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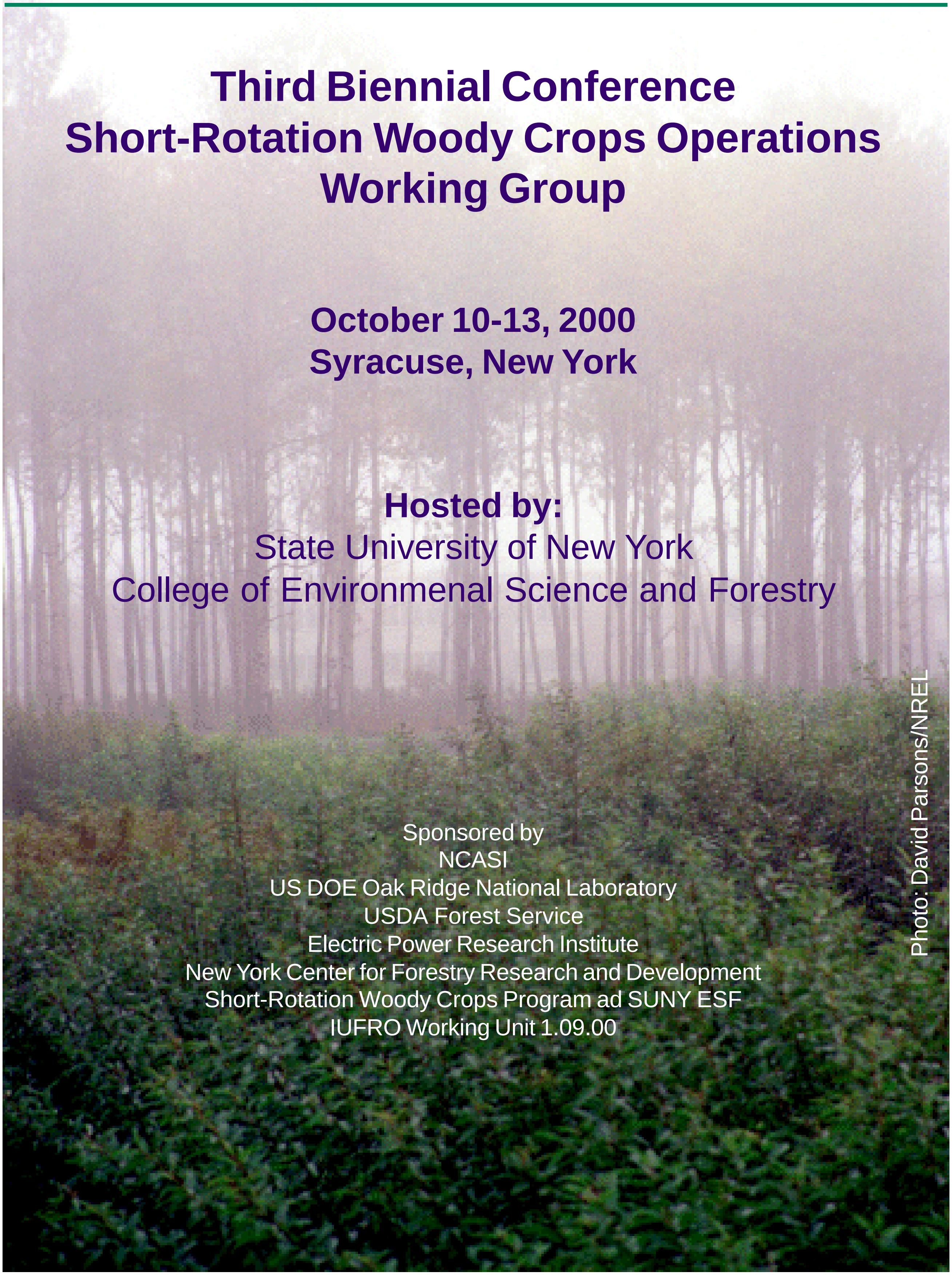

Third Biennial Conference
Short-Rotation Woody Crops Operations Working Group

October 10-13, 2000
Syracuse, New York

Hosted by:
State University of New York
College of Environmental Science and Forestry

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NCASI
US DOE Oak Ridge National Laboratory
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Proceedings of the Short-Rotation Woody Crops Operations Working Group

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Compiled by

Timothy A. Volk, Lawrence P. Abrahamson, and Jennifer L. Ballard
August 2001

These proceedings include papers or abstracts of presentations given by the authors and submitted to the organizers of the Third Conference of the Short-Rotation Woody Crops Operations Working Group. The authors are responsible for the content of the individual papers. Please direct any questions to the authors listed for each paper. Contact information for the authors can be found in Appendix 1.

Short-Rotation Woody Crops
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Prologue

Interest in the production of short-rotation woody crops (SRWC) continues to grow in North America and around the world. The primary market for SRWC, in terms of the area planted, continues to be fiber for the pulp and paper market. However, interest in SRWC to produce bioenergy and/or bioproducts is increasing. Alternative applications for SRWC, such as use in wastewater and nutrient management systems, riparian buffer strips, phytoremediation, and brownfield development are being explored, tested, and used in various locations worldwide.

While important progress has been made in the field of SRWC, there are many areas where additional research and operational experience will improve production system efficiency, overall economics, and the public's perception of SRWC. For example, changing market conditions will require deployment and refinement of different silvicultural systems for SRWC. Improving the establishment, management, harvesting, and transportation of SRWC will yield both economic gains and environmental benefits. In addition, breeding programs are producing new clones with improved insect and disease resistance, growth form, and yields, but many questions about genotype by environment interactions are not yet well understood. With rapidly developing interest in other applications and uses for biomass from SRWC, breeding programs can also focus on other traits, such as preferential uptake or break-down of soil and water contaminants (pollutants), improved nutrient and water use efficiency, and special fiber or wood composition. Finally, as the public becomes more aware of SRWC, they have some concerns about whether the fiber, bioenergy, and/or bioproducts produced from SRWC are sustainable. The sustainability of these systems needs to be quantified and communicated to the public in terms that are easily understood.

Feedback received from the Conference participants indicated that this Third Conference of the SRWC Operations Working Group was beneficial for all involved. The speakers presented informative and thought-provoking ideas on a wide range of topics related to SRWC. The moderators did an excellent job facilitating discussions and keeping the presentations on schedule. Credit for the logistics of the conference go to Horace Shaw, Kathy Cole and Kari Bakken of the Continuing Education Office at SUNY-ESF. Their planning and execution of the logistics made the event flow smoothly. Brian Kiernan coordinated the computer-based presentations and ensured that they ran effectively and efficiently. Lessons learned from previous conferences, and input from their organizers made the coordination of the Third Conference an easier task and resulted in a successful meeting.

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Short-Rotation Woody Crops Program, SUNY-ESF, Syracuse, NY
Proceedings Compilers
July 2001

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TECHNICAL SESSION: OVERVIEW OF SRWC PROGRAMS

Short Rotation Woody Crop Cooperative Research Program

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ABSTRACT

The Short Rotation Woody Crops Cooperative Research Program is a Forest Service led program on intensive forest management with participation by Department of Energy, forest industry and university collaborators. The objectives of the SRWC Co-op are to provide research and information on fundamental biological, environmental and operations aspects of intensive management through public sector research. Three core experiments are described which address these objectives. The first involves four species receiving a range of irrigation and fertilization treatments in 95 one-fifth hectare plots. A second experiment evaluates effects of intensive silviculture by monitoring hydrologic processes, soil sustainability and faunal diversity in four to six hectare catchments during conversion from mature pine forest to intensively managed pine and hardwood plantations. Other planned and ongoing experiments involve carbon allocation for pest resistance, phytoremediation of contaminated areas at the Savannah River Site, watershed-scale research, carbon sequestration, hardwood nutrient requirements, and empirical fertilization trials. This regional program supports a national collaborative Forest Service research program to address economically efficient and environmentally sound intensive culture systems.

Keywords: SWRC, silviculture, irrigation, fertilization, pest resistance, watershed

INTRODUCTION

Intensive culture management practices have attained large productivity gains in forest plantations. These practices include selection of superior genetic material, intensive site preparation, competition and pest control, irrigation and fertilization (Allen et al. 1990, Zsuffa et al. 1996). Process level understanding of such large productivity gains is essential for making informed plantation management decisions. Ecophysiological research has recently provided a better understanding of the relationship between stem growth and such processes as light interception, availability of water and nutrients and carbon metabolism (Landsberg and Gower 1997), but there is still much to be learned in this regard. There is also uncertainty regarding environmental issues such as water quality, sustainability, habitat quality and biodiversity. Further progress is also needed in crop management and engineering technology to improve operational efficiency.

In addition to fiber production for paper, lumber and energy, SRWCs can be utilized for environmental services. Environmental services include, among others, detoxifying, volatilizing or accumulating hazardous wastes in contaminated water or soil; disposing of agricultural, municipal or industrial waste water streams; sequestering carbon to mitigate global warming; placing marginal lands into conservation reserves; and protecting surface and shallow ground water with streamside buffers. The high productivity of SRWCs enhances environmental services through rapid metabolism and high nutrient demand. Interest in using SRWCs for such “green technologies” is growing because it represents a low cost alternative with wide public acceptance, and has the added advantage of producing a fiber crop.

The Short Rotation Woody Crops (SRWC) Cooperative Research Program is a collaborative research effort supporting the development of intensive forest management practices. Several USDA Forest Service Southern Research Station project leaders initiated the SRWC Co-op during the mid 1990s. These scientists recognized the need for public sector research and identified various aspects of intensive forest management practices that existing Forest Service research programs did not address. The SRWC Co-op received critical support in 1998 when DOE Savannah River, USDA-Forest Service research work units (RWU), forest products companies, and Oak Ridge National Laboratory committed finances (Table 1). At that time, the Advisory Committee approved a Charter and Science Plan.

Table 1. Contributing and Associate members of the Short Rotation Woody Crops Cooperative Research Program.

Forest Service RWUs	**Department of Energy**	**Forest Products Industry**
Athens, GA SRS-4505	Savannah River Site	The Timber Company
Auburn, AL SRS-4703	Oak Ridge National Lab	Weyerhaeuser
Charleston, SC SRS-4103		Champion International
New Orleans, LA SRS-4802[a]	**Universities**	
Research Triangle Park, NC	University of Georgia[a]	
SRS-4154	NC State University[a]	
Stoneville, MS SRS-4155[a]	Auburn University[a]	

[a]Associate members collaborate on research programs and contribute in-kind time, equipment and/or data to support core SRWC Co-op activities.

The SRWC Co-op provides research and information on fundamental biological, environmental and operations aspects of intensive management in a public sector program. Concerns over shortfalls in timber supply, as demand for fiber and solid wood products remains high, have stimulated research on intensive forest management. Fiber supply is limited because, among other reasons, National Forests have restricted timber harvesting as a result of public concerns over forest conservation. Shortening the planting-to-harvesting rotation time on lands designated for timber production provides an important way to meet society's demand for forest products while conserving National Forest lands for alternative uses. Intensifying forest management practices also raises important questions about the biology of high productivity forests, the efficient management operations required to achieve productivity goals, and the environmental consequences. Private companies have conducted much of the research on short rotation fiber farms. However, industry has not made information on cost and productivity publicly available. In addition, conservationists might view industry-generated data on environmental impacts with some skepticism. Consequently, there is an important need for concurrent research in the public sector to provide critical data from an impartial source.

Research Program

The SRWC Co-op Science Plan outlines three experiments to meet program objectives: *Experiment A*, Fundamental controls of growth and productivity; *Experiment*

B, Effects of short rotation silvicultural systems on water resources and biodiversity; and *Experiment C*, Understanding the effects of management intensity on carbon allocation patterns in trees and their susceptibility to pests and pathogens. These core research projects are described below followed by descriptions of other related research activities.

Experiment A:Fundamental controls of growth and productivity

Priority objectives of the SRWC Co-op are to provide research & information on fundamental biological aspects of productivity in intensively managed forests. Understanding how available resources accumulate and are allocated for tree growth is critical to effective forest management. Although we have clear evidence that light interception, carbon assimilation and nutrient uptake drive forest productivity (Landsberg and Gower 1997); we have few complete carbon and nutrient budgets that include both above and belowground components (cf. Vogt 1991).

Experiment A has been designed to provide a complete carbon and nutrient mass balance, and define critical processes controlling tree growth response to resource availability. We will monitor growth and stand-level processes in experimental plots, each containing one of four tree species treated with one of a variety of water and nutrient regimes. The results of this experiment will help determine processes and mechanisms controlling productivity potential by manipulating nutrient and water regimes, thus allowing us to test the following hypotheses.

Hypotheses I.

Productivity differences among management regimes, species and stage of stand development relate directly to amount and efficiency of radiation absorption (Figure 1). The linear relationship between forest growth and absorbed solar radiation provides a simple and robust model with a single parameter, ε, to describe forest production (Figure 1, Landsberg et al. 1997). This model is useful for describing age and species differences, and the impact of available resources (e.g. water and nutrients) on forest production and leaf area accumulation.

Hypothesis II.

Allocation (mass balance) of carbon and nutrients favors belowground production over aboveground production: 1) during sub-optimal water and nutrient availability; 2) during early stages of stand development; and 3) for stress tolerant species compared to competitive ruderal species (Figure 2).

Carbon and nutrient allocation belowground for root growth, and lost to root senescence (turnover) can occupy a substantial portion of net primary production and nutrient mass balance. Allocation between above and belowground components varies with water and nutrient regimes (Gower et al. 1992), stage of stand development (Scarascia-Mugnozza et al. 1996), and species selection (Steele et al. 1997). Therefore, belowground data is critical to understanding productivity and nutrient use.

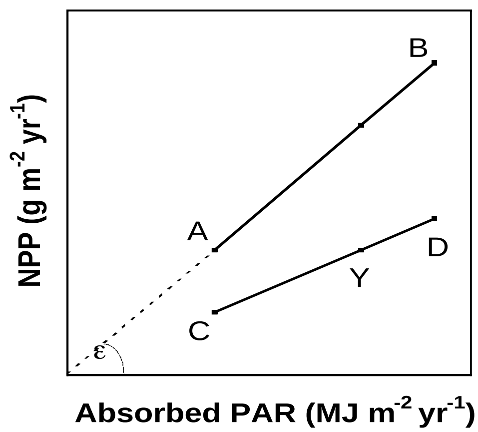

Figure 1. The dependence of dry matter production (NPP) on absorbed radiation (PAR). The slope, ε, is radiation use efficiency. The line AB represents maximum productivity under optimum conditions. The value of ε typically falls below the theoretical maximum to line CD due to inefficient utilization, i.e. factors affecting photosynthetic rate. Maximum production for CD occurs at D, yet the operating point, Y, typically falls below maximum due to incomplete absorption of incident radiation.

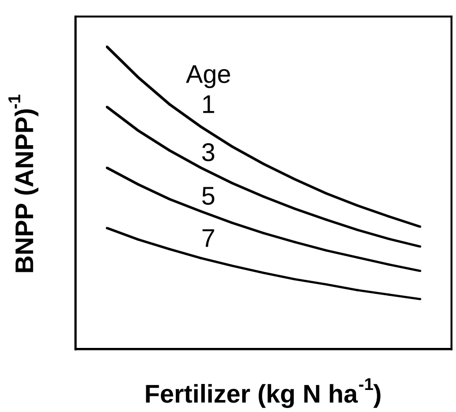

Figure 2. Hypothesized ratio of belowground net primary production (BNPP) to aboveground net primary production (ANPP). Belowground allocation is expected to be high at low nutrient availability, and decrease with increased fertility. Young trees are expected to have greater belowground production than older trees. The magnitude of these relative responses will vary among species.

Methods

The factors controlling productivity will be examined in an experiment that includes a range of fertilizer and irrigation treatment combinations (Figure 3). The core experiment (Blocks 2, 3 and 4) includes fertilized and non-fertilized treatments crossed with irrigated and non-irrigated treatments in a randomized complete block design with three replicates. Overlaid upon this block design are a number of non-replicated fertilizer treatment plots, on which we will evaluate optimal fertilizer application rates.

Code	Fert (kg N ha^{-1})	Irr
1	0	1
2	120	1
3	0	0
4	120	0
5	30	1
6	60	1
7	90	1
8	150	1
9	180	1
10	210	1
11	20	0
12	40	0
13	60	0
14	80	0
15	100	0
16	140	0

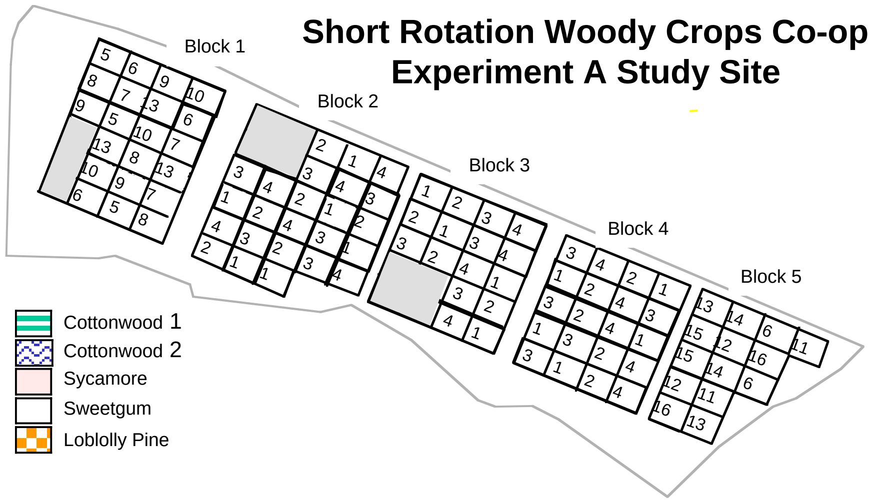

Figure 3. Plot arrangement for Experiment A. A total of 16 treatments are included, four of which are replicated three times in Blocks 2 – 4, and the remaining treatments are included in non-replicated plots in Blocks 1 and 5. Each plot is 0.2 ha (0.5 acres)

Measurements include characterization of site conditions, evaluating plant growth and nutrient mass balance, determining radiation use efficiency, and monitoring root development. Site conditions are characterized through periodic soil sampling, tabulating treatment applications, continuous measurement of weather data, and regular measurements of soil temperature, moisture and available ion concentrations. Plant growth and nutrient mass balance are evaluated through regular measurements of tree height, diameter and leaf area, as well as annual harvesting of select trees for above and belowground biomass, and nutrient analysis. Radiation use efficiency (RUE) is determined through measurement of light interception by the canopy. The ratio of light interception to productivity provide RUE estimate (see Figure 1). Root development is monitored using monthly non-destructive minirhizotron observations and annual destructive coring (Coleman et al. 2000). Site characterization, growth and nutrient mass balance measurements will be synthesized using predictive growth processes models (e.g. Landsberg and Waring 1997).

