessible minerals in the forest soil. Since wood ash is reactive and strongly basic, stabilization is needed before spreading. Most ash materials form a solid mass when mixed with water. This so-called "self-hardening" process can be utilized in stabilization. In this work wood fuel based ashes from Swedish combustion units of various types have been characterized. The chemical reactions involved in self-hardening have been identified and their effects on the leaching of nutrients are discussed. Samples of ash have been extracted from forest areas about two years after ash fertilization was carried out. Results from analysis of these samples are compared to laboratory results concerning the chemical forms and leaching behaviour of nutrients.

wood ash/ mineralogy/ stabilizaton/ hardening/ leaching properties

254. Steinbeck, K. 1981. Energy output/input ratios for short-rotation growth of American sycamore . Ann Arbor, Michigan: Ann Arbor Science Publishers; 8 p.

sycamores/ fuels/ biomass/ wastes/ short rotation woody crops/ growth/ wood.

255. --- 1979. Increasing the biomass production of short rotation coppice forests. Proceedings of the 3rd Annual Biomass Energy Systems Conference.; The National Biomass Program. Department of Energy, Solar Energy Research Institute: 47-51.

256. --- 1978. Intensively managed short rotation coppice forests. In: Choong, E. T.; Chambers, J. L., eds. 27th Annual Forestry Syposium: Energy and the Southern Forest ; Baton Rouge, Louisiana: Louisiana State University, School of Forestry and Wildlife Management: 123-129.

intensive culture/ short rotation woody crops/ coppice/ silviculture

257. --- 1983. Potentialities of short-rotation forestry for developing countries. Outlook Agriculture. 12(1):160-164.

short rotation woody crops/ economic analysis

258. Stokes, B. J. 1992. Harvesting small trees and forest residues. In: Mitchell, C. P.; Zsuffa, L.; Anderson, S.; Stevens, D. J., eds. Biomass and Bioenergy Special Issue. IEA Bioenergy Agreement Progress and Achievement 1989-1991. April 2-3, 1991; Edinburgh, UK. Oxford, United Kingdom: Pergamon Press Ltd : 131-147.

Eight countries collaborated and shared technical information on the harvesting of small trees and forest residues in a three year program. Proceedings and reports from workshops and reviews are summarized in a review of activities and harvesting systems of the participating countries. Four databases were developed for harvesting and transportation of these materials.

harvesting/ residue/ biomass/ transportation

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

A continuous speed felling and bunching prototype machine was evaluated in harvesting a three-year-old, short rotation sycamore plantation. A small tractor, grapple skidder, and large chipper were evaluated as well. Prediction equations, production rates, and costs were developed for each component of the system.

biomass/ yields/ production/ harvesting

260. Stokes, Bryce J.; Hartsough, Bruce R. 1993. Development and analysis of SRIC harvesting systems. First Biomass Conference of the Americas: Energy, Environment, Agriculture, and Industry.; August 30-September 2, 1993; Burlington, Vermont. Golden, Colorado: National Renewable Energy Laboratory: 302-308.

Reviews several machine combinations for harvesting short-rotation, intensive-culture plantations. Productivity and cost information for individual machines was obtained from published sources. Three felling and skidding systems were analyzed for two stands, a 7.6 cm average dbh sycamore and a 15.2 cm average dbh eucalyptus. These analyses assumed that whole trees were shipped at roadside. Costs and production were summarized for each system.

harvesting/ short rotation/ costs/ equipment

261. --- 1994. Mechanization in short-rotation intensive culture (SRIC) forestry. Bioenergy

'94 The Sixth National Bioenergy Conference; October 2-6, 1994; Reno/Sparks, Nevada. 309-315.

Summarizes information presented at an international conference on SRIC mechanization held in Mobile, AL in March, 1994. Most of the operational plantations in the US are intended primarily for pulp production, with energy as a by-product, therefore trees are grown to a larger size than in dedicated energy plantations. The relatively small scale of SRIC plantations, diversity of site conditions and range of material requirements make the development of specialized equipment less attractive, yet development efforts in Sweden are yielding large gains in harvesting efficiency for small trees intended solely for energy use. A cooperative endeavor in the US involving growers, researchers, manufacturers and government agencies might provide similar results for larger trees to be converted into pulp or liquid fuel.

costs/ mechanization/ equipment

262. Stokes, Bryce J.; McDonald, Timothy P. 1994. Harvesting costs and utilization of hardwood plantations. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3, 1994; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 5-13.