<u>Preliminary results</u>

Height and diameter measurements collected for the six central trees in each plot during the first growing season show a strong positive growth response to the fertilization treatment by all species. However, response to irrigation varies among species. The cottonwood 1 clone from Mississippi showed the strongest positive response to irrigation. The cottonwood 2 clone from east Texas and loblolly pine showed *no* response to irrigation. Sweetgum responded positively to irrigation only *with* fertilizer, while sycamore responded positively to irrigation only *without* fertilizer. Whole-tree leaf area follows the same response patterns as diameter measurements, but leaf nutrient concentrations are higher with fertilization in only cottonwood 1 and sweetgum. All tree hardwood species show deficiencies of copper and iron. These preliminary growth data will be confirmed by more detailed year-end measurements.

Experiment B: Effects of short rotation silvicultural systems on water resources and biodiversity: A watershed-scale experiment

As silvicultural management intensity increases, concern over environmental impacts becomes greater. Intensive silviculture involves use of pesticides and chemical fertilizer, and more frequent site disturbance for harvest and replanting than traditional silviculture. However, chemical inputs and site disturbance occur only during stand establishment, and these potential negative environmental impacts are relatively small compared with widely accepted agronomic practices involving annual chemical inputs and site disturbance. Another concern pertains to limited biodiversity in a monoculture where competitive vegetation, insects and pathogens are controlled with general pesticides targeting large biological groups to which the pest species belong. Although, optimal management regimes are generally considered to have no greater impacts than traditional silviculture on water quality and faunal diversity, data on such environmental consequences are limited. Optimizing productivity is the main focus of resource availability studies like Experiment A. However, experiments optimizing productivity are not appropriate for testing environmental impacts, because the large number of treatment comparisons require smaller plots (<1 ha) to maintain uniformity across the experimental site. Experiment B uses larger four to six hectare plots with a few species-by-treatment combinations. The selected treatments are designed to push the system and test our understanding of nutrient movement and retention processes. Additionally, we can evaluate faunal diversity in this experiment, because of larger plot sizes.

The objectives of this study are to:

- Test our understanding of the factors and processes controlling nutrient and chemical transport from forested catchments under intensive silvicultural prescriptions.
- Test interactions of forest type and ecosystem processes that affect nutrient and chemical transport.
- Establish a carbon and nutrient budget, including inputs and outputs, from intensively managed stands.
- Determine the influence of intensively cultivated plantations on invertebrate and avian diversity.

The following hypotheses will be tested:

- Streamside Management Zones (SMZ) will mitigate the effects of intensively cultivated plantations on water quality.
- Water management, i.e., irrigation, will not cause a significant increase in runoff, but will increase the rate of nutrient cycling and result in greater nutrient loss compared with no irrigation.
- Faunal diversity will change due to management practices. Variable impacts, both positive and negative, are expected on birds and invertebrates as a result of management intensity, scale, stage of stand development and the niche occupied by faunal species.

<u>Methods</u>

First-order watersheds will be instrumented to assess nutrient and chemical transport processes. Ten of these instrumented catchments will be established in existing pine forests at the Savannah River Site and monitored during a calibration phase lasting at least 12 months. Following calibration, two catchments will be used as reference plots, and monitoring will continue as the remaining eight are harvested and converted to pine or hardwood plantations. Each plantation will receive optimal nutrition and either low or high water additions. All treatments will be replicated twice for a total of ten plots containing approximately 60 ha.

Measurements will include hydrologic monitoring including precipitation, throughfall, humidity, soil moisture, water table depth, and discharge. Solute concentrations will be analyzed on water samples. The site will be characterized through soil sample analysis and weather data collection. Processes monitored will include: decomposition, nitrogen mineralization and surface erosion. Vegetative production will be monitored on the forest stand using both non-destructive measurements and whole-tree harvests. Faunal surveys will evaluate avian and invertebrate populations.
Experimental installation will proceed as follows:

- Autumn 2000: Finalize site location and secure site use permit
- 2001: Identify catchments, install gauging stations and berms, design irrigation system, and install irrigation wells
- 2001/2002: calibrate catchments
- 2003: Clear and prep catchments and install irrigation system
- 2004: Establish plantations and monitor their development

Experiment C: Understanding the effects of management intensity on carbon allocation patterns in trees and their susceptibility to pests and pathogens

Experiment C is designed to evaluate disease susceptibility with respect to carbon allocation in trees grown with intensive silviculture practices. High tree productivity requires the allocation of carbon for growth, storage, and defense according to a strategy appropriate for the environment. We do not know how intensive silviculture may affect these carbon allocation patterns. Maximum allocation to stem production is the objective of intensive management over other essential functions, such as pest resistance. To understand how intensive management can predispose trees to insect pests and disease, we must first understand how these practices influence carbon allocation among shoot and root growth, non-structural carbohydrate storage, and defensive compounds. Then we can determine differences in pest susceptibilities among treatments.
The objectives of this study are to:

- Determine how nutrient and water resource availability affect plasticity in carbon allocation patterns.
- Evaluate how changes in plasticity due to resource availability alter mechanisms of pest susceptibility.

The following hypotheses will be tested:

- Management practices that favor stem production, e.g. N fertilization, will decrease non-structural carbohydrate storage and defensive compound production.
- Practices that favor stem production change the phenology of carbon allocation such that carbohydrate reserve storage is delayed, resulting in lower energy reserves.
- Pest resistance increases as non-structural carbohydrate storage and production of phenolic constituents increases.

- Pest susceptibility increases with non-vigorous or extremely vigorous growth while moderate growth provides the greatest pest resistance; therefore intensive management practices decrease pest susceptibility.

Methods

Irrigation and fertilization treatment levels will provide a range of resource availability. Whole trees will be harvested at the time of planting and during autumn of the first, second and third years. Harvested seedling tissues will be analyzed for non-structural carbohydrate (sugar and starch) content, and for phenolic content as an indicator of allocation to defensive compounds. In addition, leaf flushing and defoliator activity will be quantified throughout the growing season.

In year two, sweetgum will be inoculated with *Botryosphaeria dothidea* and Sycamore with the decline syndrome pathogens, *Ceratocystis fimbriata platani*, *Botryosphaeria rhodina*, and *Xylella fastidiosa* (alone and in combinations). At the end of the second and third growing season, subsets of the inoculated and control-wounded seedlings will be sacrificed to evaluate pathogen spread and histochemical differences in reaction to infection among growing condition treatments.

Additional SRWC Co-op interests

Use of SRWC for Phytoremediation at the Savannah River Site

Conducted by DOE Savannah River and USDA Forest Service.

The Savannah River Site (SRS) has ongoing phytoremediation activities in high productivity forest cover types. A major effort involves using highly productive loblolly pine forests to evaporate tritium-contaminated groundwater with tritium levels in excess of safe drinking water standards. SRS currently has tritium atmospheric release permits for industrial processes that will apply to release through evaporation from the forest. Planning is underway to install irrigation distribution systems in rapidly growing plantations and establish enough acreage to evaporate the required volume, yet not allow more groundwater to become contaminated.

Another project involves irrigating cottonwood and loblolly pine with water pumped from a shallow groundwater plume contaminated with the organic solvent trichloroethylene. Tree roots are know to break down this chlorinated hydrocarbon through oxidation and metabolic activity.

The SRWC Co-op supports these phytoremediation efforts by providing information on, among other things, forest production ecology, tree eco-physiology, plant material selection, plantation establishment and maintenance, as well as appropriate irrigation and fertilization technology.

Sustainable Short Rotation Woody Crop Production Systems: A Watershed Scale Experiment and Modeling Applications

Six gauged watersheds are being used to assess SRWC cropping systems. The treatments utilize operational SRWC prescriptions for sweet gum, sycamore and sycamore plus controlled drainage. The study was initiated in 1997. Measurements of aboveground production, belowground biomass, soil chemical and physical properties, soil water, water quality, water table and discharge are being maintained. Models for hydrology and nutrient cycling are also being implemented on the project. This is an Agenda 2020 project conducted by Oak Ridge National Laboratory, USDA Forest Service, International Paper, North Carolina State Univ., and Univ. of Nevada.

Tillage Effects on Carbon and Nitrogen in a Coastal Plain Soil

The effect of site preparation on soil organic matter will be evaluated using the SRWC Co-op Experiment A site. Carbon and nitrogen concentrations in the bulk soil and in the particulate organic matter (POM) and mineral-associated organic matter (MOM) will be analytically determined. Data from the POM and MOM analyses will test the hypothesis that tillage increases the amount of organic matter associated with soil minerals. An increase in MOM may increase the storage duration of soil carbon and nitrogen by enhancing protection of organic matter from microbial decomposition. Oak Ridge National Laboratory, Oak Ridge Institute for Science and Education, and USDA Forest Service conduct this project

Development and application of DRIS norms for characterizing nutritional balance in sweetgum

Growth and nutrient data collected on two-year-old sweetgum plantations in the NC State Hardwood Co-op Regionwide-46 study were used to develop DRIS (Diagnostic and Recommendation Integrated System) norms for sweetgum. Norms were obtained from High-yield stands of the RW-46 study. We will use these norms to evaluate nutrient balance and determine fertilizer prescriptions for amendments designed to correct imbalances. USDA Forest Service and NC State Hardwood Co-op conduct this project

Mid-rotation Fertilization of Minnesota Hybrid Poplar Plantations and the Evaluation of Nutrient Balance

Twelve hybrid poplar plantations in western (Oklee) and central (Alexandria) Minnesota are being used to evaluate the effectiveness of fertilization at canopy closure. Nitrogen only (urea) and blended fertilizer treatments have been included to evaluate the need for other essential nutrients, and to test the DRIS nutrient balance diagnostic method. The initial time frame for each study is three years. Three annual fertilizer additions (50 kg N ha^{-1}) are intended to stimulate productivity. Annual increments are also being compared to a triple dose (150 kg N ha^{-1}) in the first year in the Alexandria study to evaluate timing of additions. This study is conducted by USDA Forest Service Southern and North Central Research Stations, Oak Ridge National Laboratory, WesMin RC&D, Minnesota DNR, University of Minnesota-Crookston, Agricultural Utilization Research Institute, Minnesota Power and Boise Cascade Corporation.

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Short Rotation Woody Crops Cooperative Research Program Experiment A: Fundamental Controls of Growth and Productivity

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ABSTRACT

The SRWCCRP initial experiment is designed to study growth and nutrient budgets in short rotation woody crop systems. The study area located at the Savannah River Site near New Ellenton, SC was logged in April 1999; site preparation began in May 1999. The site was tilled and slash incorporated to a depth of 30 cm. Loblolly pine, sweetgum, and sycamore seedlings and cottonwood cuttings were planted. A fertigation system was installed, and trees received experimental treatments starting April 2000. ANOVA treatments compared irrigated (I), fertilized (F; 120 kg N ha^{-1}), and I + F with controls (non-I + non-F). Regression plots received a range of fertilizer regimes. Above and below ground tree growth as well as environmental characteristics will be monitored throughout the rotation. Monthly height, diameter, and leaf area measurements on subplots indicate strong treatment differences, as the I + F plots were larger and held more leaf area. Furthermore, trees in F plots were more vigorous than those in I plots, indicating that nutrition seems to be more influential than soil moisture in controlling plant growth.

Short Rotation Woody Crops for Florida

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ABSTRACT

Florida's long growing season and abundant moisture results in highly productive short rotation woody crops (SRWC). Potential oven-dry annual yields of promising species are: 19.9 Mg ha^{-1} yr^{-1} (8.9 ton ac^{-1}) for cottonwood (*Populus deltoides*), 23.1 Mg ha^{-1} (10.3 ton ac^{-1}) for closely-spaced slash pine (*Pinus elliottii*), 31.4 Mg ha^{-1} (14.0 ton ac^{-1}) for *Leucaena* (*L. leucocephala* (Lam.)), 66.6 Mg ha^{-1} (29.7 ton ac^{-1}) for castor bean (*Rininus communis*), 25.1 Mg ha^{-1} (11.2 ton ac^{-1}) for intensively managed *Eucalyptus* amplifolia in north Florida, and 36.1 Mg ha^{-1} (16.1 ton ac^{-1}) for *E. grandis* in central and south Florida. Flatwoods soils and reclaimed phosphate land are well suited to growing short rotation woody crops (SRWC). Thousands of acres of land, with low opportunity costs of $37.06 to $61.78 ha^{-1} yr^{-1} ($15 to $25 ac^{-1} yr^{-1}) in central and parts of south Florida, and $86.48 to $160.62 ha^{-1} yr^{-1} ($35 to $65 ac^{-1} yr^{-1}) in the north and west Florida are potentially available. One potential use for SRWCs is co-firing with coal in existing power plants. A recently completed feasibility study at Lakeland Electric, estimated costs, including production, harvest and transportation, of $1.76 per mm Btu for *E. grandis* and $1.73 for *Leucaena*. Harvest costs were estimated to be more than 70% of total cost with feller-buncher technology on *Eucalyptus* and almost 50% with a high capacity forage harvester (e.g. Claas) on *Leucaena*. Successful test burns were completed at Lakeland Electric's McIntosh Plant and at Tampa Electric's (TECO) Gannon Plant. Both plants are now permitted to continuously co-fire biomass with coal.

Keywords: short rotation woody crops, woody biomass, yield potential, co-firing, production costs, harvest costs, test burn, fuel value.

INTRODUCTION

Biomass research has been conducted at the University of Florida since the late 1970's. The Center for Biomass Programs was established in 1980 and has coordinated research and education efforts since that time. Initially, a 10-year research effort was funded by a grant from the Gas Research Institute (GRI) to study high yielding crops for manufacturing methane gas. A wide variety of plants were evaluated and those with the greatest yield potential were selected. Tall-growing bunchgrasses were identified as having potential for short rotation crops. These grasses are indigenous to the tropics, utilize the C_4 pathway of carbon fixation, and produce long hardened stems (Prine et al. 1988). Examples include elephantgrass (*Pennisetum purpureum* L.), also referred to as napiergrass, sugarcane (*Saccharum* sp.) and Erianthus [*Erianthus arundinaceum*(Retz)]. Woody crops include *Leucaena*, a tropical shrub/tree, and several species of *Eucalyptus*.

More recently, cottonwood, closely spaced slash pine, and castor bean have been studied as potential biomass crops (Prine et al. 2000).

In addition to utilizing biomass to manufacture methane, other opportunities include producing ethanol and direct combustion to generate electricity (Stricker et al. 1997, 19956; Stricker, 1996). A biomass to ethanol system in central Florida using a dedicated feedstock supply system based on sugarcane, elephantgrass, *Leucaena* and *Eucalyptus* appeared to be feasible. The ethanol production plant would primarily utilize sugarcane juice. Also, an associated lignocellulose conversion facility would convert the sugarcane residues and other feedstocks to ethanol. The estimated cost for fuel grade ethanol was $0.25 L^{-1} ($0.93 gal^{-1}) The second part of the study estimated the cost for generating electricity by burning *Eucalyptus*, slash pine, *Leucaena* or elephantgrass. Operating cost for the generation plant was estimated to be $43.00 $MW\text{-}hour^{-1}$ and fuel cost of $38.50 to $46.20 Mg^{-1} ($35 to $42 ton^{-1}), dry weight, resulting in a power cost of $68 to $80 $MW\text{-}hr^{-1}$.

Interest in use of biomass grown in central Florida has recently expanded to include co-firing biomass with coal to generate electricity. A feasibility study was conducted in conjunction with Lakeland Electric, a municipal electric utility, and the Southeast Regional Biomass Energy Program (Segrest et al. 1998(a), 1998(b)). This was the first utility-sponsored feasibility study of biomass co-firing in Florida. Additional work is underway establishing a demonstration planting of *Eucalyptus* and cottonwood with financial support from TECO, The Florida Energy Office, and the DOE.

Florida's Climate

Florida has a semi-tropical climate with two seasons, summer and winter. Summers are warm and humid while winters are cool with frequent frosts or freezes in north and west Florida. Central Florida experiences occasional frost with freezes some years and then several years without major freezes. Frosts are rare in south Florida and freezes infrequent. Average maximum temperatures range from 24.7 ^{o}C (76.5 ^{o}F) at Pensacola in the western panhandle to 28.8 ^{o}C (83.9 ^{o}F) at Homestead, south of Miami (Table 1).

Annual precipitation averages 157.5 cm (62 in) at Pensacola and 149.9 cm (59 in) at Homestead. Most of the annual precipitation in peninsular Florida occurs from June to September. North and west Florida experiences a better rainfall distribution during the winter months. Florida has a long warm growing season with an average growing season of 260 days at Pensacola, 300-320 days in central Florida and greater than 320 days in south Florida.

Land

Thousands of acres of land are potentially available for growing SRWCs and other biomass crops in Florida. Two of the most abundant soil types capable of supporting biomass production are flatwoods, which are flat and often poorly drained, and reclaimed phosphate mined lands in central Florida. Both are primarily used for cattle grazing but would also be suitable for SRWC. The opportunity cost for this and other grazing land in central and south Florida is in the range of $37.06 to $61.78 ha^{-1} yr^{-1} ($15 to $25 ac^{-1} yr^{-1}). Opportunity cost for land in north and west Florida is estimated to be in the $86.48 to

Table 1. Average temperature, rainfall and growing season at four locations in Florida

	Avg. High	Avg. Low	Average	Annual Rainfall	Avg. Growing Season
	---------------- ^{0}C (^{0}F)		------------------	--cm (in)--	---days---
West Florida	24.7 (76.5)	14.9 (58.8)	19.8 (67.7)	158.0 (62.2)	260
North Florida	26.0 (78.9)	13.9 (57.1)	20.0 (68.0)	130.3 (51.3)	260-300
Central Florida	28.9 (84.0)	16.9 (61.5)	22.7 (72.8)	124.2 (48.9)	300-320
South Florida	28.8 (83.9)	17.9 (64.2)	23.4 (74.1)	149.1 (58.7)	>320

\$160.62 ha^{-1} yr^{-1} (\$35 to \$65 ac^{-1} yr^{-1}) range. Opportunity cost is the value of the next best alternative use or, pasture and row crops in west and north Florida or cash rent for grazing cattle in central and south Florida.