The use of SRIC practices in hardwoods to meet fiber suply needs is becoming increasingly widespread. With many of the plantations approaching first harvest, questions have been raised about the adaptability of conventional harvest systems to SRIC stands. This study was initiated to test the use of harvest equipment common to the Southern United States in SRIC stands. Objectives were to determine productivity, costs, and recovery of felling, skidding, and processing short rotation sycamore stands.

costs/ harvesting/ short rotation/ equipment/ plantations

263. Stokes, Bryce J.; Watson, William F. 1985. Integration of biomass harvesting and site preparation. In: Rockwood, Donald L., ed. Proceedings of the 1985 Southern Forest Biomass Workshop; June 11-14, 1985; Gainesville, Florida. Gainesville, FL: Institute of Food and Agricultural Sciences:

Assesses the costs of various site preparation methods with vaious levels of harvesting residue. Site impacts, soil compaction, and disturbance were examined. The results indicate that conventional harvesting systems can be used to harvest energy wood components of some stand types. The integration of biomass harvesting and site prepaation can result in a credit to be applied to the harvesting or site preparation operations. One-pass harvesting has the most potential for

reducing harvest costs for some stand types. Single disking had the most site preparation savings. Usually, the soil characteristics were returned to comparable conditions after site preparation.

economics/ harvesting/ site preparation/ biomass

264. Stone, R. N.; Bradley, D. P. 1987. Externalities from fuelwood production by short rotation intensive culture forestry. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems.; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 219-223.

Any economic activity has both positive and negative impacts. Depending on the interest of the economist and the resources at his disposal, some of these effects may have to be ignored, either for convenience or lack of methods and data. Those ignored are called externalities. Yet, the relevance of the entire analysis hinges on which externalities were left out. A variety of SRIC effects not yet evaluated in depth and therefore external to the analyses to date, are discussed along with a brief description of the criteria by which they might be internalized.

economics/ cost-benefit analysis/ water quality/ soil erosion/ environmental impacts/ mono-culture

265. Strand, R. F.; Whitesell, C. D. 1989. Managing Eucalyptus plantations for maximum yield. Proceedings of the Third Pacific Basin Biofuels Workshop; Oahu, Hawaii: University of Hawaii, Hawaii Natural Energy Institute: 89-98.

plantation management/ Eucalyptus/ short rotation intensive culture/ fertility/ biomass/ soil properties

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

poplars/ economic analysis/ short rotation woody crops/ harvesting/ storage/ poplars

267. --- 1987. Setting standards for the economic analysis of woody biomass: Total costs systems. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems.; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 238-252.

A series of short rotation Populus plantations involving four management strategies were evaluated in tandem with alternate harvest and storage strategies to determine the least cost method for supplying biomass to conversion sites. All inputs were itemized on both a financial and energy basis to establish the unit output costs for commercial-scale systems.

Populus/ costs

268. Strauss, C. H.; Grado, S. C. 1991. Financial and energy costs for SRIC woody biomass. Louisiana Department of Agriculture and Forestry, Southern Biomass Conference; January 7-10, 1991; Baton Rouge, Louisiana. Louisiana Department of Agriculture and Forestry:

269. --- 1992. Input-output analysis of energy requirements for short rotation, intensive culture, woody biomass. Solar Energy. 48(1):45-51.

A production model for short rotation, intensive culture plantations was developed to determine the energy and financial costs of woody biomass. The model was based on hybrid poplars planted on good quality agricultural sites at a density of 2100 cuttings/ha, with average annual growth forecast at 16 metric ODT/ha. Energy and financial analyses showed preharvest costs of 4381 MJ/ODT and $16/ODT. Harvesting and transportation requirements increased total costs to 6130 MJ/ODT and $39/ODT for the delivered material. On the energy cost basis, the principal input was land, whereas on a financial basis, costs were more uniformly distributed among equipment, land, labor, materials and fuel.

270. Strauss, C. H.; Grado, S. C.; Blankenhorn, P. R.; Bowersox, T. W. 1983. Costs of establishing dense plantations for short rotation management systems. Proceedings of the 7th International FPRS Industrial Wood Energy Forum; September 19-21, 1983; Nashville, Tennessee. Madison, WI: FPRS: 122-128.

Financial and energy investments necessary to establish dense plantations of Populus under four management strategies have been determined for two dissimilar sites. Management strategies were control, fertilization, irrigation, and fertilization/irrigation and the two sites represented favorable and unfavorable inherent growth conditions. The establishment costs will be coupled with annual maintenance costs, fertilization and/or irrigation costs (when applicable), and biomass values to determine the return on the investment for each management alternative, by site.

costs/ economics/ management/ short rotation

271. --- 1987. Microeconomic accounting model for woody biomass systems. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems.; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 92-107.

An accounting model of a short-rotation intensive culture woody biomass system was developed to determine the unit cost of the feedstock, delivered and stored at a conversion site. The model established the variable and fixed cost structure for the plantation, harvest and storage stages of a commercial-scale operation. The unit costs of production were used to predict a least cost pattern of supply from the alternate strategies proposed within each stage of the system. Limitations to the model included adherence to a general technical design for the plantation strategies and the development of unit costs from fixed levels of production.

economic analysis/ commercial scale/ supply system/ costs/ production

272. Strauss, C. H.; Grado, S. C.; Blankenhorn, P. R.; Sowersox, T. W. 1988. Economic evaluations of multiple rotation SRIC biomass plantations. Solar Energy. 41(2):207-214.

A series of short-rotation intensive culture (SRIC) Populus plantations involving four management strategies (control, fertilization, irrigation, and fertilization-irrigation) were evaluated in tandem with alternate harvesting and storage strategies to determine the least cost method for supplying biomass to an ethanol conversion facility. The plantations were based on Populus hybrid NE-388., a tree spacing of 0.6 m x 0.8 m, and a rotation length of four years.First rotation yields from the various strategies ranged from 33 to 42 oven-dry metric tonne per hectare (Mg(OD) ha-1). An average yield increase of 12% was realized from the second rotation coppice plantations. The control strategy had the lowest production costs for the two rotations, averaging $32 Mg -1 (OD).

biomass plantations/ short-rotation intensive culture

273. Strong, T. F. 1989. Rotation length and repeated harvesting influence populus coppice production . Duluth, Minnesota: U.S. Forest Service, North Central Forest Experiment Station; NC-350.

biomass/ short rotation woody crops/ mortality/ sprouting/ stump height.

274. Stuart, B. 1984. Design and development of the short-rotation harvesting system. Blacksburg, VA: Virginia Polytechnic Institute; 101 p.

Describes the design, construction, and testing of a prototype harvesting attatchment. Also discusses the effect of crushing woody biomass to enhance moisture loss.

harvesting/ equipment/ products.

275. Stuart, W. B.; Marley, D. S.; Teel, J. B. 1983. A prototype short rotation harvester. Proceedings of the 7th international FPRS industrial wood energy forum;

September 19-21, 1983; Nashville, Tennessee. Madison, WI: FPRS: 167-174.

Many attempts to analyze the economic or technological feasibility of short rotation energy plantations have not fully suceeded because of the lack of harvesting technology. This article describes the design and testing of a prototype short rotation harvester.

harvesting/ short rotation/ equipment/ technology

276. Stuart, William B. 1994. Mechanization of short-rotation, intensive culture wood crops. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 43-51.

Three impediments to harvester development -- cultural, operational, and economic -- that have plagued the development of short-rotation harvesting equipment are discussed. Strategies for the future include concentrating on cropping strategies that a) result in material that can be harvested by heavy-duty agricultural equipment, b) result in material that can be handled by conventional forestry equipment, or defining a small subset of options between these limits and develop purpose-built equipment to suit. Demand/supply and cost/price relationships have to be more stringently defined before short- or long-line equipment manufacturers will enter this market.

costs/ harvesting/ equipment/ short rotation

277. Tardiff, Mary Louise. 1994. Update of short rotation intensive culture in Canada. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 133-143.

Canada is a large country with abundant quantities of biomass in many diverse forms. Forest industries and related operations alone annually produce 39 million oven dry t. But in the past fifteen years, bioenergy has contributed only 7% of Canada's total energy supply. Many provinces of Canada are fortunate in having affordable natural gas and hydro-electric power. As a result, the demand for wood fuel energy sources has risen very slowly.

biomass/ energy

278. Teel, J. B. 1983. The design and development of a prototype short-rotation harvesting system. Blacksburg, VA: Virginia Polytechnic Institute and State University; 168

p.

279. Thornton, F. C.; Joslin, J. D.; Bock, B. R.; Houston, A.; Green, T. H.; Scheonholtz, S.; Pettry, D.; Tyler, D. D. 1996. Environmental effects of growing woody crops on agricultural land: First year effects on erosion, and water quality. Proceeding of Second Symposium on Environmental Impacts of Bioenergy Crops; June 27 - July 1, 1996; Vejle, Denmark. Biomass and Bioenergy: 30.

The objective of this study is to assess the effects of converting row crop agriculture land to short-rotation woody crops (SRWC) on erosion, surface water quality and quantity, and groundwater quality. Three physiographic regions of the Southeast, varying in soils, slope, and erodibility, were used. Replicate plots were equipped with a flume and four pan lysimeters so that event sampling of runoff and groundwater could be conducted. Cropping treatments had little effect on the runoff volumes collected; however, sediment produced by the various treatments was significantly influenced by the crop. At all three sites, spring and fall generally had the highest sediment losses. The highest absolute losses of sediment occured at the Mississippi Delta site. Conventional tilled cotton (*Gossypium hirsutum* L.) lost 16.2 Mg/ha, compared to 2.3 Mg/ha for cottonwood (*Populus deltoides* L.) over 14 months. While sediment losses at a loess-belt site in west Tennessee were three-fold higher under no-till corn (*Zea maize* L.) than sycamore (*Platinus occidentalis* L.), total sediment loss was less than 1 Mg/ha for both treatments. At the north Alabama site, no-till corn and sweetgum (*Liquidambar styraciflua* L.) with a fescue (*Fescue elitor* L.) cover crop did not differ with respect to erosion. However, sediment losses under sweetgum without a cover crop were significantly higher, exceeding 5 Mg/ha. Nutrient losses of N and P in both runoff and lysimeters were primarily influenced by spring mineral fertilizer applications. Spring and early summer lysimeter nitrate values exceeded EPA guidelines for drinking water in the row crop treatments.

short-rotation woody crops/ erosion/ water quality/ row crop agriculture

280. Tillman, D. A. 1978. The resource base for wood fuel. In. Wood as an energy resource. New York: Academic Press: 159-185.