Phosphate mining has been ongoing in Florida since the late 1880's. Central Florida is the center of mining activity. In addition, mining activity is conducted on a smaller scale in north central Florida. Phosphate is mined by an open pit method. Approximately 121,460 ha (300,000 ac) have been mined and an additional 1,214 to 1,619 ha (3,000 to 4,000 ac) is mined each year. After mining and reclamation, there are three main landforms: overburden, sand tailings, and phosphatic clay. Overburden, a mixture of sand and clay, is removed from the land surface to the top of the ore body and piled on the side. Phosphate ore, currently being mined, is an unconsolidated mixture of sand, clay and phosphate mineral. The sand, called sand tailings, is separated from the ore and hydraulically pumped to fill mine cuts between overburden piles. Tailings are then capped with material from the tops of overburden piles. Phosphatic clay is washed from phosphate ore and pumped, at about 3-5% solids, to settling areas. During reclamation, a crust is formed on the clay surface while the sub-surface remains plastic (Stricker, 2000). Phosphatic clay soil, which covers about 40% of the mined area, is highly fertile and has potential for growing SRWC as well as a number of other crops.

Rahmani et al. (1999) conducted a GIS study in Florida and found that, considering land availability and cost of transportation, central and north-central Florida would be the best places in peninsular Florida to develop biomass to energy systems. Counties with the greatest biomass production potential included: Marion, Volusia, Osceola, Polk, Hillsborough, and Putnam in central Florida, Alachua County in north-central, and Nassau County in northeast Florida (Table 2). Production potential for each of these counties was over 400,000 Mg yr^{-1} (440,000 tons yr^{-1}). Marion County had the greatest potential with 1,090,900 Mg yr^{-1} (1,200,000 tons yr^{-1}). Lands identified as having potential for biomass production are presently being used for other economic activities. In addition, some of the land is in state and national forest and other land belongs to timber and paper companies. For land to be shifted to biomass production the value of biomass would need to outbid other uses. Actual production would likely fall short of potential.

Table 2. Counties with the greatest biomass producing potential in peninsular Florida[a]

County	Number of Parcels	Land Area	Potential Production
		-- ha (ac)--	--Mg yr^{-1} (ton yr^{-1})--
Alachua	1,642	73,000 (180,380)	268,180 (295,000)
Hillsborough	1,353	75,000 (185,325)	424,000 (466,400)
Marion	6,331	181,000 (447,250)	1,126,000 (1,238,600)
Nassau	2,194	74,000 (182,850)	482,730 (531,000)
Osceola	1,637	96,000 (237,220)	531,000 (584,100)
Polk	1,474	85,000 (210,035)	461,000 (507,100)
Putnam	2,459	85,000 (210,035)	455,000 (500,500)
Volusia	3,758	98,000 (242,160)	525,000 yr^{-1} (577,500)

[a] From Rahmani et al. 1999

Tree Species and Yield Potential

Species that may be grown as SRWCs in Florida include cottonwood, *E. grandis*, *E. amplifolia*, *Leucaena*, slash pine, and castor bean. Of these species only cottonwood and slash pine are native to Florida. In central Florida, and perhaps other areas, there is a great deal of resistance, in the environmental community, to growing non-native tree species. This resistance is largely the result of introduced non-native species that have escaped and replaced native species.

These exotic species include melaleuca (*Melaleuca quinquenervia*), Chinese tallow (*Sapium sebiferum*), and Brazilian pepper (*Schinus terebinthifolius*). Melaleuca has been particularly destructive to ecosystems in the Everglades area of south Florida. Castor bean, grown commercially in central Florida during World War II, now occurs along roadsides and ditch banks. *Leucaena* has been observed growing in the vicinity of established stands. On the other hand, *Eucalyptus* has been grown in south and central Florida since the 1970's with no evidence of escaping into the environment (Rockwood, 1996).

Eucalyptus trees grow faster than native tree species in peninsular Florida (Rockwood, 1996(a)). Under intensive culture, *E. amplifolia* can yield as much as 25.1 oven-dry Mg ha^{-1} (11.2 ton ac^{-1}) on good sites in northeastern and perhaps northwestern Florida. *E. grandis* can yield up to 36.1 oven-dry Mg ha^{-1} (16.1 ton ac^{-1}) in central and southern Florida (Prine et al. 2000). *Eucalyptus* grows best on agricultural lands, lands recently in agriculture or marginal agricultural lands. *E. amplifolia* requires high quality land with a high pH. *E. grandis* grows well on sandy or organic soils (Rockwood, 1996(a), 1996(b)). Both species may be grown on poorer sites if amendments are added to raise nutrient and/or pH levels.

Cottonwood and slash pine, while yielding less than non-native species, may be preferred in some areas. However, lower yields place both species at an economic disadvantage compared to higher yielding non-natives. Cottonwood yields as high as 19.9 oven-dry Mg ha^{-1} yr^{-1} (8.9 oven-dry ton ac^{-1} yr^{-1}) have been reported at a municipal effluent site in central Florida. Closely spaced slash pine can produce up to 23.1 oven-dry $^{-1}$ Mg ha^{-1} yr^{-1} (10.3 ton ac^{-1} yr^{-1}) if fertilization and weed control is applied (Prine et al. 2000). Slash pine requires relatively well-drained sites and would not be recommended for phosphatic clay or poorly drained flatwoods soils. In addition, it will not coppice and thus must be replanted after each harvest, fortunately, the cost of pine seedlings and planting is relatively inexpensive.

A regional cottonwood genetic improvement program (Warwell et al. 1999) is developing clones to augment or replace clones developed previously for the Mississippi Delta area. In 2001, preliminary selections will be made from some 1,000 new clones under test in Florida, Alabama, North Carolina, and Missouri, and entered into additional tests. All new clones are also in clone banks in Florida and Mississippi for preservation and future propagation.

Leucaena is a tropical legume shrub/tree that may be established with field planted seed. Because *Leucaena* seedlings are weak and don't compete well with weeds, clean tillage, cultivation, and/or herbicides are recommended to control weeds and grasses until the crop is established. After a two-year establishment period, annual harvests may be made for 10 years or more. Annual average yield over a four-year period at Gainesville, when *Leucaena* was harvested each year, measured 31.4 oven-dry Mg ha^{-1} (14.0 tons ac^{-1}), while average annual yield, when *Leucaena* was grown for four years and harvested once, was 19.3 Mg ha^{-1} yr^{-1} (8.6 ton ac^{-1}) (Prine et al. 2000). Where freezes don't kill stems in the winter, *Leucaena* may be grown several years before harvest. Freeze-killed stems will usually stand for one season allowing for two years of growth to be harvested in the winter of the second year. *Leucaena* has many sustainable attributes because, as a legume, it fixes nitrogen and the leaves, with their high nutrient content, usually fall to the ground after a harvest or freeze and nutrients are recycled for the next season.

Tall growing castor bean forms a "tree" 9.1 to 12.2 m (30 to 40 ft) tall in the tropics (Prine et al. 2000). Castor bean can be established with seed in a prepared seedbed. Where top growth is not killed annually, but is damaged by frost, plants grow 4.9 to 9.1 m (16 to 30 ft) tall. Tall castor bean planted in April 1997 at Gainesville, FL, grew to 6.7 m (22 ft) tall and produced an oven dry stem yield of 40 Mg ha^{-1} yr^{-1} (17.8 ton ac^{-1}). Unharvested plants survived the winter but stems were killed to 3 m (9.8 ft) above the soil. During the following season these plants grew to only 5.3 m (17.4 ft) and produced a two-season dry stem yield of 65.4 Mg ha^{-1} (29.2 ton ac^{-1}). In February 2000, samples from a naturally seeded stand of a tall castor bean ecotype were harvested at Lakeland, FL. Many of these plants were over 7 m (23 ft) tall and had been growing since the previous winter. Highest yielding areas in the stand produced an average yield of 66.6 Mg ha^{-1} (29.7 ton ac^{-1}). Additional research is needed with castor bean as an energy crop. The presence of ricin and possibly other toxic compounds in plant parts may limit castor bean's potential as an energy crop.

All species survive and grow best when competing vegetation is well controlled during the first two years. On poorly drained flatwoods or reclaimed sites bedding is essential. Beds should be at least 30 cm (1 ft) high. Initial site preparation, if bedding is involved, is usually sufficient for vegetation control during the first season for *Eucalyptus*, slash pine, and cottonwood. With good tree growth during the first year, trees typically dominate other vegetation for the rest of the rotation (Rockwood, 1996(a), 1996(b)). *Eucalyptus*, cottonwood, and *Leucaena*, all regrow (coppice) after harvest so multiple harvests may be made from an initial planting. Castor bean doesn't coppice well if mature when harvested. To maintain high yields, it will be necessary to reseed after harvest.

Production Costs and Fuel Value

Production costs and delivered fuel costs for *Leucaena* and *Eucalyptus* were estimated as part of a feasibility study conducted with Lakeland Electric (Segrest et al. 1998(a), 1998(b)). Delivered costs for *Leucaena* totaled $13.38 green Mg^{-1} ($12.16 ton^{-1}) or $1.92 mm Btu^{-1} and $20.17 green Mg^{-1} ($18.34 ton^{-1}) or $2.66 mm Btu^{-1} for *Eucalyptus* (Table 3). Estimated harvest costs for *Eucalyptus* was more than double that of *Leucaena*. Harvest costs for *Eucalyptus* were based on the conventional feller-buncher harvest system, while costs for *Leucaena* were based on the use of a Claas high capacity forage harvester equipped with a wood head. The forage harvester system reduced harvest cost from 70% of total cost for the feller-buncher to 48% of total cost. Harvest cost was the single largest cost in the SRWC production system. Costs presented here are for the first harvest cycle from a new planting. Research data are not available on the productive life of stands of *Leucaena* or *Eucalyptus* under frequent harvest. Estimates are that *Leucaena* will have a productive life of 10 years and *Eucalyptus* of longer than 10 to perhaps as long as 20-25 years.

Table 3. Estimated delivered fuel costs per ton and per mm Btu

	Leucaena	*Eucalyptus*	*Leucaena*	*Eucalyptus*
	--Cost green Mg^{-1} (ton^{-1})[a]--		--Cost per mm Btu--	
Yield ha^{-1} yr^{-1} (a^{-1})	56 (25)	72 (32)		
Establishment	$3.84 (3.49)	$2.79 (2.54)	$0.55	$0.37
Harvest	$6.46 (5.87)[b]	$14.30 (13.00)[c]	$0.93	$1.89
Transport	$3.08 (2.80)	$3.08 (2.80)	$0.44	$0.41
Total Cost	$13.38 (12.16)	$20.17 (18.34)	$1.92	$2.67
REPI Credit			$1.50	$1.50
Net Cost			$0.42	$1.17

[a] Assumes moisture content of 60%
[b] Estimated harvest cost when harvested with high capacity forage harvester (Claas) with wood head.
[c] Estimated harvest cost when harvested with feller-buncher.

Fuel value of *Leucaena* was 17,449 Btu kg^{-1} (7,915 Btu lb^{-1}) or 17.41 mm Btu Mg^{-1} (15.83 mm Btu ton^{-1}) on a dry basis and 6.96 mm Btu Mg^{-1} (6.33 mm Btu ton^{-1}) on a green basis. Btu content of *Eucalyptus* was slightly higher with 18,298 Btu kg^{-1} (8,300 Btu lb^{-1}) or 18.3 mm Btu Mg^{-1} (16.6 mm Btu ton^{-1}) on a dry basis or 7.6 mm Btu Mg^{-1} (6.89 mm Btu ton^{-1}) on a green basis.

The U.S. Energy Policy Act of 1992 created a cash payment incentive of $.015 KWh^{-1} for non-taxable utilities who use renewable energy sources. This incentive is called the Renewable Energy Production Incentive (REPI) (Sanderson et al. 1996). When converted to Btu equivalents, the $.015 converts to about $1.50 million Btu^{-1}. Lakeland Electric's current cost for coal is reported to be about $1.50 mm Btu^{-1}. With the REPI credit, many of the biomass fuels appear to be cost competitive with coal. When the REPI credit is deducted from the total cost per mm Btu, the net cost of *Leucaena* is $0.42 and *Eucalyptus* $1.16. As stated earlier, harvest cost for *Leucaena* is lower than for *Eucalyptus* because costs were based on use of the Claas harvester. The

Claas harvester could also be used to harvest *Eucalyptus*, however, a different management system would be needed. More trees would be planted per hectare and production cycles would be reduced to either an annual harvest or every two to three years depending on growth rate of trees.

In addition to the REPI credit, the Energy Policy Act makes tax credits available to tax- paying utility companies (called the Section 45 tax credit). The current inflation adjusted value of the tax credit is \$0.17 KWh^{-1}.

One finding of the Lakeland Electric feasibility study was that the utility is not interested in dealing with a group of individual growers to secure a supply of biomass fuel. In order to supply fuel to a utility, a group of landowners will need to form a cooperative or deal with an independent fuel supplier. The cooperative or fuel supplier would contract with the electric utility and in turn contract with landowners to supply the fuel. Under a separate project, working with Lakeland Electric, a model biomass fuel contract was developed as a guide for those interested in growing fuel for an electric utility (Stricker et al. 2000).

Co-firing Tests

Successful co-firing tests were completed at Lakeland Electric's McIntosh-3 plant and at TECO's Gannon Plant, south of Tampa. Lakeland Electric's McIntosh plant is a 385 MW pulverized coal plant that is designed to also burn municipal solid waste (MSW). The Lakeland test involved direct burning of *Eucalyptus* material, originally intended for mulch to 5% of the heat energy to the plant. The *Eucalyptus* material was introduced to the boiler pneumatically through a port normally used to introduce MSW.

The Gannon plant is 1000 MW with a coal-fired cyclone boiler. Ground yard waste material was added to a coal conveyer and introduced to the boiler through a coal port. The test burn was continuous for 72 hours and supplied 2.75% of the heat energy (5% by volume) to the plant. As a result of this test TECO has approval from the Public Service Commission to market "green" energy from biomass fuel. Also, as a result of the test burns both plants have regulatory approval to continuously co-fire biomass fuel.

There are many opportunities for co-firing biomass in west central Florida. Presently there is about 13,000 MW of fossil fuel generating plant capacity in the area, more than in many mid-western states. All major combustion technologies are represented including: pulverized coal, cyclone burners, combined cycle natural gas, wet slurry coal gasification, and natural gas boiler. Additional power plants are scheduled to be built in the next few years.

Research and Demonstration Projects

Three projects were recently initiated to continue development of SRWC for biomass fuel in Florida. At Water Conserve II, an effluent utilization site near Winter Garden, cottonwood, *Leucaena*, *E. amplifolia*, *E. grandis*, cypress (*Taxodium distichum*), and castor bean are being studied. Growth in response to four cultures, all involving application of sewage effluent, has been assessed through 2.5 years. Compost and mulching combined with effluent have greatly enhanced growth. The growth of three cottonwood clones, that were the best clones in a previous sewage effluent study at Tallahassee (Rockwood et al. 1996), were best in the effluent + compost + mulch culture, reaching an average height of 12 m (39 ft). *E. grandis* was the most productive species, with individual progenies achieving heights of 15m (49 ft.) and DBHs of 15cm (5.9 in) in the maximum culture.

A 48.6 ha (120 a) demonstration planting of mainly *E. grandis* and some cottonwood was installed on a phosphatic clay site near Lakeland to demonstrate yield potential in a large scale planting and to evaluate different harvest systems. Two planting configurations were used, one for conventional harvest with a feller-buncher and a double row configuration for more frequent harvest with a Claas-type harvester.

The Florida Institute of Phosphate Research recently funded a new project, Commercial Tree Crops for Phosphate Mined Lands. The project will develop cypress, slash pine, and cottonwood tree crops for commercial energy-wood, mulchwood, pulpwood and/or saw timber on phosphatic clay soils in Polk County over five years. Objectives of identifying and developing superior genotypes and appropriate management practices will be accomplished mainly through a series of field tests and commercial plantings to document productivity of selected genotypes and to estimate their commercial value.

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The Status of Salix Consortium's Willow Biomass Program

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ABSTRACT

Over 20 organizations have teamed up to facilitate the commercialization of willow and poplar biomass crops as a renewable feedstock for bioproducts and bioenergy that produces multiple environmental and rural development benefits. The Consortium is pursuing the quantification and application of some of these benefits including:

1. sequestration of soil carbon under perennial willow crops,
2. phytoremediation of brown field sites using willow and poplar,
3. avian and soil microarthoropod diversity in willow and poplar biomass crops,
4. using willows as nutrient filters in riparian zones and other systems,
5. application of biosolids on willow biomass crops,
6. development of living willow snow fences,
7. willow and poplar for pulp and bioproducts,
8. willow and poplar plantings as an alternative cover for landfills

Over 200 ha of willow and poplar biomass crops are currently being managed in New York State. The recent introduction of the Step planter has increased the planting rate from 0.25 ha hr^{-1} to 1.0 ha hr^{-1}. The first commercially harvested material, scheduled for 2001/2002, will be co-fired with coal at the Dunkirk power plant, used for gasification tests, and as a cellulosic feedstock for research on the production of bioproducts. A willow biomass enterprise can play an important role in bolstering the region's farm and forestry sectors, increasing energy independence, strengthening the protection of the environment, and mitigating waste and pollution problems. Continuing gains in crop yields from research efforts, reductions in production costs, and the quantification and valuation of environmental and rural development benefits, will be essential to the establishment of a successful commercial willow biomass enterprise.

Keywords: Short-rotation woody crops, co-firing, rural development

INTRODUCTION

The cultivation of willow in the Northeastern and Midwestern United States has been occurring for over 150 years. In the 1840s German immigrants in western New York and Pennsylvania began cultivating willows for basket production because high quality wild strains were not abundant enough. By the late 1800s cultivation of willows for basketry and furniture had spread from the shores of Maryland to the western borders of Wisconsin and Illinois. At the turn of the century New York State dominated willow cultivation, with 60% of the total reported area, and about 45% of the income generated from willow products, in the United States. Almost half of this production occurred in the area around Syracuse (Hubbard 1904). As the demand for willow baskets dropped off rapidly in the 1920s and 1930s, only pockets of willow cultivation for specialty products remained throughout its former range.

The cultivation of willows was revitalized in upstate New York in the mid 1980s at the State University of New York College of Environmental Science and Forestry (SUNY-ESF). The focus was research on the production of willow as a locally produced, renewable, cellulosic feedstock for bioproducts and bioenergy. Willows are well suited for biomass cropping systems because they are easily propagated from cuttings, grow rapidly, coppice vigorously, currently have few pest problems, produce a uniform feedstock, and have large potential for genetic improvement over a relatively short period of time. In addition to a renewable feedstock, willow-cropping systems can simultaneously produce valuable environmental and social benefits. The production, quantification, and valuation of these benefits are essential in order to make the system economically viable under the current bioproducts and bioenergy industry structure.

Encouraging production results from early willow biomass trials and increasing concern about the environmental impacts associated with the use of fossil fuels led the to the formation of the Salix Consortium in 1993. The founding members included SUNY-ESF, Niagara Mohawk Power Corporation (NMPC), New York State Electric and Gas (NYSEG), and the New York State Research and Development Authority (NYSERDA). Since then participation in the Consortium has shifted and changed due to restructuring of the electricity industry in New York State. Over 20 organizations and agencies, representing a broad spectrum of interests including farmer groups, environmental organizations, conservation groups, government agencies, research institutions, and industry, are actively involved with the project. Despite the diversity of interests among participants, there is agreement on the following goal: to facilitate the commercialization of willow biomass crops as a locally grown, renewable, cellulosic feedstock for bioproducts and bioenergy in the Northeastern and Midwest regions of the United States. The goal will be reached by simultaneously optimizing the production system to produce the highest yields with the lowest possible cost; educating potential producers and facilitating their participation in the production of the crop; and expanding markets for bioproducts and bioenergy. The scenario is challenging because there is currently not enough willow biomass established to initiate large-scale use of the material, while at the same time there are currently no long-term commitments that will assure producers of a stable market in the future.

In 1995, the Salix Consortium's feasibility study (Neuhauser et al. 1995) was one of three competitively bid national projects selected to demonstrate the development of a dedicated feedstock energy project under the Biomass Power for Rural Development program supported by the United States Departments of Energy and Agriculture. The goals of this project were to establish 320 hectares of willow biomass crops by 2001, retrofit a coal fired power plant and successfully co-fire 10-20% biomass with coal to generate electricity, conduct crop development research and apply the results to large scale plantings to improve the production system, and to quantify environmental benefits associated with the production and use of willow biomass crops. To reach these goals a series of simultaneous activities, including research, regional clone-site trials, a large-scale demonstration program, and outreach and education efforts, were initiated (Figure 1).

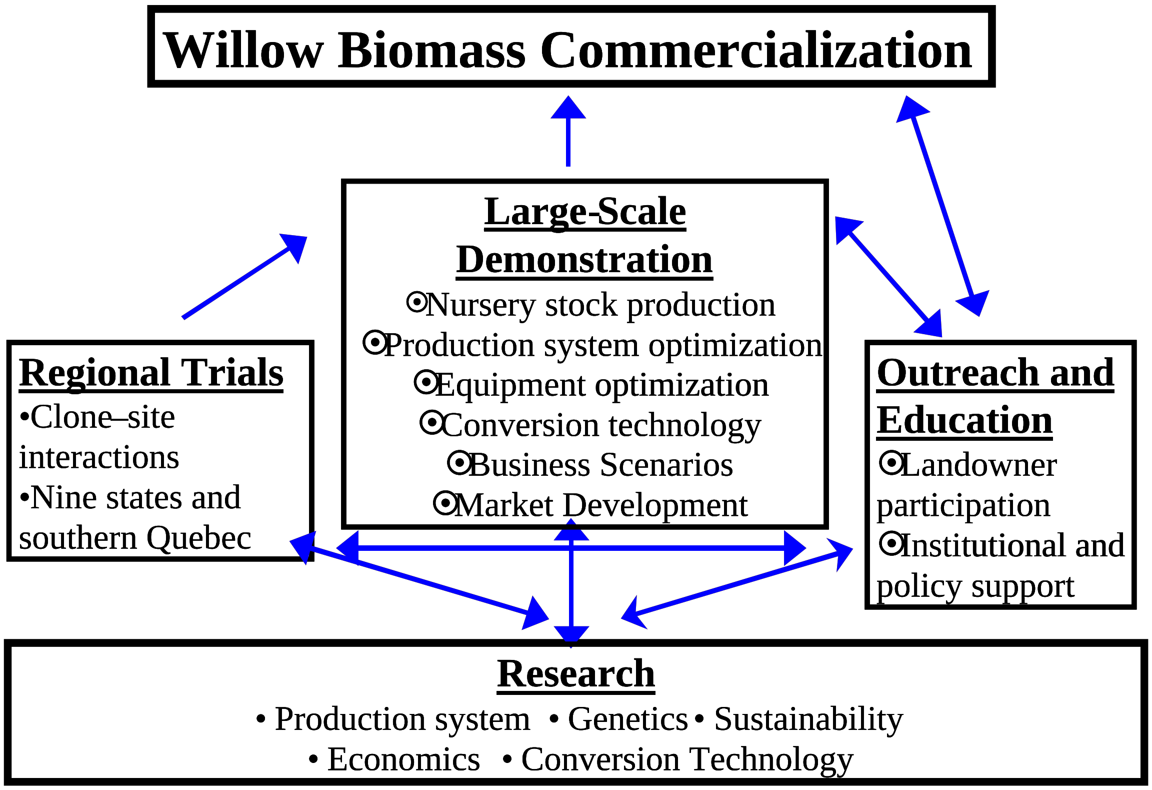

Figure 1. Components of the Salix Consortium's program that are being implemented simultaneously to reach the goal of commercialization.

Production System And Research

The willow biomass production system being developed by the Consortium is based on years of research at SUNY-ESF, as well as extensive work in Sweden (Larsson et al.1998), the United Kingdom (Armstrong et al. 1999), and Canada (Kenney et al. 1996). Its basic characteristics are: intensive site preparation using a combination of chemical and mechanical weed control, double-row mechanical planting of 15,300 plants ha^{-1}, and mechanical harvests on three- to four-year cycles (Figure 2) (Volk et al. 1999). Yields of fertilized and irrigated willow grown for three years have exceeded 27 odt ha^{-1} yr^{-1} (Adegbidi et al. in press). First rotation, unirrigated trials in central New York have produced yields of 6 to 9 odt ha^{-1} yr^{-1}. Second rotation yields of the five best producing clones have increased by 18 - 62% (Figure 3). First rotation yields from a trial comparing slow release nitrogen fertilizer with composted chicken manure and biosolids produced yields of 8.3 to 11.7 odt ha^{-1} yr^{-1} (Adegbidi 1999).

Various efforts are underway that will improve the yields of willow biomass crops in the United States. Breeding efforts, which have been underway for almost two decades in Sweden, have been successful with yield increases of commercially released varieties of 19 - 94% (Svalöf Weibull 2000). Traditional breeding efforts were initiated at SUNY - ESF in 1995 when over 100 clones of willow were collected from the northeastern United States. Additional collections were made in the summer of 2000. Since 1998 more than 250 controlled inter and intra specific crosses have been completed (Kopp 2000). The first set of F1 progeny have gone through an initial screening and will be planted in field trials in the spring of 2001. Yield increases similar to those from breeding programs in Sweden are expected. Additional improvements in yield will be realized by optimizing the production system in terms of improved site preparation and weed control, modifying rotation lengths, improving integrated pest management practices, selection of the best clones for different sites, and optimizing fertilization regimes.

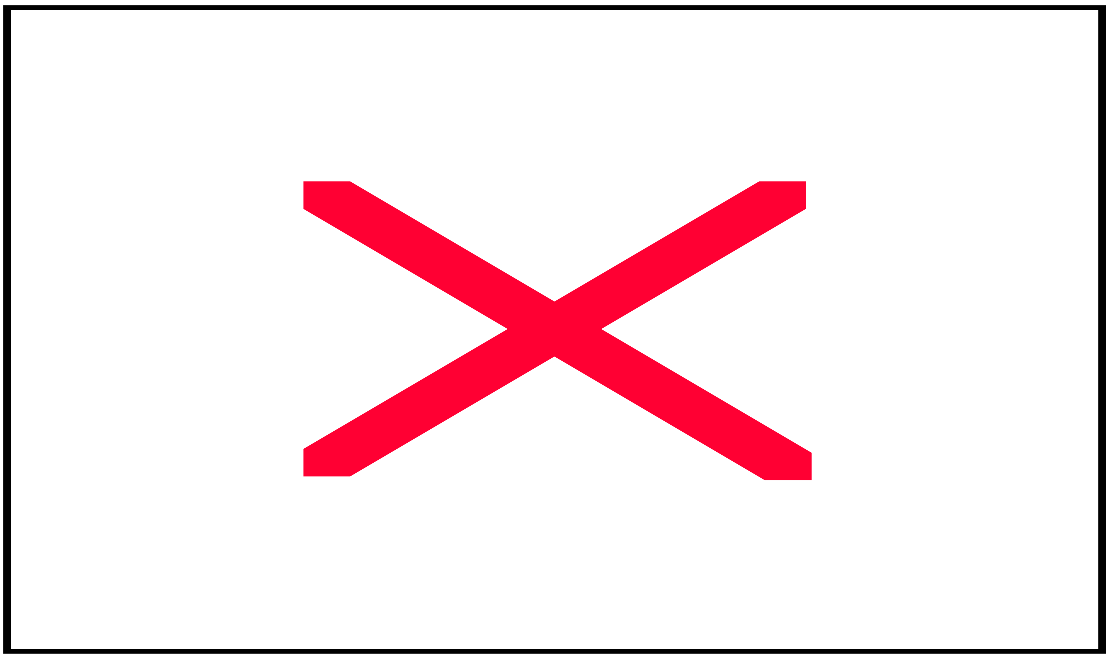

Figure 2. Willow biomass crop establishment and harvest cycle currently in use by the Salix Consortium.

Research is currently underway to quantify some of the potential environmental benefits including: sequestration of soil carbon under willow biomass crops over time (Ulzen-Appiah et al. 2000); phytoremediation of brown fields with willow biomass crops (Jackson 2000); the use of willows as nutrient filters in riparian zones and as part of on-farm manure management systems, the use of willows and poplars as an alternative cover for landfills (McMillan et al. in press), the application of biosolids or manures on willow biomass crops (Adegbidi 1999), the development of living willow snow fences (Volk et al. 2000), quantification of avian (Dhondt and Sydenstricker in press) and soil microarthropod (Minor and Norton in press) diversity. Initial modeling efforts of the rural development benefits associated with a willow biomass enterprise indicate that about 76 direct and induced jobs will be created for every 4,000 hectares of willow established (Proakis et al. 1999).

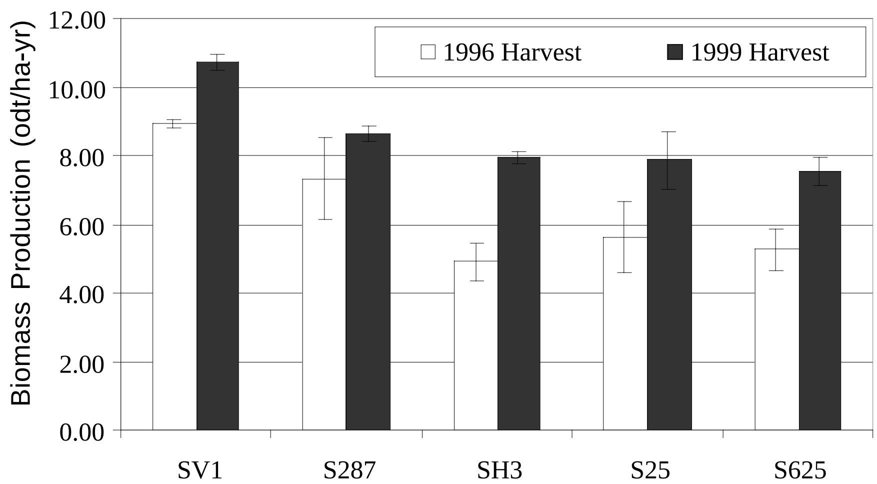

Figure 3. Annual yield (mean ± standard error) of first (1996 harvest) and second (1999 harvest) rotations for the five top producing clones in 1999.

Outreach And Education

Since its inception the Salix Consortium has conducted an outreach and education program with the following goals:

1. to educate and train natural resource and agricultural professionals about the production of and benefits associated with this new crop,
2. raise the level of awareness and understanding about willow biomass crops among landowners so that they can make informed decisions about the suitability of growing the crop,
3. clearly communicate research results, and their practical applications, to agriculture and natural resources professionals, landowners, policy makers, environmental organizations, and other interested groups.

Ultimately, education efforts should translate into new actions, in this case, the active participation of different target audiences in the production and use of willow biomass. Initial outreach and education efforts targeted agriculture and natural resource professionals and landowners. As the program developed, target audiences were expanded to include local, regional, and national level policy makers; environmental organizations; small businesses; and potential end users (Volk et al. in press).

Educational techniques to reach these various audiences have included individual one on one interactions; community meetings; newsletters; local, regional, and national media coverage; annual field days; displays and presentations at county, state and national events; and a network of demonstration farms and research trials. The mix of techniques used will vary among target audiences, since no one approach will have the same degree of impact on different groups.

Through interactions with various audiences during outreach and education efforts several barriers to the adoption of willow biomass crops have become apparent among landowners (Volk et al. in press). Specific steps have been taken to address these issues with a high degree of success. However, the single largest barrier still remains, the lack of a secure long-term market for willow biomass. Progress is being made on this front as well, with the recent certification of willow biomass as a green source of energy by Green-e Renewable Electricity Certification Program and co-firing test scheduled with willow biomass at the Dunkirk power plant in the spring of 2001.

Despite the challenges and uncertainties, the outreach and education program has produced significant positive change among many target audiences. This has been demonstrated by the shift in the nature of inquires from knowledge centered to skill and action oriented. Most requests now focus on how individuals and groups can participate in the program, either as potential producers of willow biomass crops or as contractors involved in the establishment and management of willow biomass. In the first few years of the program about 100 landowners, representing over 1,800 hectares of land in central and western New York State, expressed interest in participating in the large-scale demonstration project. Many additional landowners have inquired about participation since the Consortium secured the land area required to meet it planting goals in 1999.

Regional Clone-Site Trials

A common response to early education efforts was a desire to see willow biomass crops being grown in the field. This interest, combined with a research interest to determine which clones are best suited to the range of soil and climatic conditions across the Northeastern and Midwestern United States, led to the establishment of 21 different clone-site and/or genetic selection trials (Figure 4). Trials were previously conducted in southern Ontario by the University of Toronto (Kenney et al. 1996). The current clone-site trials range in size from 0.5 – 1.0 hectares with between six and 40 different clones of willow and poplar being screened at each site. In addition to providing valuable research data, these sites have become focal points for outreach and education efforts in these different regions. First hand experiences are fundamental in facilitating the adoption of a new crop like willow.

Commercial Scale Demonstration

Between 1998 - 2000 over 280 hectares of willow biomass crops were established in western New York within a 60 kilometer radius of the Dunkirk power plant under the Biomass Power for Rural Development Program. Smaller areas totaling about 20 hectares have been established in central New York. Approximately 200 hectares in western New York are still under active management. About 80 hectares were lost due low survival and changes in land rental agreements. This area was lost due to a combination of a severe drought in 1999, poor weed control, and poor quality of planting stock. Over the course of the project many lessons about large-scale production have been learned and significant progress has been made to address the weed control and planting stock issues.

Figure 4. Nine states in the United States and southern Quebec, Canada where willow clone-site or genetic selection trials are established.

Fourteen different landowners are currently involved in the commercial-scale demonstration program. Field sizes range from 2 to 40 hectares. Smaller fields are immediately adjacent to one another so that no collection of fields was smaller than 6 hectares in size. All of the sites were in a hay crop the previous year or had been fallow for one to five years. These types of field conditions are common across New York because the agriculture industry, and in particular the dairy industry, has been in decline over the past decade. Four to six different willow clones were planted in each set of fields. Two clones of hybrid poplar are being planted and assessed for use in the high density, double-row system. Planting was done with either the modified Froebbesta planters, which use 25 cm long cuttings, or the Step planter, which uses 1.0 to 2.5m long whips. Field assessments indicate that the modified Froebbesta machines planted at a rate of 0.25 ha hr^{-1} while the Step planter operated at a rate of 1.0 ha hr^{-1}, including time for reloading and turning around at the end of the fields (Phelps et al. 1999). These types of gains in efficiency in the production system will improve the commercial viability of the system.

The near-term energy market strategy for willow biomass is co-firing at pulverized coal power plants. The 104 MW Greenidge pulverized coal power plant in Yates County was retrofit and has demonstrated continuous co-firing of wood residues at 10% by heat input for three years. The production of 1 MW of power would require about 320 hectares of willow biomass crops, if willow was the sole source of woody biomass for co-firing. Test firing of willow biomass at Greenidge has been performed and valuable lessons were learned about processing and handling the material. As a part of utility restructuring in the state, NYSEG sold the Greenidge power plant to Atlantic Electric Service (AES). While this plant remains a potential market for willow biomass, the future participation of the new owners is still being clarified. Niagara Mohawk Power

Corporation (NMPC) successfully completed wood co-firing tests at the 400 MW Dunkirk power station in western New York State. The station's new owner, NRG Energy Inc., has completed the retrofit of one 96 MW boiler at the station. Test burns using willow and other wood biomass are scheduled for spring 2001. The immediate fuel for co-firing will be wood residues from the forest products industry, with willow biomass becoming a part of the mix in 2001 when the first 40 hectare of willow biomass crops in the nation are harvested. Willow biomass crops were recently certified as a green source of energy by Green-e Renewable Electricity Certification Program, which will enhance its energy market value.

Longer-term conversion uses include gasification, pyrolysis, and combined heat and power systems. Discussions are underway to test willow in several gasification systems ranging in size from tens of kilowatts to several megawatts. Increased effort by other outside groups is focused on the fabrication of new biobased materials and chemicals from willow biomass as an alternative to products currently derived from non-renewable fossil fuels. These products include biodegradable plastics; pharmaceutical agents; cellulose nanocrystal preparation, modification and applications; stimuli responsive elastomers; and the development of micron-sized dispensers for insect pheromones. Preliminary tests at the Empire State Paper Research Institute at SUNY - ESF have shown that willow biomass can be successfully pulped to obtain fibers with good paper making potential (Cheshire et al. 1999). The development of these value-added bioproducts will provide several new markets for producers. The development of these value-added bioproducts will provide several new markets for producers.

SUMMARY

Despite the challenges and barriers, the Salix Consortium has made significant progress towards its goal of developing a willow biomass enterprise since its inception in 1993. Various target audiences have demonstrated significant shifts in their attitudes and actions related to the production and use of this new crop. Regional trials have become focal points for the discussions in other states and are beginning to provide valuable information about the production of the crop in other regions. Research results have been used to improve production in commercial scale demonstration project and to quantify some of the environmental benefits associated with the crop. However, hurdles still need to be overcome. Continuing research gains in crop yields, reductions in production costs, and the quantification and valuation of environmental and rural development benefits, will be essential to the establishment of a commercial willow biomass enterprise. Science alone will not overcome all of the barriers limiting the development of a willow biomass enterprise. Strong federal and state government visions and supportive policies and regulations are necessary to establish strong and reliable renewable markets for biomass so that it can become a viable competitor to a barrel of oil or a ton of coal.