Wood use, as an energy source is limited in its availabilty, here we are searching through energy supply options.

281. Timmons, J. F. 1987. Complementary opportunities for forestry in cropland management, energy production and environmental quality. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems.; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 258-267.

U.S. Forestry is facing a unique opportunity to manage excess cropland, produce energy, and improve environmental quality. SRIC forest technology is well suited to using and improving idled cropland under the Conservation Reserve Program. SRIC technology can (1) conserve and improve soil and water on fragile land not currently needed for crop production and (2) produce biomass, on this otherwise idled land, for conversion into energy. Much more research is required to more fully develop the scenarios and techniques to enable forestry to participate fully in these opportunitites.

biomass/ energy/ environmental impacts/ plantations/ management

282. Trimble, J. L. 1983. Short rotation woody crops program. In: Daniels, R. F.; Dunham, P. H., eds. Proceedings of the 1983 Southern Forest Biomass Workshop.; June 15-17, 1983; Charleston, South Carolina. Asheville, North Carolina: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station.: 2-3.

The Short Rotation Woody Crops Program (SRWCP) is an integrated research program with a single objective: to improve the productivity and economic efficiency of growing woody plants for energy. The SRWCP currently includes 23 research projects across the United States. Eighteen are located at universities, with others at the U.S. Department of Agriculture-Forest Service experiment stations (2), and at private corporations (3). The program is sponsored by the U.S. Department of Energy's Biomass Energy Technology Division and is managed at Oak Ridge National Laboratory.

283. Tschaplinski, T. J. ; Wright, L. L. 1995. Woody plant research of the Biofuels Feedstock Development Program. Biologue. 12:32-35.

short rotation woody crops/ biofuels/ feedstocks

284. Turhollow, Anthony. 1994. The economics of energy crop production. Biomass and Bioenergy. 6(3):229-241.

This paper presents 1989 and 2010 cost estimates for growing and supplying biomass for five combinations of major cropping strategies and regions. Four of the dedicated feedstock supply systems (DFSS) use herbaceous energy crop (HEC) technologies, and one uses short-rotation woody crops (SRWC). The costs of producing systems for hybrid poplar, sorghum, switchgrass and energy cane are determined through the examination of such factors as cultivation systems, species, treatments, regions and site variability. The Midwest and South are the areas of focus. At the assumed yields, sorghum in the Midwest and energy cane in the Southeast, appear to be the low-cost DFSS. To be competive with corn in the Midwest and soybeans in the Southeast, dedicated energy crops must sell at

between $43 and $60/dry Mg in 1989 and $30 and $43/dry Mg in 2010.

short-rotation woody crops/ energy crops

285. Turnbull, Jane Hughes. 1994. Developing sustainable integrated biomass systems. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3, 1994; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 115-123.

Discusses the economics of competing feedstocks, the environmental and economic drivers, developing sustainable systems, steps towards large-scale energy crop production, determining the feasibility of integrated systems, and commercialization.

economics/ bioenergy/ commercial scale/ energy/ environmental impacts/ production

286. Tuskan, G. A.; Downing, M. E.; Wright, L. L. 1994. Current status and future directions for the U.S. Department of Energy's short-rotation woody crop research. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3, 1994; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 123-131.

The U.S. Department of Energy initiated the Biofuels Feedstock Development Program at ORNL in 1978. The programs goal is to provide leadership in the development, demonstration and implementation of environmentally acceptable and commercially viable biomass supply systems. Three model short-rotation woody crop species have been selected for futher development based on their productivity, adaptability, and suitability as biomass feedstocks.Currently, harvesting and transportation expenditures account for 50-60% of total production costs. The productivity goals are 20-30 t/ha/yr with the current average across all sites and clones at10 t/ha/yr. To increase average productivity rates, silvicultural enrichments, genetic improvements, and molecular genetics techniques are being applied to all model species.

costs/ biomass/ genetics/ management/ production/ harvesting/ silviculture

287. Van Veen, J. A. 1981. Feasibility study of short rotation forestry for combined pulp and energy purposes in sparsely populated areas. No. EUR 7561 EN. 19 p.

288. Venketeswaran, S.; Nagmani, R.; Gandhi, V. 1983. Tissue culture propagation of trees for biomass energy production. Proceedings of the 7th international FPRS

industrial wood energy forum; September 19-21, 1983 ; Nashville, Tennessee. Madison, WI: FPRS: 140-155.