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The Swedish Case: A Commercial Introduction of Short-Rotation Coppice on a Large Scale - Experience and Conclusions

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ABSTRACT

The production of willow in Sweden is no longer a developing project, but the production of a commercial crop among others. The willow wood chips are sold and delivered on the market for solid biofuels. The solid biofuel market consists mainly of forest industry by-products including sawdust, bark and residues from felling. The solid biofuels contribute to 20 % of the total energy consumption in Sweden.

Agrobränsle AB started in 1988, with the mission to commercialize Short-Rotation Coppice (SRC). In the year 2000, Agrobränsle sold cuttings to 900 hectares. This coming winter we will harvest 3,000 hectares and deliver willow wood chips to 20 different district heating plants in southern Sweden.

With the harvesting machines now working well, the next challenge is to develop the logistics to be able to transport and deliver the right amount and quality of willow wood chips at the lowest cost. Prices of solid biofuels have decreased due to taxes on demolition wood in European countries. At the same time costs have increased. Still willow production is competitive in many regions, especially for land owners without the ordinary machinery for arable production.

The Swedish government has recently decided that Swedish farmers are allowed establishment grants for 1,000 hectares per year until the year 2003.

Keywords: short-rotation coppice, willow, Sweden, Agrobränsle AB

INTRODUCTION

Agrobränsle AB is a commercial company working with development and trade in products from Salix plantations. Our main activities are marketing of cuttings for planting, organising harvesting, and delivering Salix wood chips to district heating plants. We have 15,000 hectares of Salix planted in Sweden. Deliveries of Salix chips are increasing from year to year. During the winter, 2000/2001, a total of about 220 GWh will be harvested.

We use six Claas harvesters and one Bender. Contractors own the harvesting machines. The contractors spend the period from November to March harvesting. Most of the district heating plants in central Sweden are using Salix chips.

The development of SRC production has proceeded faster than had been initially planned. On the other hand, the work of disseminating information and changing old and ingrained attitudes has been more demanding and difficult than expected.

SRC wood chips are a low value product, and can only become profitable if the production can be done on a large scale with small margins. The normal administration cost in Sweden for contracting district heating plants and delivering wood chips is 6 - 8 % of the price. We are aiming for at least 30,000 hectares of SRC to reach all benefits from a large-scale production.

Establishment and Management of SRC

Planting SRC

From 1991 until 1996, Agrobränsle planted 1,500-2,000 hectares annually. Planting is usually done with different Step-planters. During the first years, Agrobränsle owned the planting machines. When the machines were functioning well in 1994, we sold them to contractors. Our idea was to own machines during their development phase. When machines are fully developed and in production, the contractor is a more efficient owner.

The contractors are spread out over our working area and we need at least 1,200 hectares of planting per year, to achieve most of the benefits of large-scale planting. After several years of very low planting, it is now increasing again. During the year 2000 more than 600 hectares was planted. Willow production is very competitive in areas with a district heating plant within 80 kilometers, especially if the landowner has old machinery or little knowledge about grain production.

Harvesting

We agree and sign a harvesting contract with every farmer before harvest. The contract regulates items such as sufficient turn around land, marked out hindrances in the field, possible storage areas, and prices. If the farmer is interested, we also discuss sludge and weed control treatments that can be introduced in the next spring.

In the autumn a harvesting programme is designed that includes a detailed plan of harvesting each farm. We try to arrange the harvesting to coincide with the need for deliveries to different boilers. Machinery or boiler breakdowns and bad weather always disturb the programme and sometimes demand immediate changes. Different types of machines and logistic systems facilitate and make the systems more flexibles.

Different Harvesting Systems

Swap load system

A large part of the harvesting and delivery system uses the CLAAS Jaguar and the container system. The wood chips are directly loaded at harvest from the forage-harvester into a tractor-drawn container of 35 m^3. When the container is full, a new tractor with an empty container takes over. The container is carried on a swap load system and can be carried by both a tractor and a lorry. One lorry carries three containers that can be loaded in 40 minutes. The harvesting capacity and time for loading depends on the amount of biomass in the field and on the size of the field.

Short Time Salix Chips Storage

The system of direct chipping and storing in piles close to the field is another common system. In Sweden during winter, the ground is generally frozen and can be used as a hard base on which the wood chips can be stored. During wet and mild harvesting conditions, other hard surfaces close to the willow stand are used if available.

The use of small, hard ground storage increases the harvesting capacity due to the independence of the harvester and the container transporting chain, which is dependent on district heating plants receiving wood chips. For example, many large districts heating plants are not open for deliveries on weekends, but the harvesting must continue if conditions are suitable.

When loading from the ground, the container system is seldom used since it is rather expensive. Instead, ordinary self-loading wood chip vehicles equipped with a crane are used.

Whole shoot harvesting

When harvested as whole shoots willow can be chipped at the field and transported to the plant in one of the above systems or transported as brushwood by trucks, for later chipping at terminal storage or plant. Harvesting whole shoots for later chipping is however far more expensive than chipping directly with the harvesting machine. Direct chipping as well as harvesting whole shoots costs 30-35 SEK/MWh, ($3.00-$3.50 /MWh). Whole shoots will then be chipped with an ordinary forest chipper at an additional cost of 30-35 SEK/ MWh. Chips from whole shoots will be drier when chipped. This may increase the value of the material, but not as much as the increased costs of chipping.

Administration

Agrobränsle has 1,250 growers with an average planted area of 12 hectares. Altogether there are around 3,000 fields planted. In our database the fields are given their geographic position by co-ordinates. We can note the production level of every field and then forecast the production and harvested amount in a certain area. In this way it is easier to start the discussion with the different plants and know the amount of wood chips to be delivered from a certain area.

Supply Risks - Background of the Swedish Solid Biofuel Market

Different boilers are built for different kinds of fuel. When deciding what kind of boiler to build, a driving factor is the amount of different fuels available for the boiler. The wrong choice of boiler can potentially increase the risk. Here we will not discuss the choice of boiler, but focus on solid biofuels (Table 1).

A district heating plant must continuously deliver its product, heat. There is a demand on delivery very close to 100 % of the time. In Sweden, solid bio-fuel plants are bound by legislation to have an oil burner as back-up in order to assure the deliveries of heat. For a well run and profitable plant the supply of fuel is as important as the delivery of heat. Oil can be used for short periods, but will ruin the economics of the plant if used frequently.

In Sweden, the plant contracts with producers of fuel and middlemen to cover the annual needs. Contracts usually cover three years. The contract stipulates price, volume of energy delivered per year, month and day, quality, size of chips, moisture content, how to decide energy content, etc. The contracted amount of energy is usually given as an interval, whereas the customer can take out the contracted volume ± 10 %. The final requested and consumed volume is determined based on the actual weather conditions during the year, with less consumption at higher temperatures and vice versa. Outside the contracted volume interval, there will be negotiations on either new prices on excessive amounts or claims for damages on undelivered amounts.

Table 1. Decreasing the supply risk.

Activity	Consequence
Build a boiler that has a broad range of fuel alternatives.	More expensive boiler.
Contract several suppliers.	Increases the amount of people producing fuel in a deficit situation.
Maintain good communication with the suppliers to assure they can supply the contracted volumes.	Cheap and efficient, always underestimated.
Large contracted volumes compared with consumption.	Will assure supply but will be costly if not used.
Enlargening the option range of volume out take.	Will roll over the risk onto the supplier and therefore, in the end, increase the price.
Hard penalties on suppliers not fulfilling their contract.	Prices will rise.
Promoting the suppliers to develop and rationalise.	Will establish for stable or decreasing prices and enlarging volumes.
Encouraging other energy companies to build solid biofuel boilers.	Will give the suppliers developing possibilities and stable prices. Since the supplier will not contract a new plant if he doesn't have the volume requested. The competition problem between fuel buyers is usually exaggerated.

How to Decrease the Supply Risk, If Starting Up a Market

The plant can contract several suppliers or one. The supply risks decrease as the market for solid fuels grows and the amount of actors on the market increases. The supply risk on today's solid biofuel market in Sweden is not a problem. Currently, there is a large overproduction of fuel due to several years of warm weather. However, it is important that there is a good working relationship between the supplier and the customer.

In Sweden, the market for solid biofuels is a well established market economy. Therefore it is possible to cover deficits with purchases of fuel on the spot market. It has been common among the Swedish plants to hold for example 20 % of their fuel needs uncontracted and buy this fuel on the spot market.

Supply Risks - Variation in Yields

It is important to realise that energy crops can never be the only fuel on a solid biofuel market in a cost efficient way. Energy crops require long term production and variation of yields are large compared with the consumption of the product. A solid biofuel market should, therefore, also be based on forest residues and by-products from the industry. In the Swedish solid biofuel market willow will always be the minor part. However, willow has large benefits due to its function as a large, living storage of wood chips, harvested at the same time that it is needed. The growing of willow potentially reduces the amount of stored wood chips at terminals, and thus reduces costs and the investment of capital.

When SRC is a large proportion of the solid biofuel supply, low yields or extremely high consumption can be a problem. This can be met by harvesting larger areas and/or by gathering forest residues and transporting them from longer distances.

There may be harvesting problems with SRC during winters with mild and wet weather. Harvesting machines that will operate effectively under difficult conditions are under development. During mild winters, the consumption of fuel is much lower so the demand for biofuels is lower.

Break-Downs in Energy Plants and Plant Stoppages

During the heating season, there are fairly frequent periods when the biofuel suppliers are temporarily not allowed to deliver wood chips. There are several different reasons for plant stoppages or delivery stops, such as:

- to much fuel delivered by the suppliers
- break downs or fire in the transporting system
- cinders and slag in the boiler, or other repairs

New boilers often have start up problems during their first firing season. When delivery stops occur, Agrobränsle switches harvesting capacity from immediate container deliveries to small hard ground storages near the farm. Thus the harvesters can work continuously. This is extremely important since the harvesting season is restricted to the winter and during periods when the heavy machines can access the fields.
It is difficult for a supplier to be ready to deliver the contracted amount of energy and then not be allowed to deliver. Breakdowns and delivery stops definitely make the production of fuel more expensive. It is not always easy to transfer the rising costs to the energy company, even if the contract is clear on this point. There is a long-term local relationship between the supplier and the energy company. Disagreements can sometimes be solved with new contracted volumes or increasing prices for the future.

Long-term Supply Contracts

It is very important for a new business venture to feel secure about new investments. Here a long-term agreement on deliveries is absolutely necessary for producers and buyers to invest money in a new technical area. Both parties have benefits from making a long-term agreement during the period when investments are written off. If there is a well functioning large market for the products involved, you do not always need a long-term contract. A decision can be made on the basis of the supplier’s knowledge and judgement about the market.

Solid biofuels is a long-term local market. It demands mutual respect and fair-trading. There is no point in making a good profit at the expense of the other party. If he finds out that he has a bad contract he will compensate for this in the next negotiation or never make an agreement with you again. A win-win situation will ensure a solid market in the long run.

Long-term contracts will stabilise the volume and prices of the solid biofuel market and then secure the economy for both parties. Large surplus or deficits of fuel will not occur. The supplier of fuel will be able to make long-term agreements with other producers of fuel and producers of SRC energy crops can feel safe in investing in their new crop.

Practical Experiences with the Flevo Project in the Netherlands

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ABSTRACT

Research and development on short rotation woody energy crops in The Netherlands has developed from on station testing in experimental plots the size of a few hectares, to a pilot stage of a few dozen hectares in 2000. In three years time the area planted with Short-Rotation Coppice (SRC) will increase to 200 hectares, supplying 10% of the annual feedstock of a CHP plant in Lelystad (i.e 1,500 odt/a/yr). In the Flevo-case, social acceptance was considered an important factor to success.

INTRODUCTION

Present status of the Flevo-project

Do dedicated energy crops have any chance at all in a densely populated area such as The Netherlands? Apparently so, because this spring the first 50 hectares of Short-Rotation Wood Crops (SRWC) have been established successfully in the province of Flevoland. In a couple of years time there will be 200 ha of coppices planted, which are to provide 10 percent of the total feedstock of a biomass fueled combined heat and power plant in Lelystad. However, to get such a demonstration project started at a practical working level was not an easy matter. It took seven years of preparation plus a detailed business plan and a lot of lobbying to convince local decision makers and the State Forest Service to set aside land for this particular learning process. Substantial government incentives were needed to finally win over a Dutch utility to invest in the bio-power plant. The participatory process required several round table meetings with all stakeholders before a joint letter of intent was signed. Many parties were involved: State Forest Service, Netherlands Organization for Energy and the Environment, Shell company, Environmental organizations, province, municipalities and several consultants.

A Bioguide was issued, suggesting appropriate and sustainable cropping systems. This helped a lot to level out the last lumps and barriers raised by environmental groups. The result was that no artificial fertilizers and no herbicides were allowed, not even at the initial site preparation stage. Indigenous planting stock of local provenances had to be included. The working out of a business plan in which 12 different product-market combinations were presented in detail, was another means to enhance the social acceptance of this project. A so-called SWOT analysis (strength, weaknesses, opportunities and threats) identified the most appealing and most viable ones. Based on these analyses, in the summer of 1999 the parties involved took a positive decision about the implementation of the Flevo-project, based on the concept of integrated and multiple-land use. The first 12 ha were established by the spring of 1999, of which, unfortunately, only 50% survived the first growing season. This steep learning curve did not discourage a further plantings of 45 ha of willow cuttings (including the five or six hectares, which had to be replanted) in the following season. Status by mid September 2000 is that the crop is doing very well and we seem to have won the race against the weeds. The challenge now is to keep the momentum and to motivate all parties to continue. Additional funds are required to scale up to 200 ha. We definitely need political support for the next stages and the acquisition of land remains a crucial factor, due to the complicated land-use planning procedures in Holland.

Some Results on Salt Uptake by Willows

After monitoring the first year growth of willows growing on dredging sludge in a container test, some additional analyses on salt uptake have been done with very significant results. The sludges were contaminated by mineral oil, PAC's and heavy metals and were classified as slightly brackish, with salt contents of about 1050 mg/liter (550 mg/kg). Sixteen different willow varieties have been tested and first year growth was measured, as a result of which a clear ranking followed. The top 10 clones are presented in decreasing order of biomass production (Table 1).

Table 1: The top ten willow clones, ranked by biomass production and their salt uptake (mg Cl/kg) grown in dredging sludge

TOP 10 IN BIOMASS GROWTH	**Salt uptake (mg Cl/kg)**
Salix alba 'Het Goor	1600
Salix alba 'Lievelde'	2200
Salix triandra 'Black Hollander'	3800
Salix alba 'Belders'	3200
Salix triandra 'Zwarte driebast'	5600
Salix dascyclados '57/57'	2700
Salix dascyclados 'Loden'	3000
Salix fragilis 'Belgisch rood'	4100
Salix triandra 'Grisette'	3300
Salix rubens 'Bouton aigu'	3000

These data suggest significant clonal differences in salt-uptake by willow. Even between species, there seem to be differences in salt-uptake: Salix alba and Salix dascyclados had the lowest chloride contents; whereas Salix viminalis and Salix fragilis had the highest salt-uptake. This may offer perspectives to selection and breeding.

Other Relevant Issues

An important issue when considering the large-scale deployment of woody biomass will be: How to guarantee that the biomass production takes place under sustainable management regimes? In some countries good practice guidelines have been developed based on consensus (e.g. the Dutch Bioguide). Certification too may be an appropriate tool to consider; especially certification schemes approved by the Forest Stewardship Council (FSC). The question is should we try to develop a draft FSC standard for energy crops? If so, which adjustments are needed? Moreover, what are the consequences?

The Dutch FSC standard for plantation forestry requires that in all plantations at least 10% of the area be planted with mixed indigenous tree species. Half of that area (i.e. 5 %) located at the edges, along watercourses, or adjacent to more natural areas, is not to be harvested at all. A second important issue is that the ecological disadvantages associated with monocultures and clear felling will have to be compensated for by additional requirements, such as the ones stated under Principle 10 of the Dutch FSC standard. These include:

- Not allowing the use of pesticides, unless the necessity has been clearly demonstrated to the satisfaction of the certifier;
- The size of felling areas has to be limited to 5 ha;
- For plantations over 20 ha, felling has to be restricted to an area not exceeding 25% in the last 5 years;
- Temporary plantations are excluded from the FSC standard.

The scale of operations suggested here (i.e. limited to five hectares) will result in a mosaic of stands with different age and structure over time. According to FSC, this could make a significant contribution to landscape diversity. Are these FSC requirements reasonable and acceptable to us or should we develop our own standard for energy crops? This could be an interesting issue to focus on in future meetings of the Short-Rotation Wood Crops Operations Working Group.

Willow Biomass Production in Southern Quebec: Potential, Problems and Future Perspectives

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ABSTRACT

Salix discolor Mühl. and *Salix viminalis* L. were planted in 1995 for a pilot study of short-rotation intensive culture (SRIC). Plantations were established on abandoned farmland with different drainage conditions, a well-drained site and another one with poorly-drained conditions. After three seasons growth, the two species were cut down and an experiment was designed to study the field performance of plants following coppicing. A dose of composted sludge equivalent to 100 kg of "available" N/ha^{-1} was applied to some plots in the spring of the first season after coppicing while others were left unfertilized. The aims of the experiment were i) to investigate plant response (growth and productivity) to plantation site conditions and sludge application; ii) to draw up an inventory of fungal pathogens identified on the stems and leaves of *S. viminalis.* Over two seasons, growth parameters were followed. Height and aboveground biomass were greater for *S. viminalis* than for *S. discolor* on all fertilized plots. *S. viminalis* planted on the poorly-drained site had the highest biomass yield (38.56 t/ha^{-1}). Both species showed best performances on poorly drained sites. A moderate dose of wastewater sludge (100 kg of "available" N/ha^{-1}) may be a good fertilizer for willows in the second cycle of growth. Some fungal pathogens identified on *S. viminalis* are mentioned for the first time in the literature in North America (USA, Canada, Quebec). This study concludes that the growth of willows could be maintained and even increased from one cycle to another.

Keywords: willows, biomass production, coppicing, annual yield, wastewater sludge fertilization, willow pathogens.

INTRODUCTION

Studies on the production of woody biomass for energy purposes through short-rotation intensive culture (SRIC) of willows have demonstrated that the climatic and edaphic conditions of Southern Quebec are conducive to the development of this technology. Productivity-oriented agriculture as practiced in Quebec causes thousands of hectares of less fertile farmland to be abandoned. This land, unused for traditional agriculture, is characterized by clay or sandy textured soils, and could be reconverted for the production of willow biomass of carefully chosen clones, using adapted culture techniques (Labrecque et al. 1993).

Experiments conducted in the south of Quebec (Canada) for the past ten years with two willow species (*S. viminalis* and *S. discolor*) on small areas have produced yields of between 15 and 20 t ha^{-1} of dry-matter every year (Labrecque et al. 1993, 1994, 1997). It has also been demonstrated that fertilization of willows with wastewater sludge significantly increases biomass productivity on the treated plots, and contributes to recycling an undesirable residue (Hytönen, 1994, Labrecque et al. 1995, 1997, 1998).

Short-rotation plantations suffer from a range of diseases of fungal and bacterial origin. Some pathogens occur worldwide and others only in certain areas (Christersson et al. 1994). In the northern regions of North America, where surfaces planted with willows in SRIC increase each year, studies on pathogens that could affect vitality and yield are very important.

In 1995, a pilot study with willows in SRIC was undertaken in the Upper Saint-Laurent region in Southern Quebec (Canada). The objectives of the study were to compare the establishment, growth and performance of two willow species cultivated on sites with different characteristics and to assess the impact of fertilization with wastewater sludge on yields during a second rotation cycle of growth (following coppicing done in the fall of 1997). Another objective was to initiate study of willow diseases by drawing up an inventory of fungal pathogens identified on the stems and leaves of *S. viminalis*.

METHODS

Study Area

Experiments were conducted in the Upper Saint-Laurent region (45^{o}05’ N, 74^{o}20’ W) 90 km southwest of Montreal. Meteorological data were collected at a permanent station of the Environment Ministry of Quebec. The climate of the area is continental, characterized by an annual average temperature of 6.4°C and an annual average precipitation of 954 mm (Ministère de l’Environnement du Québec, 1991). The frost free period is 182 days and the total number of degrees above 5°C is 2106. Mean total precipitation during the growth season (from May to September) calculated over a period of 29 years (1961 to 1990) was 427 mm.

The two growing seasons (1998 and 1999) were characterized by warm temperatures, which remained above normal until the middle of summer (Figure 1). During the first growing season, the precipitation cumulated from May to September reached 525 mm and exceeded the normal by 98 mm. The monthly distribution of rainfall was particularly favorable to the growth of willows in SRIC, as 87.4 % of the total precipitation fell during the period of their active development (June to August). In 1999, the 413 mm of precipitation, which fell during the growth period, was 14 mm lower than normal. However, the monthly distribution of the rainfall was unfavorable to the growth of willows, as a high percentage (37%) of this precipitation occurred in September.

Site Characteristics

Experiments were conducted on marginal sites abandoned by traditional agriculture for several years. Two one-hectare sites with different soil characteristics (Table 1) were selected: Site 1 (sandy-loam, well-drained) and Site 2 (clay loam, poorly drained).

Species and Experimental Design

Two willow species were chosen: *S. viminalis*, a species which has been introduced from Europe, and *S. discolor* Mühl., a species indigenous to Quebec and which grows naturally the Upper Saint-Laurent region.

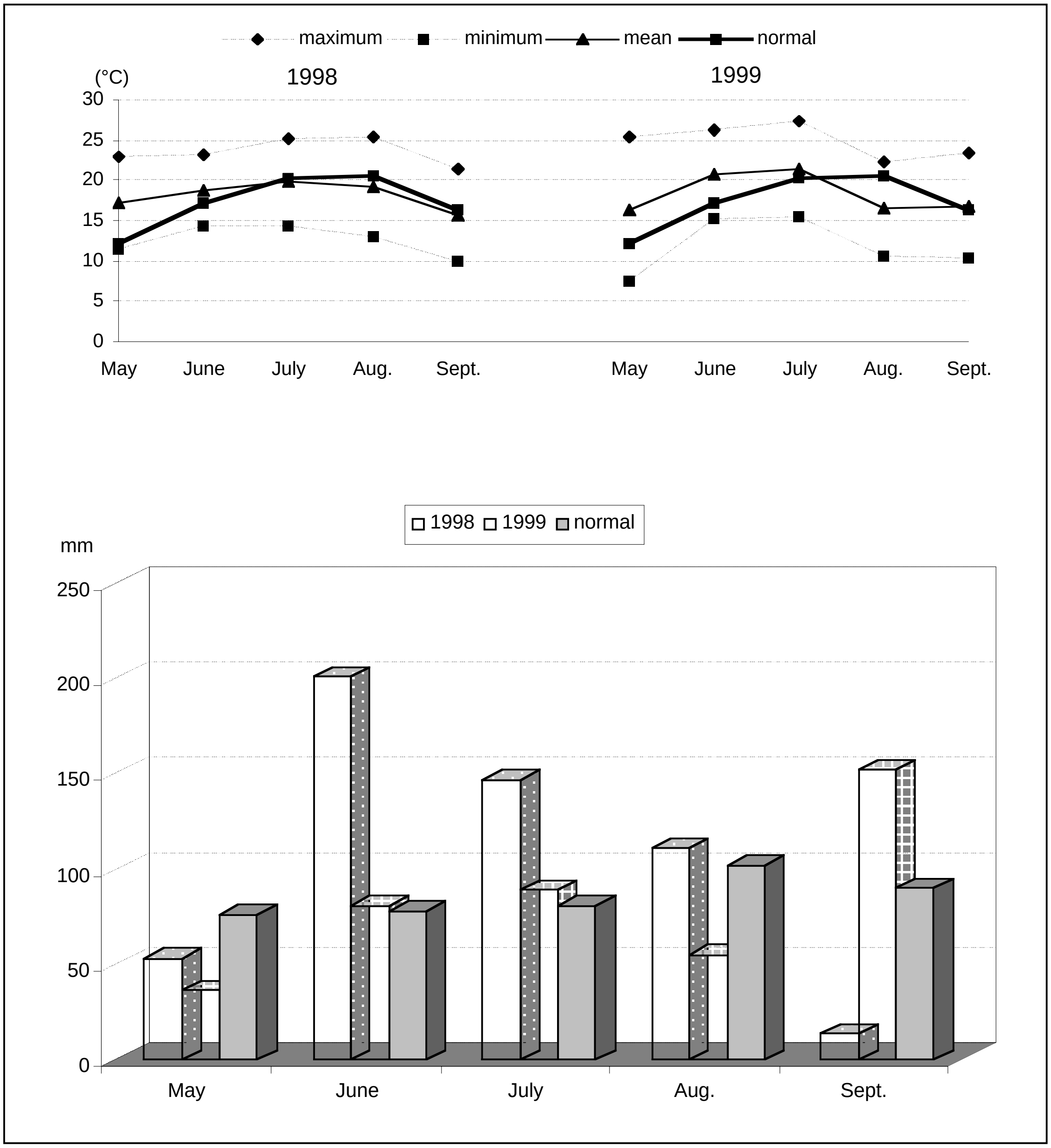


Figure 1. Meteorological data recorded at the experimental sites during the two growing seasons.

The establishment of the plantation took place in May 1995. The plantation design comprised several plots 3 meters apart from each other. Each plot had 6 rows 1.5 m apart. With an interval of 0.30 m between plants on the same row, a density from 18 000 to 20,000 cuttings per hectare could be obtained. In November 1997, at the end of a three-year growth cycle, all the trees were coppiced.

Table 1. Soil characteristics of the two experimental sites.

	Site 1	Site 2
Sand %	76.92	9.28
Loam %	14.36	42.0
Clay %	8.72	48.72
Texture	Sandy loam	Clay loam
Organic matter	5.7	5.5
pH	5.6	6.4
P kg/ha	76	34
K kg/ha	246	438
Ca kg/ha	4005	8460
Mg kg/ha	239	2419

Two large (10,000 m_ each) experimental plots were set up in the spring of 1998. Each design comprised 6 blocks in which the two species and two fertilization treatments were randomized: a control treatment (T0) and a fertilized treatment (T1) corresponding to the application of about 20 t ha^{-1} of wastewater sludge (equivalent to 100 kg ha^{-1} "available" N). The sludge dose was calculated on the basis of the theoretically available N content for the first season following the application ("available" N = inorganic N + 0.30 organic N) determined per kg of dry-matter of sludge. Sludge characteristics and the elements brought into the soil by the fertilization treatment are shown in Table 2. In order to conform to established standards for the valorization of sludge in Quebec, total content of some elements and metals was tested.

Table 2. Sludge characteristics.

CHARACTERISTICS	Units	Content	Qt. App. (kg/ha)
Dry matter	%	60,4	18 832
Organic matter	kg/t	302	5 687,26
N-total Kjeldhal	kg/t	14,5	273,06
N-(NH_4+NO_3+NO_2)	kg/t	1,37	25,80
N "available"	kg/t	5,31	100,00
P (P_2O_5)	kg/t	11,38	214,31
K (K_2O)	kg/t	2,64	49,72
Ca (CaO)	kg/t	53,2	1 001,86
Mg (MgO)	kg/t	9,96	187,57

Measurement and Sampling

On each of the two sites, 144 randomly chosen plants (six plants for each species, fertilization treatment and block) were measured three times during each season (June, August and November). The height (from stem origin to its apex) of the main stem as well as the number of sprouts produced by each plant were measured. At the end of each season, all these plants were coppiced and weighed in the field with a spring balance.

Green samples were oven-dried at 70°C (to constant mass) then weighed to evaluate the dry matter content. Productivity (t ha^{-1}) was calculated taking into account plantation densities and dry matter of biomass. The chemical analyses (soil and sludge) were conducted by a certified laboratory (Agri-Direct Laboratory) using methods recommended by the Conseil de production végétale du Québec (1988).

Analyses of variance (three-way ANOVA) followed by multiple comparisons of means according to Tukey's method were performed on growth and productivity (SAS Institute Inc., 1989). The number of sprouts was analyzed using log-linear models.

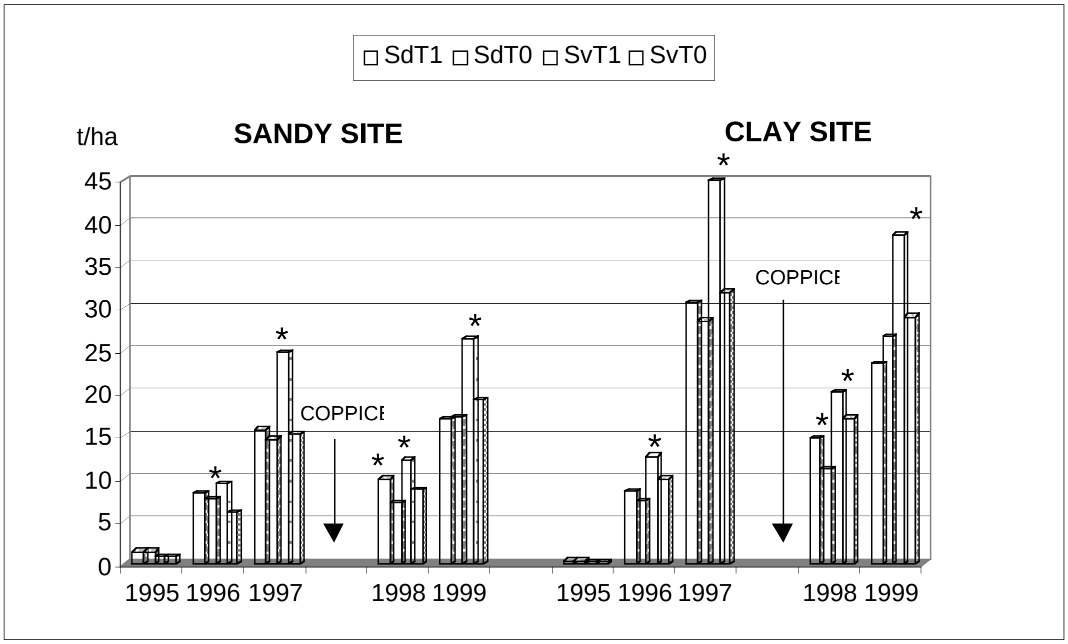
RESULTS AND DISCUSSION

Growth and Productivity

In general, climatic conditions in southern Quebec are comparable to those of southern Sweden, where the world’s largest willow plantations under SRIC can be found (Moren and Perttu, 1994). Thus, in both areas, average precipitation during the growing season varies from 350 to 500 mm, but the sum of temperatures (above 5°C) is greater in Quebec. In Sweden, irrigation of the plantations is being contemplated because the quantity of water available during the season is considered to be insufficient for maximal growth, more specifically because precipitation distribution is not uniform (Perttu, 1998). Although the situation is similar in Quebec, such a costly practice is difficult to imagine. Considering this aspect, it might be advantageous to cultivate willows on sites with slower drainage conditions.

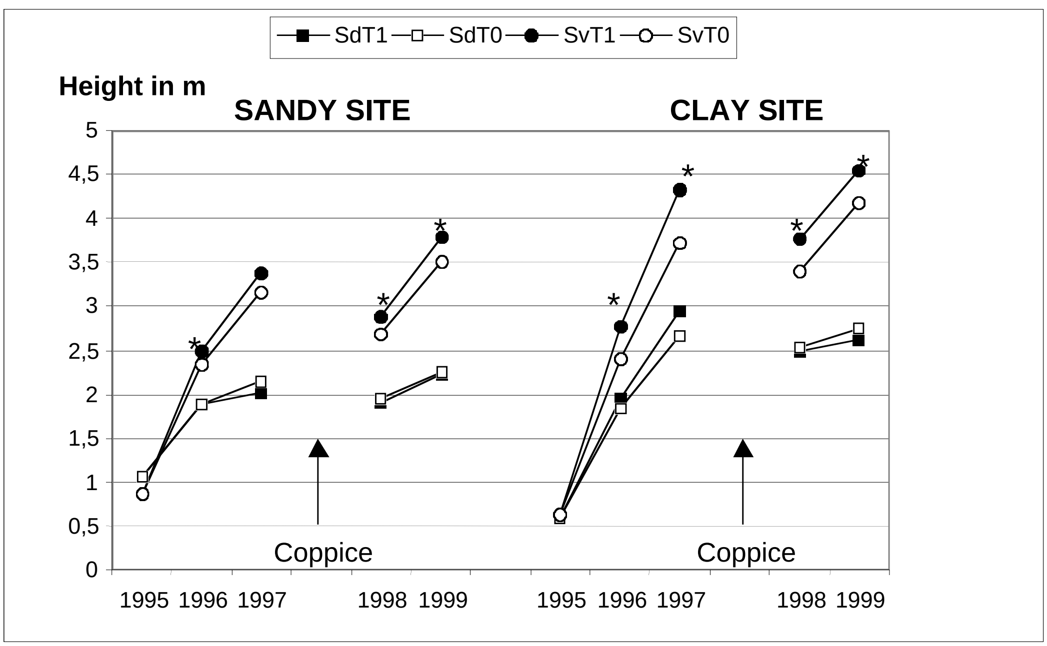
Results of growth and yield on poorly-drained sites shown in Figures 2 and 3 confirm this idea. During the two seasons of follow-up, willows planted on the clay site were taller than those cultivated on the sandy site (Figure 2). Stem height of *S. viminalis* was always superior to that of *S. discolor*. The height of *S. viminalis* was also positively affected by fertilization treatment. This tendency was not observed for *S. discolor*. Figure 2 also compares the height of the main stem before and after coppicing. It shows that the regrowth of plants following coppicing was very active, particularly for *S. viminalis*. At the end of the first growing season following coppicing (1998), plants were almost as high as they were at the end of the first rotation cycle (1997). At the end of the 1999 growing season, stem height of *S. viminalis* was superior to the height reached by the plants prior to coppicing. The regrowth of *S. discolor* after coppicing was less active and stem height remained relatively limited.

At the end of both growing seasons following coppicing (1998 and 1999) we observed that the two willow species on the clay site produced a significantly higher quantity of woody biomass compared to what they produced on the sandy site (Figure 3). Samples harvested at the end of each season showed that the fertilized plots of *S. viminalis* allowed the highest production of biomass (38.56 tons dry mass per hectare, 20.16 t the first year and 17.9 t the second year). In the absence of fertilization, no significant difference was found in the yield produced by both species on both sites. Sludge application in the spring of 1998 increased the productivity of both species on both plantation sites during the first growing season (Figure 3). By the end of the first growing season (1998), the sludge dose equivalent to 100 kg/ha of "available" N applied on the sandy site induced an increase in biomass production of 38.2 % and 40.5 % for *S. discolor* and *S. viminalis* respectively. On the clay site, the increase in productivity



* : indicates a significant difference ($P < 0.05$) between control treatment (T0) and a fertilized treatment (T1).

Figure 2. Comparison of the height of the main stem before and after coppicing.



* : indicates a significant difference ($P < 0.05$) between control treatment (T0) and a fertilized treatment (T1).

Figure 3. Comparison of production in biomass at the end of each growing season, before and after coppicing.

due to fertilization treatment was 31.5 % for *S. discolor* and 17.3 % for *S. viminalis*. The fertilization treatment does not seem to have any continuing impact on the productivity of

S. discolor during the second year. Significant differences were only found for *S. viminalis*. At the end of 1999, the best yields were obtained by *S. viminalis,* which profited from the fertilization treatment. Thus, the sludge application induced an increase of productivity of 37.3 % on the sandy site and of 33.2 % on the clay site, compared to the unfertilized plants. The increase in productivity due to fertilization was greater on the sandy site, which was less rich in elements than the clay site.

For *S. discolor*, the production in biomass after two growing seasons on the fertilized plots was not significantly different from that on unfertilized plots. The best biomass production was 26.66 tons of dry biomass per hectare, which represents only 67.1 % of the biomass obtained by *S. viminalis* under the same conditions. The yield of 38.56 tons of dry biomass per hectare obtained by *S. viminalis* on the fertilized plots on the clay site after two years of growth shows the exceptional productivity of this species. Moreover, this yield was obtained under the conditions of dryness and excessive temperatures, which characterized the summer of 1999.

Results indicate that the clay site was more favorable to the development of both willow species. Under these conditions, the cations exchange capacity is better; the availability of the elements higher (supported by a neutral pH); and the balance between Ca and the Mg is optimal (Table 1). Moreover, the plants profit from a good availability of water due to the higher retention capacity of clay soils (Doucet 1992). This also indicates that the yield over several years of cultivation and coppicing could be maintained and even increased from one cycle to another. Our results compare well with those published by Hofmann-Schielle et al. (1999) who find that *S. viminalis* can increase growth considerably in the second rotation by 44 to 75% on clayey soil, and up to three-fold on sandy loam soil, as compared with the yield of the first rotation cycle.