Tissue culture methods and somatic cell genetic studies offer a new dimension for genetic improvement of forest trees and therefore clonal mass propagation of Sapium sebiferum Roxb. and a tropical legume, Leucaena leucocephala de Wit. are studied because of their usefulness for biomass energy production. Regeneration of plants in large numbers from seedlings and tissue cultures have been achieved to produce "test tube trees" in the laboratory. Transferring tissue culture technologies to biomass tree crops like these and others for use in industrial and commercial aspects of energy production appears very feasible for the future.

biomass/ genetics/ bioenergy/ production

289. Vyas, A. D.; Shen S.Y. 1982. Analysis of short-rotation forests using the Argonne Model for Selecting Economic Strategy (MOSES). Argonne, IL: Argonne National Laboratory, Energy and Environmental Systems Division; ANL/CNSV-36. 50 p.

The use of MOSES is demonstrated. The model, which employs a complimentarity algorithm, has a capability to select the most economical harvesting cycle given data on biomass production costs and yield as a function of tree spacing, financial parameters, and the management system for a short-rotation forest. The results of analyses of three hypothetical plantations are summarized. The results support three general conclusions regarding short-rotation forestry. For straight-row planting at a 4 x 4 ft spacing, forage harvesting is more economical than whole-tree harvesting. Production costs for straight row plantings can be further reduced through use of a circular saw harvester on which research is now being conducted. Costs can be minimized, however, by planting cuttings very densely and forage harvesting year-old saplings.

290. Vyas, A. D.; Shen, S. Y. 1982. An economic analysis method for short-rotation forestry. 2nd National Conference on Renewable Energy Technologies.; August 1, 1982; San Juan, Puerto Rico. Argonne National Lab: 16 p.

A method for economic analysis of short-rotation forestry is presented; a model that employs linear complementarity optimization is an important component of this method. Given data on biomass production costs and methods for short-rotation forestry, the model selects the rotation period (i.e., harvesting cycle) that maximizes the net present value of all future profits for a specified return. The ability to select the optimal rotation period is a unique feature of the model. The model's output, combined with independent analysis of the effect of tree spacing on production costs and woody biomass yield, allows specification of least-cost production systems for short-rotation forestry.

291. Wang, F. C.; Richardson, J. R.; Ewel, K. C.; Sullivan, E. T. 1981. Preliminary energy analysis of utilizing wood biomass for fuel. In: Mitsch, W. J.; Bosserman, R. W.; Klopatek, J. M., eds. Proceedings, 1981 International Symposium on Energy and Ecological Modeling; NewYork: Elsevier Science Publishers Ltd.: 673-680.

short rotation woody crops/ fuels/ economic analysis/ energy content

292. Wart, K. T. ; Ostry, M. E. 1993. Mid-rotation disease impact on hybrid poplar plantations in the north-central United States. American Journal of Botany. 80:83.

short rotation woody crops/ renewable energy/ poplars/ hybrids/ Melampsora/ disease

293. Watson, W. F.; Miller, D. E.; Stokes, B. J.; Broussard, M. L. 1986. Energy budget for an energy wood harvesting system. Proceedings of the 8th Annual Southern Forest Biomass Workshop.; June 16-19, 1986; Knoxville, Tennessee. 103-107.

294. White, E. H. ; Hook, D. D. 1975. Establishment and regeneration of silage plantings. Iowa State Journal of Research. 49:287-296.

295. White, T. A.; Rolfe, G. L.; Faix, J. J.; Zimmerman, R. W. 1979. Pilot studies of woody biomass for energy. Illinois Agricultural Experiment Station DSAC. 7:221-226.

short rotation woody crops/ solar radiation/ ethatnol / methanol/ natural gas

296. Whitesell, C. D.; Debell, D. S.; Schubert, T. H.; Strand, R. F.; Crabb, T. B. 1992. Short-Rotation Management of Eucalyptus: Guidelines for Plantations in Hawaii . Albany, California : U.S. Department of Agriculture, Pacific Southwest Research Station; Gen. Tech. Rep. PSW-GTR-137. 30 p.

Ten year study on the island of Hawaii for Eucalyptus plantations. Techniques are described for seedling production, plantation establishment, maintenance, biomass yield estimation, and harvest. Biological relationships are described to aid decisions on site selection, initial spacing, fertilizer schedules, and rotation length. Environmental issues faced by growers are discussed.

Albizia/ admixtures/ Eucalyptus grandis/ Eucalyptus saligna/ plantation management/ plantations/ Hawaii/ short rotation woody crops.

297. Whitesell, C. D.; Miyasaka, S. C.; Strand, R. F.; Schubert, T. H.; McDuffie, K. E. 1988. Equations for predicting biomass in 2- to 6-year-old Eucalyptus siligna in Hawaii. Berkeley, CA: USDA Forest Service, Pacific Southwest Forest and Range Experiment Station; Research Note PSW-402. 4 p.

Eucalyptus saligna trees grown in short-rotation plantations on the island of Hawaii were measured, harvested and weighed to provide data for developing regression equations using non-destructive stand measurements. Regression analysis of the data from 190 trees in the 2.0- to 3.5-year range and 96 trees in the 4- to 6-year range related stem-only and total above-ground biomass to diameter at breast height and total height. Equations developed for each age class are recommended over equations developed for the combined data base (286 trees). For younger stands (4-years) recommended equations include one based on diameter measurements only, thus simplifying field measurements.