Inventory of the Potentially Pathogenic Diseases

This study was also interested in the diseases that could potentially affect the plantation. Diseases resulting from a fungi contamination could be a very important limiting factor in the production of biomass from short-rotation coppice willow, and the use of fungicides would be unacceptable for economic, environmental and practical reasons (McCracken and Dawson, 1997). Many factors favor the development of diseases in such a system of culture. The monoculture based on a few clones or species, the microclimate (humidity, temperature) inside the plantation due to a high density of stems, the exchange of cuttings from one area to another or from one country to another, etc. are factors that could give rise to the development of pathogens.

Several potentially pathogenic fungi were identified on the stems and the leaves of the clone of *S. viminalis* cultivated in our plantations as indicated in Table 3. Fungi identified were compared with those reported for willows in North America and mentioned by various authors (Ginns, 1986; Farr et al. 1989; Myren et al. 1993; Innes et al. 1994; Hawksworth et al. 1995; SPPQ 1996; Vujanovic et al. 1998).

This non-exhaustive inventory allowed the identification of 35 pathogenic fungal species on *S. viminalis* in SRIC. The majority of these identified fungi constitute a first mention for these pathogens on willows in North America. Several of these fungi are regarded as being particularly pathogenic for the willows. It is the case of *Alternaria spp*., *Melampsora spp*. and *Venturia spp*. that were found on leaves, and *Cryptodiaporthe spp*., *Glomerella spp*. and *Valsa* identified on branches. These new results must be considered seriously with regard to the development of the technology of SRIC in Quebec and in North America.

CONCLUSIONS

The first growing season following coppicing was very favorable to the growth of willows in SRIC because precipitation was abundant during June and July when the development of the willows was at its maximum. On the other hand the second season began with very high temperatures and less precipitation than normal, both of which have affected the growth of willows, especially on the sandy site. Rainfall was higher in June and July but temperatures remained above normal.

Our study showed that growth and yield are influenced by climatic conditions and that the full potential of productivity is expressed when growing seasons are cooler with extended periods of rain, especially during June and July.

The two species perform best in terms of growth and productivity on the clay site. On this site, a yield of 38.56 tons dry mass per hectare was produced by *S. viminalis* after two years of growth following coppicing. This species also remains the most productive on all plantation sites, fertilized or unfertilized.

Sludge from sewage stations constitutes a good fertilizer for willows in SRIC. Our results suggest that the application of 20 tons of dry matter sludge per hectare (100 kg of "available" N) involves few risks of nitrates and metals leaching into the soil. However, this dose seems insufficient to meet the needs of willows for several seasons, especially on sandy soil, which is less rich in resources. Ideally, the fertilizer must be applied annually in small doses, but this is likely to increase costs and, from a technical point of view, would be difficult to carry out.

Results obtained two years following coppicing indicate that growth and yield of willows could be maintained and even increased from one cycle to another. The fact that we were able to identify and inventory so many pathogenic fungi demonstrates the importance of considering this aspect if willow cultivation using the technology described is to be expanded. The possible propagation of diseases could dramatically decrease the productivity of willows in SRIC. In order to increase our knowledge about these diseases and to develop means of defense, thorough studies are necessary and must be undertaken in the near future.

ACKNOWLEDGEMENTS

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Technical Session: Management and Economics of SRWC

Future Market Scenarios for Pulpwood Supply from Agricultural Short-Rotation Woody Crops

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ABSTRACT

The North American Pulp And Paper (NAPAP) model and USDA POLYSYS agricultural policy analysis model were linked to project future market scenarios for pulpwood supply from agricultural short-rotation woody crops in the United States. Results suggest that pulpwood supply from fast-growing hybrid poplars and cottonwoods will become marginally economical but fairly limited in the next several decades. This supply could become significant under certain scenarios, such as reduced hardwood pulpwood supply from natural forests or limited future expansion in paper recycling. Woody crops might also be developed as feedstock for fuels or chemicals, but competitive development of hybrid poplars for such markets would require higher biomass feedstock values than current market values.

INTRODUCTION

The NAPAP model is a partial equilibrium model of the entire North American pulp and paper sector. It projects market conditions and technological changes by solving for annual equilibrium levels of supply, demand, and prices, given basic assumptions about long-run economic growth and population. The annual projected market equilibrium is obtained by optimizing total consumer and producer surplus of the pulp and paper sector, subject to constraints of production capacity, technology, and material balance (Ince, 1999, Zhang et al. 1996). Production capacities of different processes evolve gradually over a multi-decade projection period, with annual changes in capacity favoring efficient processes in continuous response to evolving market conditions. POLYSYS is a similar model of the U.S. agricultural sector that solves for annual equilibrium planting levels among agricultural crops by optimizing net present values of agricultural crops (Ray et al. 1998). POLYSYS includes short-rotation woody crops (SRWC) as well as other major agricultural food and fiber crops and livestock. It includes cropland acres currently in major crop production or that are idled, in pasture, or in the Conservation Reserve Program. POLYSYS computes an optimal allocation of agricultural land use among various crops each year.

The NAPAP and POLYSYS solutions were linked by sharing projections of equilibrium supply quantities and prices for SRWC. The NAPAP model projects for each year the equilibrium demand quantities of all types of wood pulp fiber, including pulpwood from forests, wood residues, and recycled paper, as well as pulpwood from SRWC. As part of the equilibrium solution, the NAPAP model computes equilibrium (shadow) prices for hardwood pulpwood each year. The pulpwood price projections are passed to POLYSYS, where pulpwood prices influence SRWC planting and land allocation decisions. POLYSYS in turn computes land area allocation to SRWC and provides the NAPAP model with estimates of SRWC supply (including yields and costs).

The combined NAPAP/POLYSYS system will generally converge upon a stable equilibrium pathway within a limited number of iterations (5 to 7).
Technical assumptions in POLYSYS include productivity and cost data, interest rates, and an "adoption factor" for SRWC, all of which can influence results and provide a technical basis for alternative scenarios. The U.S. Department of Energy Bioenergy Feedstock Development Program (http://bioenergy.ornl.gov/) developed regional productivity and cost data for hybrid poplars and cottonwoods programmed into POLYSYS. POLYSYS regions that can produce SRWC include the majority of USDA Agricultural Statistical Districts (ASDs), including most districts in the eastern United States plus those western districts deemed to have climate and soil conditions suitable for such crops. The rate of SRWC adoption is controlled by a fixed constraint on the percentage of available cropland area that may be planted to SRWC each year within each ASD (the so-called adoption factor). Productivity and cost data in POLYSYS vary by ASD, with estimated woody crop rotation lengths varying from 6 to 12 years depending on geographic location. The productivity and cost data developed by Oak Ridge Laboratory were based on field experience with short-rotation poplar plantations since the 1970s and on expert opinion. The data represent productivity levels considered to be achievable based on conventional technology. The productivity and cost data assume that woody crops are fertilized periodically and treated chemically to suppress weed competition early in the rotation; this is common practice in conventional poplar plantations, although chemical applications are much lower than for most other agricultural crops. The productivity and cost data do not assume that the woody crops will be irrigated; irrigation is used in a few highly productive plantations in the West and South, affording higher productivity and shorter rotations but higher costs per acre.

Base Case Assumptions and Alternatives

The market analysis stems from a base case outlook along with some alternative scenarios derived by varying base case assumptions in the economic models. The NAPAP model operates with assumptions about future U.S. population and economic growth that drive projected trends in pulp, paper, paperboard, and wood panel consumption and production. The population and economic growth assumptions were derived from U.S. Census Bureau and Economics Research Service projections (Fig. 1). In general, although demand projections vary substantially among individual products and projections are derived by equilibrium analysis rather than by trend extrapolation, the projections indicate a continuation of historical trends in paper and paperboard consumption. With the conventional trend assumptions about population and real GDP, the NAPAP model projects a gradually decelerating trend in U.S. per capita consumption of paper and paperboard products, and a gradually declining trend in consumption per unit of real gross domestic product (GDP) (Fig. 2).

On a total tonnage basis, U.S. paper and paperboard consumption is projected to increase from 103 million short tons in 1999 to 126 million tons in 2010 and upwards of 185 million tons in 2050. The projected annual rate of growth in tonnage decelerates over the next 50 years and averages just 1.1%, less than half the average rate of the past 50 years. Population, economic growth, and end-use assumptions primarily drive the projected demands. Projected shifts in fiber supply exert only modest influences on

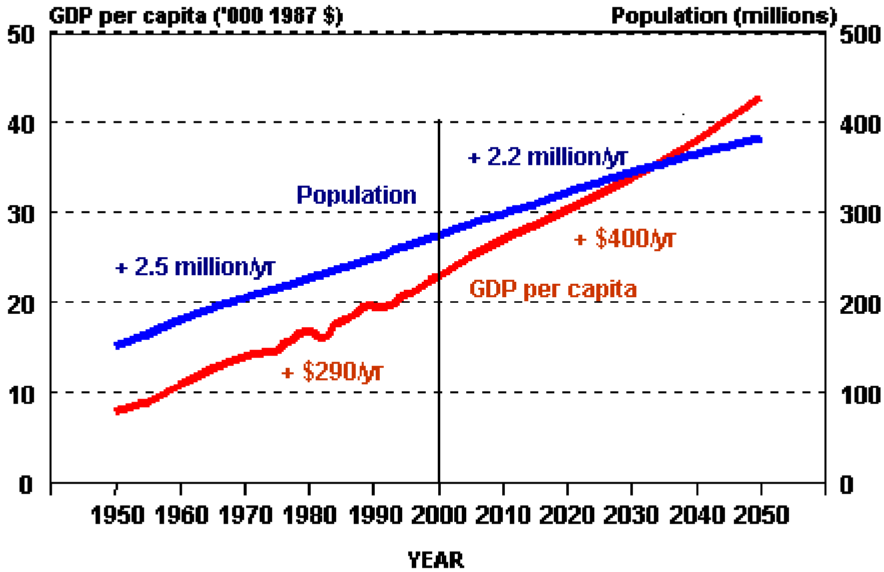

Figure 1. Historical and projected trend assumptions for U.S. population and GDP per capita. Slower population growth and increasing GDP per capita are projected.

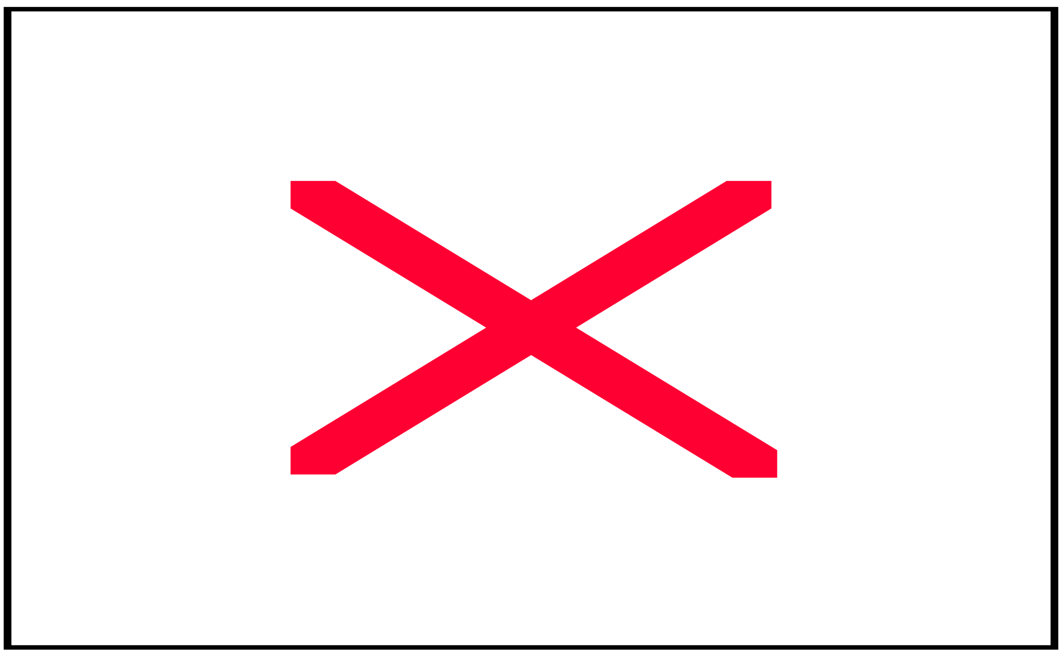

Figure 2. Historical and projected trends in equilibrium annual U.S. per capita paper and paperboard consumption, and consumption per unit of real GDP (1992 US$).

equilibrium demand levels, as indicated by a flat projected trajectory for long-run product prices despite increased consumption.

The base case outlook assumes increased U.S. imports of pulp, paper, and paperboard over the next decade, with slower than historical growth in exports, consistent with recent trends. However, the analysis indicates that domestic production will account for the bulk of projected increases in domestic demands, as in past decades. U.S. imports of paper and paperboard surged in recent years, attracted by a strong dollar. Exports declined as a result of the Asian economic decline in 1997 and 1998 and more recently because of the high dollar value. Imports are projected to continue increasing over the next decade (from 17 million tons in 1999 to more than 20 million tons by 2010). In the long run, however, with projected expansion in U.S. softwood pulpwood supplies, annual paper and paperboard exports are projected to increase while imports are projected to decline somewhat in the period after 2010. Paper and paperboard exports are projected to recover from 1999 levels (at less than 10 million tons) and climb gradually over the projection period. Projected annual U.S. trade flows remain small in relation to domestic production and consumption (Fig. 3).

A key assumption about SRWC in the base case outlook is that no productivity or cost saving improvements occur over the projection period. This assumption is probably overly conservative, as the productivity and economic potential of agrifiber crops are likely to improve over time with advances in biotechnology and cultivation techniques, but future assumptions about yield gains for woody crops have not yet been programmed into POLYSYS. Thus, in the base analysis, productivity and costs of woody crops remain constant over the next 30 years in the POLYSYS model (projections extend from 2000 to 2030). The fixed productivity and cost assumptions could be varied in POLYSYS to derive alternative supply and demand scenarios, but the base case outlook assumes conservatively that productivity, crop yields, and costs for SRWC will remain constant at current established crop productivity levels.

Similarly, the analysis of timber supply embedded in the NAPAP model also has a set of fixed forest productivity assumptions, although the analysis does project continuing shifts in forestland area from lower to higher management intensity classes, such as from natural forests to plantations. An important projected shift in U.S. fiber supply and demand is an increase in pulpwood supply from softwood (coniferous tree species) plantations. Southern pine pulpwood supply is projected to become more abundant after 2010 as a result of expanded southern pine forest plantations and shifts to higher intensity timber management regimes. On the other hand, pulpwood supplies from natural hardwoods (deciduous broad-leaved tree species) are projected to be constrained by available forest inventories in the long run. Thus, after continuing to increase over the next decade, hardwood pulpwood supply from forestland is projected to level out after the year 2010.

In this analysis, the NAPAP model incorporates an assumption that hardwood fiber from SRWC such as hybrid poplars or cottonwoods (*Populus* sp.) can be substituted on an equal weight basis for hardwood from natural forests (after adjusting for the typical lower density of poplars). However, the analysis does not assume any cost advantages in the pulping process associated with utilization of hybrid poplars. This assumption may also be regarded as rather conservative given that recent biotechnology research indicates that strains of poplars with lower or modified lignin content may be developed in the

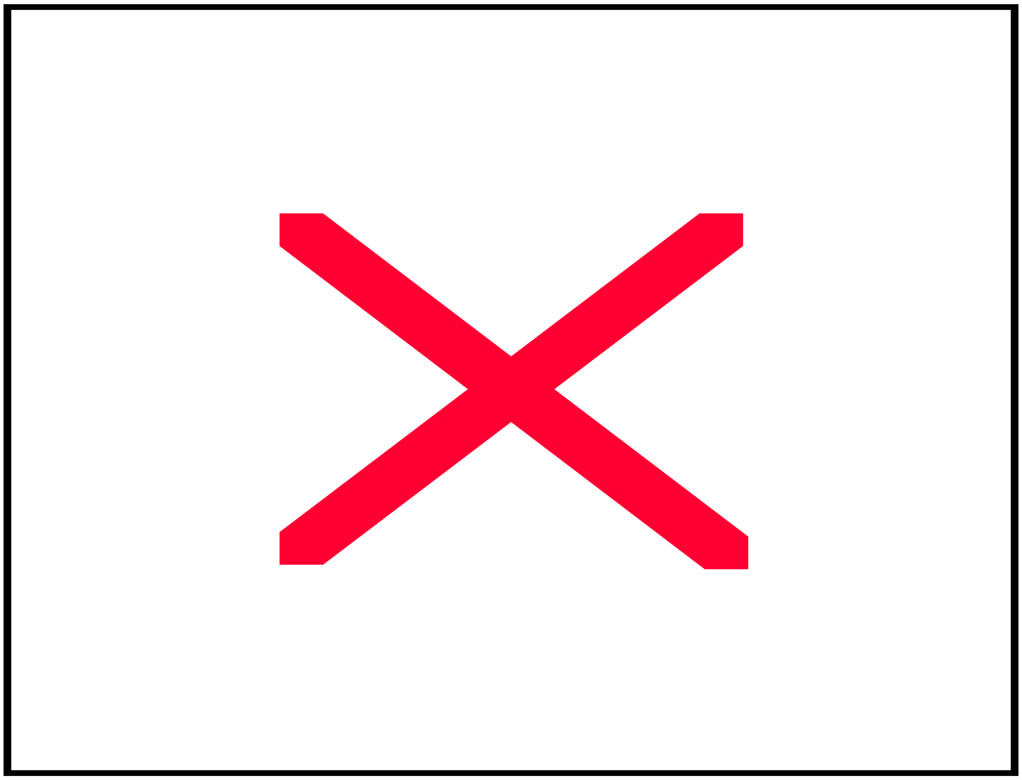

Figure 3. Historical and projected U.S. paper and paperboard production, consumption and trade.

future and could substantially reduce costs of pulping and pulp bleaching. In the future, the NAPAP model could be modified to reflect cost savings associated with the use of modified hybrid poplar crops in alternative scenarios, if such estimates of production cost savings become available.

Conventional sources of hardwood pulpwood supply include pulpwood harvest on forestland and wood residues (chips and slabs primarily from hardwood sawmills). The U.S. hardwood pulpwood market is dominated by hardwood timber supply in the South, the leading region in production and consumption of pulpwood. For example, hardwood pulpwood supply in the eight-state South Central region increased by about six fold over the past 40 years, as the pulp and paper industry expanded in the South and as hardwood pulpwood utilization increased relative to softwoods. In the early 1950s, softwoods accounted for nearly 90% of pulpwood use; today, hardwoods account for nearly 40%. Although hardwood supply and demand have increased, softwoods such as the southern pines still remain dominant in total U.S. pulpwood supply.