298. Wierman, Charles A. 1994. Management of irrigated hybrid poplar plantations in the Pacific Northwest. In: Stokes, Bryce J.; McDonald, Timothy P., eds. IEA/BA Task IX Activity 1. Short Rotation Intensive Culture Forestry. Mechanization in SRIC Forestry; March 1-3, 1994; Mobile, AL. Auburn, AL: USDA Forest Service, Southern Forest Experiment Station: 57-63.

Boise Cascade Corporation had embarked on a project to establish 8,000 ha of irrigated hybrid poplar plantations in the Columbia River Basin of eastern Oregon and Washington. These tree farms will provide approximately 15 to 20% of the raw material supply for the company's pulp and paper mill at Wallula, WA. The fiber will be used in the production of uncoated free sheet white papers. In addition to increasing the fiber available to the mill, the hybrid poplar provide other benefits including: reduced bleaching and improved paper qualities of brightness, opacity and print ability. Fiber farms are developed on existing agricultural land. Traditional irrigation systems are converted to drip irrigation. Planting sites are prepared with mechanical cultivation and pre-emergent herbicides. Planting stock is unrooted dormant cuttings produced in stool beds. Planting is done by hand during the month of April. Crop tending consists of irrigation, weed control, fertilization and pest control. A six-year rotation is planned at which time the trees are expected to be approximately 18-20 m in height and 15-20 cm dbh.

management/ plantations/ short rotation

299. Withrow-Robinson, B.; Hibbs, D.; Beuter, J. Poplar chip production for Willamette Valley grass seed sites. Oregon State University, Corvallis, OR: Forest Research Laboratory; Research Contribution 11.

The authors evaluated the production potential of hybrid poplar in the Willamette Valley. All well-managed hybrid poplar stands in the valley, a total of 28 stands on 13 different soil series, were measured. They ranged in age from 2 to 7 years. Site index curves, a volume production model, and a classification of valley soils by production potential were developed. An economic analysis of four different poplar management systems showed poplar to be a profitable crop in many

situations. Markets and possible market trends were also examined.

300. Woodfin, S. L.; Fredrick, D. J.; Stokes. B. J. 1987. Selected harvesting machines for short rotation intensive culture biomass plantations. St. Joseph, MI: American Society of Agricultural Engineers; 18 p. p.

Three different harvesting systems were observed and analyzed for productivity and costs in a short rotation intensive culture plantation of 2 to 5 year old sycamore. Individual machines were compared to create an optimum system.

forest engineering/ harvesting/ mechanization/ tractors/ smallwood/ feller-bunchers/ skidders/ biomass/ logging/ fuelwood.

301. Woodfin, S. L.; Wright, L. L.; Curtin, D. T. 1987. SRIC:Integration of production and harvesting system costs. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems ; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 115-150.

Biomass production and harvesting cost functions are developed and combined to determine total system costs. Such an approach allows the analysis of how compromises within the function segments can improve total system performance. Although these data are very limited, new concepts of harvesting near the mazimum current annual increment are discussed. A regression equation of the favored rotation age in relation to planting density is formed. This relationship leads to other regressions of biomass yield to planting density and production costs to density. Harvesting productivity rates are simulated from research data. The production and harvesting costs for each density are combined in the form of present net worth and annual equivalent value and illustrated as a function of planting density. The results show a logarithmic increase in costs as planting density increases.

biomass/ harvesting/ production/ economics/ proceedings/ short rotation

302. Wright , L. L. 1988. Commercialization of short-rotation intensive culture tree production in North America. In: Klass, D. L., ed. Proceedings, Energy from Biomass and Wastes XIII; Chicago, Illinois: Institute of Gas Technology: 309. 20.

industrial participation/ economic analysis/ short rotation woody crops

303. Wright, L. L. 1991. The economic viability of short rotation woody crops. In. Policy Implications of Greenhouse Warming Report of the Mitigation Panel. Appendix H: Biomass. Washington, DC: National Academy Press: 21.

economic analysis/ short rotation woody crops.

304. --- 1994. Production technology status of woody and herbaceous crops. Biomass and Bioenergy. 6(3):191-209.

Several woody and herbaceous energy crop species have been selected as high-potential candidates for supplying biomass feedstocks. Successful methods for their establishment and maintenance have been developed. Recommended species vary as a function of region of the country and soil type. Yields are equally variable. The crops that have received the most research and development include hybrid poplars (fast-growing trees) and switchgrass (a perennial grass). Some information is also available on other tree crops, thick-stemmed perennials and annuals. Supplying large volumes of biomass to energy facilities on a daily basis requires that consideration be taken of the harvest timing, storage and delivery characteristics of different feedstocks as well as their yield, cost and energy properties. Our summary suggests that a combination of crops will be needed to provide large amounts of low-cost and environmentally sustainable year-round supplies of biomass feedstocks.

biomass feedstocks/ sustainability

305. Wright, L. L.; Cushman, J. H.; Ehrenshaft, A. R.; McLaughlin, S. B.; Martin, S. A; McNabb, W. A.: Ranney, J. W.; Tuskan, G. A.; Turhollow, A. F. 1993. Biofuels feedstock development program annual progress report for 1992. Tennessee: Oak Ridge National Laboratory; Environmental Sciences Division Publication No. 4196. 43 p.

The purpose of this report is to highlight the status and accomplishments of the research that is currently being funded by the BFPD. Areas include Short Rotation Woody Crop Research, Herbaceous Energy Crops Resesrch, Environmental Research and Analysis, Economic Analysis and Integration.

highlights/ short rotation/ herbaceous energy crops/ environmental impacts/ economics.

306. Wright, L. L.; Cushman, J. H.; Layton, P. A. 1989. Expanding the market by improving the resource. Biologue. 6 :12-19.

Dedicated energy crops--trees and grasses grown specifically for fuels or energy feedstocks--can increase the overall amount of biomass available for energy. They can also ensure that biomass feedstocks occur where they are needed, when they are needed. Because crop production systems can be matched with compatible sites, dedicated energy crops greatly reduce the chances of environmentally--related restrictions on the expansion of biomass energy systems.

energy crops/ feedstocks/ biomass

307. Wright, L. L.; Ehrenshaft, A. R. 1990. Short Rotation Woody Crops Program: Annual Progress Report for 1989. Oak Ridge, Tennessee: Oak Ridge National Laboratory; ORNL-6625.

biomass/ economic analysis/ short rotation woody crops/ economic analysis/ management/ land.

308. Wright, L. L; Graham, R. L.; Turhollow, A. F. 1990. Short-rotation woody crop oportunities to mitigate carbon dioxide buildup. North American Conference on Forestry Responses to Climate Change; Washington, DC: Climate Institute: 137-156.

fossil fuels/ carbon dioxide mitigation/ short rotation woody crops/ economic analysis/ management

309. Wright, L. L.; Graham, R. L.; Turhollow, A. F.; English, B. C. 1992. The potential impacts of short-rotation woody crops on carbon sequestration. In: Sampson, R. N.; Hair, D., eds. Forests and Global Change, Chapter 8. Washington, DC: American Forestry Association: 123-156.

fossil fuels/ yields/ land base/ short rotation woody crops/ carbon dioxide.

310. Wright, L. L; Hall, R. B. 1991. Overview of biofuels feedstock development work in the United States. In: Hall, R. B.; Hanna, R. D.; Nyong'o, R. N., eds. International Energy Agency 1991 Joint Meeting of the task V Activity Groups and Workshop of the Task II Activity Group; Ames, Iowa : Iowa State University : 26-32.

biofuels/ feedstocks/ short rotation woody crops/ productivity

311. Wright, L. L. ; Hughes, E. E. 1993. U.S. carbon offset potential using biomass energy systems. Water, Air, and Soil Pollution. 70:483-497.

A previous analysis had assumed that about 20% of 1990 U.S. C emissions could be avoided by the substitution of biomass energy technologies for fossil energy technologies at some point in the future. Short-rotation woody crop (SRWC) plantations were found to be the dedicated feedstock supply system (DFFS) offering the greatest C emission reduction potential. High efficiency biomass to electricity systems were found to be the conversion technology offering the greatest C emission reduction potential. This paper evaluates what would be required in terms of rate of technology implementation and time period to reach the 20% reduction goal.

emissions/ bioenergy/ technology/ implementation

312. Wright, L. L.; Perlack, R. D.; Layton, P. A.; Wenzel, C. R.; Trimble, J. L.; Ranney J.W. 1985. Short Rotation Woody Crops Program: Quarterly Progress Report for the Period June 1 to August 31, 1985 . Oak Ridge, Tennessee: Oak Ridge National Laboratory; ORNL/TM-9832.

short rotation woody crops/ species selection/ breeding/ environmental impacts/ economic analysis/ physiology.

313. Wright, L. L.; Ranney, J. W. Short rotation woody crops: Using agroforestry technology for energy in the United States. In: Graca, L. R., ed. Proceedings in the 2nd Annual Brazilian Conference on Forest Economics and Planning ; 139-154.

short rotation woody crops/ agroforestry/ energy production

314. --- 1987. Validation and standardization of SRIC production costs. In: Lothner, D. C.; Bradley, D. P.; Gambles, R. L., eds. Economic Evaluations of Short-rotation Biomass Energy Systems.; August 11-13, 1987; Duluth, Minnesota. IEA/BA: 230-237.

The objective of the SRIC Program has always been to improve the productivity and cost efficiency of growing woody plants for energy. The program has reached a stage now where research results indicating improved productivity and reduced costs can be tested in larger plots. Monoculture Viability Trials ranging in size from 10 to 35 ha are being established in 3 locations with cofunding from industry. One major component of the trials is to accurately determine all costs associated with establishing, maintaining, and harvesting an operational-scale, short-rotation intensive culture plantation. A standardized cost accounting spreadsheet for reporting cost information has been agreed upon by all investigators involved.

costs/ production/ short rotation intensive culture

315. Wright, L. L.; Ranney, J. W.; Layton, P. A. 1988. Recent progress in the short-rotation woody crops program. In: McCaskey, T. A.; Lockaby, B. G., eds. Southern Biomass Conference; July 26-28, 1988; Auburn University, AL. Auburn, AL: 35.

The SRWCP reaches 10 years in 1988. Its primary charge has been to develop the technology required for supplying the United States with an adequate and dependable supply of renewable wood feedstocks for energy conversion at a low cost. Widespread attainments of high yields in SRIC plantations depends on the development of genetically improved hardwood clones with characteristics of rapid juvenile growth, resistance to pests and disease, and tolerence to drought and on

the availability of land with relatively few growth limitations. Obtaining a wood quality that facilitates conversion to liquid fuels could be important in reducing the overall costs of biofuel production. Projects funded through the SRWCP are making progress in developing the technology required to make SRIC a sucess.

short rotation/ genetics/ production

316. Young, H. E. 1980. A balanced view of the forest as a source of energy material. Proceedings of the joint IEA/IUFRO forestry energy workshop and study tour.; October 2, 1980; Garpenberg, Sweden. Garpenberg, Sweden: Swedish University of Agricultural Sciences, Department of Operational Efficiency: 59-63.

317. Zavitkovski, J.; Hansen, E. A.; McNeel, H. A. 1979. Nitrogen-fixing species in short rotation systems for fiber and energy production . In: Gordon, J. C.; Wheeler, C. T.; Perry, D. A., eds. Symbiotic Nitrogen Fixation in the Management of Temperate forests. Oregon State University, Forestry Research Laboratory: Corvallis, Oregon: 388-402.

nitrogen fixation/ short rotation woody crops/ fiber content.

318. Zobel, B. J. 1981. Wood quality from fast-grown plantations. TAPPI Journal. 64:71-74

forestry/ plantations/ short rotation woody crops/ Eucalyptus/ hardwoods/ softwoods/ mechanical properties.

319. Zobel, B. J.; Jett, J. B., and Hutto, R. 1978. Improving wood density of short-rotation southern pine. Tappi Journal. 61(3):41-44

320. Zobel, B. J. and Kellison, R. C. 1972. Short-rotation forestry in the southeast. Tappi Journal. 55(8):1205-1208

321. Zsuffa, L. 1988. Genetic improvement of willows for energy plantations. In: Mitchell, C. P.; Zsuffa, L.; Anderson, S.; Stevens, D. J., eds. Forestry, forest biomass and biomass conversion.; The IEA Bioenergy Agreement (1986-1989) Summary Reports: 35-47.

The objectives of Task II were to facilitate the development of superior, high yielding willow clones for energy plantations by a) exchange of genetic stock b) exchange of information on breeding studies and c) joint actions. The results of this cooperative activity are discussed accordingly. Significant achievements are in a) enrichment of genetic stock b) evaluation and stimulation of genetic studies and breeding programmes and c) joint actions on disease surveys, clonal identification problems, joint testing methods and willow feedstock qualities for energy conversion. The development of high yielding stock seems to be within reach.

genetics/ biomass/ production

322. Zsuffa, L. and Balatinecz, J. J. 1975. Poplar pulpwood production with a one-year rotation. Populier. 12(1):6-8

323. Zsuffa, L.; Gambles, R. L. 1992. Improvement of energy-dedicated biomass production systems. In: Mitchell, C. P.; Zsuffa, L.; Anderson, S.; Stevens, D. J., eds. Biomass and Bioenergy Special Issue. IEA Bioenergy Agreement progress and Achievement 1989-1991.; April 2-3, 1992; Edinburg, UK. Oxford, United Kingdom: Pergamon Press Ltd.: 11-15.

Some of the issues adressed by Task V of the IEA/BA are reviewed, and progress in these areas noted. Future work to be carried out on production systems in Task VIII is described.

biomass/ energy/ production

324. Zsuffa, L.; Kenney, W. A.; Gambles, R. L. 1992. Wood feedstock qualities for energy conversion and the potential for their biological improvement. In: Mitchell, C. P.; Zsuffa, L.; Anderson, S.; Stevens, D. J. Biomass and Bioenergy Special Issue. IEA Bioenergy Agreement Progress and Achievement 1989-1991. April 2-3, 1992; Edinburg, UK. Oxford, United Kingdom: Pergamon Press Ltd, 55-69.

The accomplishments of the Wood Feedstock Quality activity of Task V of the International Energy Agency's Bioenergy Agreement are described. Areas investigated included energy products and co-products from woody biomass; effects of harvesting, processing and storage on feedstock quality; the effect of feedstock quality on the efficiency of biomass conversion; the potential for biological improvement; the need for standardization of feedstock qualities; and the need for clonal characterization.

biomass/ feedstock quality/ products/ conversion

KEYWORD INDEX