Softwoods have been intensively managed in the United States, with pulpwood supplied increasingly from pine plantations in the South. Hardwood forest resources are generally not managed as intensively, and therefore hardwoods on forestland have generally lower productivity than do softwoods. Pine plantations in the South typically have productivity that ranges several times higher than that of natural forest stands (in average volume growth per acre). Hardwood plantations, such as hybrid poplars on agricultural land, also have typically much higher productivity than do natural hardwoods in forest stands, often up to five or six times higher, although higher productivity comes at the expense of higher costs.

Pine plantations on private lands in the South increased by approximately 25 million acres between 1952 and 1997, a more than tenfold increase, displacing hardwoods in many cases. The area of pine plantations in the South is projected to increase by more than 15 million additional acres in the decades ahead. The outlook for pulpwood supply corresponds to the current base case outlook in the Forest Service draft 2000 RPA Timber Assessment, a recently completed Forest Service national study of the overall timber supply and demand situation in the United States (see http://www.fs.fed.us/pnw/sev/rpa/). The Forest Service analysis indicates that the historical and ongoing increase in hardwood pulpwood consumption in the U.S. South cannot be maintained for more than another decade or so, without incurring significant depletion of remaining available hardwood timber inventories on industrial and private forestlands. Thus, the timber supply outlook assumes that hardwood pulpwood harvest on forestland in the South will increase modestly over the next decade but then level out at a plateau beyond 2010. This assumption may be varied in the NAPAP model, with an alternative scenario reflecting the possibility that hardwood pulpwood supply from forestland may gradually recede after reaching projected peak levels in the South around 2010. Potential supply of hardwood fiber from agricultural land will increase if hardwood supply from forestland recedes.

Projected trends in paper recycling also have an influence on projected pulpwood markets. The tonnage of paper and paperboard recovered for recycling has doubled since the mid 1980s, but growth in recycling is slowing down and is projected by the NAPAP model to follow a decelerating trend in the future. The rate of paper recovery for recycling rose dramatically from around 25% in the late 1970s to around 45% in recent years, but the recovery rate appears to be reaching a plateau (Fig. 4). The recovery rate in the base outlook is projected to climb gradually to 50% by 2010 and to around 55% toward the end of the projection period. By adjusting maximum feasible recovery rate assumptions in the NAPAP model, it is possible to construct an alternative future scenario for paper recycling, such as a scenario with lower projected recycling rates. In general, lower projected recycling rates will tend to increase the projected demand for hardwood fiber from agricultural land.

Market Outlook and Alternative Scenarios

The market outlook derived from the NAPAP and POLYSYS models indicates that hardwood pulpwood supply from agricultural SRWC such as hybrid poplars and cottonwood will become marginally economical in the decades ahead. The analysis projects that hardwood pulpwood supply from forestland in the South will reach a peak by around 2010 and then plateau, as hardwood pulpwood harvest on forest industry land recedes over the next decade. However, sustained real price increases for hardwood pulpwood are not projected to occur until approximately 2015 to 2020, when hardwood pulpwood harvest on non-industrial forest land is expected to decline in the South. After 2020, projected real prices for hardwood pulpwood will be sustained at levels sufficient to induce limited expansion of pulpwood supply from agricultural SRWC, but with only modest projected quantities of SRWC supply from agricultural fiber during the decade after 2020.

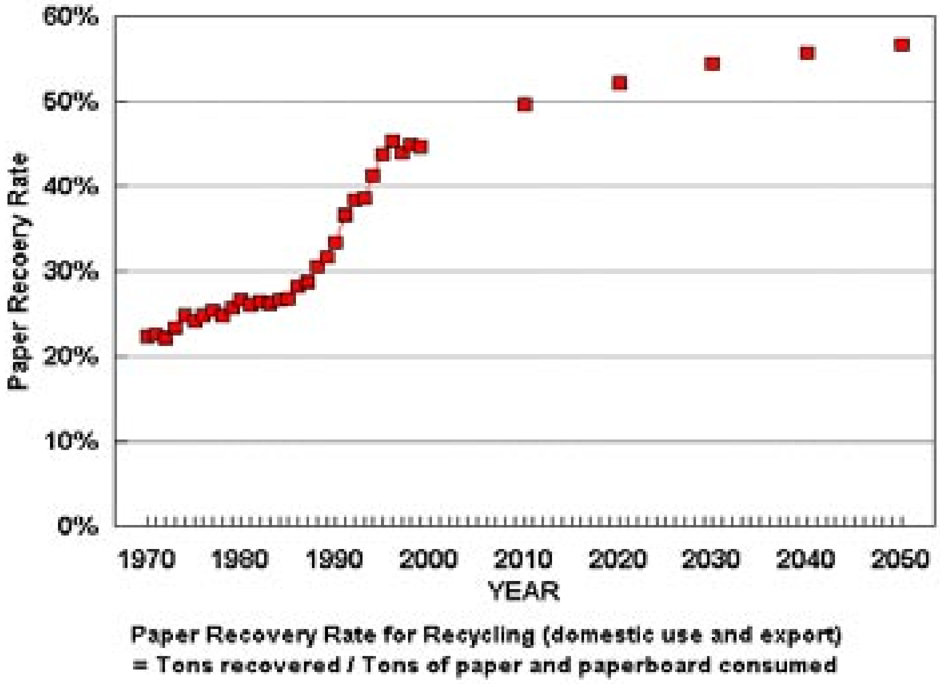

Figure 4. Historical and projected trends in U.S. wastepaper recovery rate.

Two principal alternative market scenarios were explored in this study within the context of assumptions outlined above. One alternative scenario was based on the possibility that hardwood pulpwood supply in the South would not only peak around 2010 but supply may also then recede after 2010. This alternative scenario is called the “low hardwood” (LHW) scenario, referring to lower or reduced hardwood pulpwood supply relative to the base case (in which hardwood pulpwood supply merely plateaus after 2010). The LHW scenario reflects a possibility that increased urbanization coupled with changing forest management practices and shifting forest landowner preferences (voluntary or otherwise) could result in declining Southern hardwood pulpwood harvest after 2010, even though a reduction may appear unlikely or unnecessary to sustain hardwood forest resources in the future. The LHW scenario is obtained by simply imposing more restrictive constraints in the NAPAP model on the projected harvest of hardwood pulpwood from forest industry and non-industrial private forestlands in the South. In the LHW scenario, hardwood pulpwood harvest on forestland in the South increases up to the year 2010, as in the base case, but then recedes to levels just below current harvest levels by 2030.

A second alternative scenario was based on an assumption that future paper recycling rates may be lower than projected in the base case outlook. In this alternative scenario, the rate of paper recovery for recycling gradually increases, but it does not reach 50% by 2010 as projected in the base case outlook. Instead the recovery rate remains below 50% over the projection period (the recovery rate is still projected to increase, but only very modestly in the decades ahead). This alternative scenario is called the “low recycling” (LR) scenario, referring to a lower projected trend in recycling relative to the base outlook. The LR scenario is obtained by imposing more restrictive constraints on maximum feasible recovery rates for various commodity categories of recovered paper supply in the NAPAP model.

In addition, variations of the base case outlook and the alternative scenarios were created by adjusting the real discount rate and the adoption factor assumptions for SRWC in POLYSYS. In the base case, the real discount rate for SRWC in the agricultural sector was set at 6%, while the adoption factor was set at 3% (not more than 3% of cropland area available for crop transfer in any ASD would be planted to SRWC). In general, it was observed that lowering the discount rate or raising the adoption factor tended to increase projected supply of SRWC, as expected. However, raising the adoption factor also tended to introduce market volatility by making the SRWC planting and harvest levels more highly variable over time. The base case, LHW, and LR scenarios, coupled with variations in discount rate and adoption factor assumptions, illustrate a spectrum of results and a range of future market possibilities for SRWC.

RESULTS

The projected cumulative sum of agricultural SRWC harvests for pulpwood under different scenarios over the projection period (from the year 2000 to 2036) is illustrated in Figure 5. The projected sum of SRWC harvest for the base case at 6% discount rate (HWM_DR6) is only about 15 million cubic meters over the entire projection period, a quantity equivalent to less than one-half of 1% of projected total pulpwood consumption in the United States. However, when the discount rate assumption for SRWC was reduced to 3% (leaving the discount rate at 6% for all other agricultural crops), the projected sum of SRWC harvest exceeded 50 million cubic meters over the projection period (HWM_DR3).

Significantly greater supply and harvest of SRWC for pulpwood occurs under the low hardwood (LHW) scenarios, with a cumulative harvest over the projection period of around 100 million cubic meters under the conventional 6% discount rate assumption (LHW_DR6). A cumulative harvest of around 200 million cubic meters occurred with a 3% discount rate (LHW_DR3). A cumulative harvest of 300 million cubic meters occurred with a 3% discount rate and the adoption factor raised from 2% to 5% (LHW_DR3_AF5). Finally, with low hardwood supply and low paper recycling (LHW_DR6_LR), the projected cumulative harvest of SRWC exceeded 800 million cubic meters over the projection period.

Projected annual equilibrium harvest levels for SRWC fluctuate from year to year but generally increase under all scenarios. Figure 6 illustrates projected annual harvest levels for various scenarios, ranging from the base scenario (HWM_DR6) to the scenario with low hardwood supply and low recycling (LHW_DR6_LR). At the highest extreme, the projected annual harvest of SRWC for pulpwood approaches 50 to 60 million cubic meters per year beyond the year 2020, or upwards of 15% of projected annual U.S. pulpwood consumption.

In addition to projected nationwide trends in harvest and supply of agricultural SRWC for pulpwood, the NAPAP/POLYSYS system projects regional supply and demand trends, including projections of SRWC harvest by ASD. For example, Figures 7 and 8 respectively illustrate the projected SRWC harvest by ASD in the year 2025 for the low hardwood scenario (LHW_DR6) and the low hardwood scenario with low recycling (LHW_DR6_LR). In general, in all scenarios, projected SRWC supply and harvest volumes are the greatest in the South, particular in the South Central region (where the largest concentration of pulp and paper industry capacity exists in the United States). In those scenarios where higher levels of SRWC supply and harvest are projected (e.g., LHW_DR6_LR (particularly in the North Central region). In some years, there is some projected supply in the West (exclusively in the Pacific Northwest states of Oregon and Washington), although not as large or consistent as projected supply in the eastern regions of the United States.

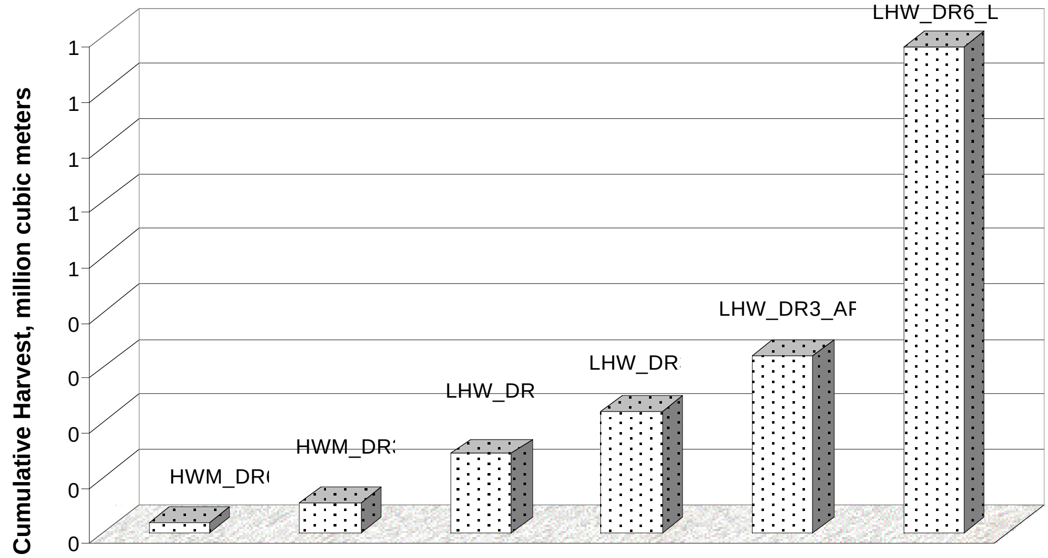

Figure 5. Cumulative projected harvest of agricultural SRWC. HWM = hardwood medium supply; LHW, hardwood low supply; LR, low recycling scenario; DR6 and DR3, 6% and 3%discount rates, respectively; and AF5, adoption factor raised from 2% to 5%.scenario), a considerable volume is also projected in the North

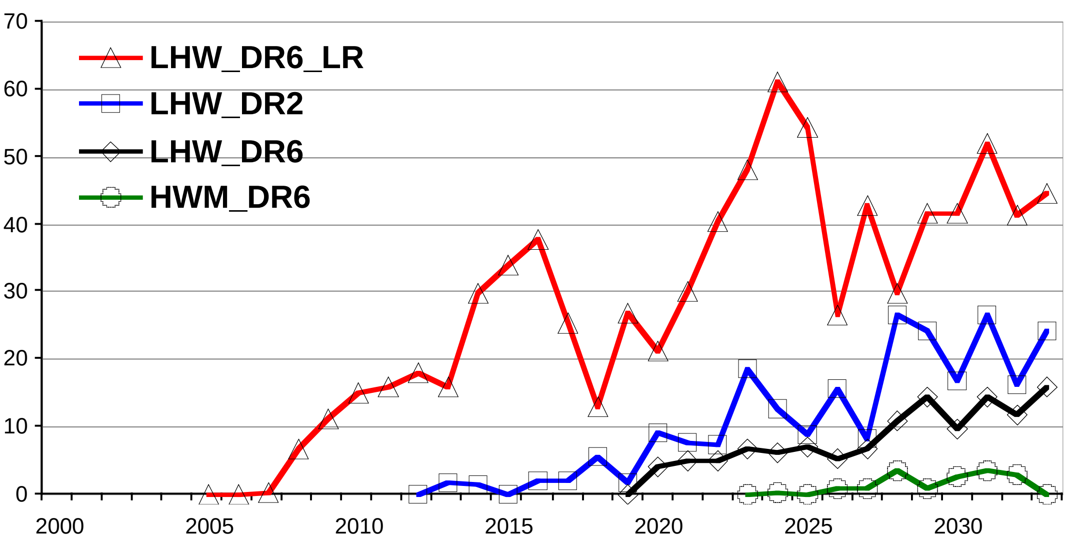

Figure 6. Projected annual harvest of agricultural SRWC.

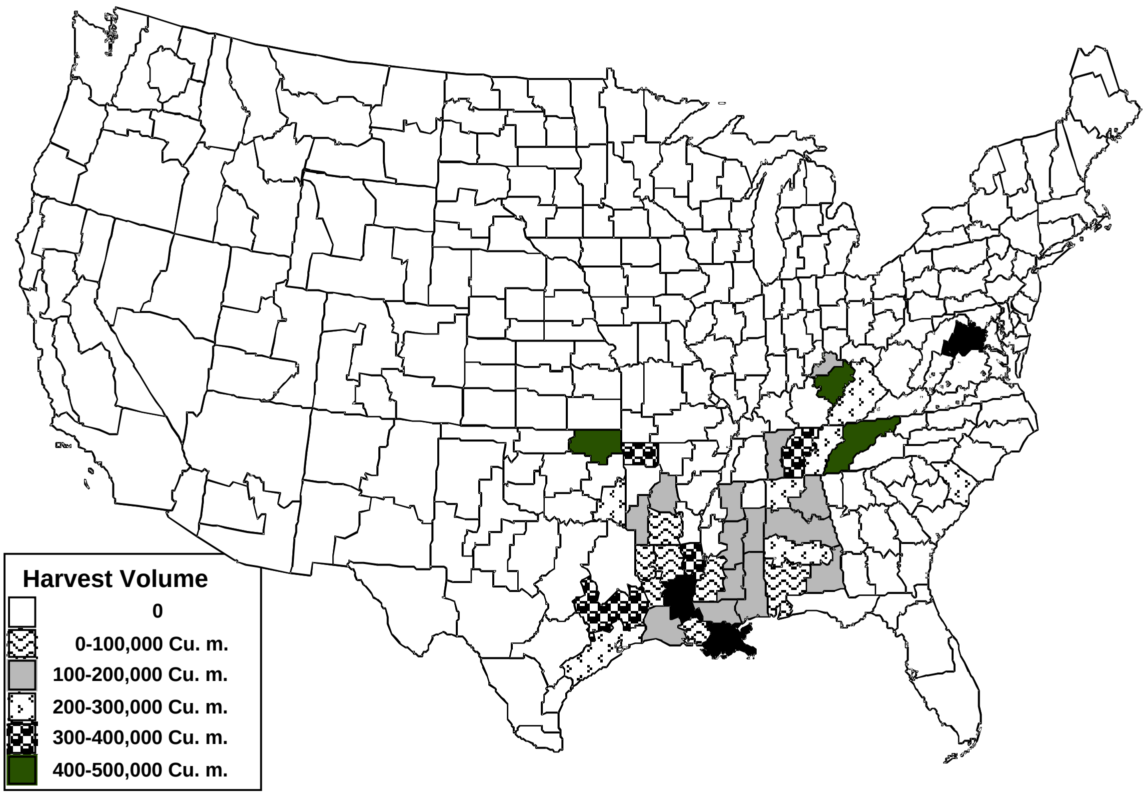

Figure 7. Projected SRWC harvest by Agricultural Statistical District in 2025 for low hardwood scenario (LHW_DR6).

Figure 8. Projected SRWC harvest by Agricultural Statistical District in 2025 for low hardwood scenario with low recycling (LHW_DR6_LR).

CONCLUDING REMARKS

The results of the NAPAP/POLYSYS analysis suggest that pulpwood supply from fast-growing hybrid poplars and cottonwoods will become marginally economical but fairly limited in the next several decades. This supply could become significant under scenarios such as reduced hardwood pulpwood supply from natural forests or more limited future expansion in paper recycling. It is also recognized that woody crops (or other types of crops) may be developed as feedstock for fuels or chemicals. However, at present, the value of whole-tree chip wood fuel in the United States is only approximately half the market value of pulpwood and therefore much less likely to support development of hybrid poplar or cottonwood crops for fuel than for pulpwood. Competitive development of hybrid poplars for fuel or chemical feedstock markets in the United States would require biomass feedstock values several times higher in real prices than current market values for wood biomass fuel.

AUTHOR CONTRIBUTIONS AND ACKNOWLEDGMENTS

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Regional Economic Costs of Short Rotation Woody Crop Production

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ABSTRACT

The motivation for documenting actual full economic costs of production of short rotation and other bioenergy crops comes from the need to understand both regional differences in these costs, and species-specific costs. Differences in costs that are regional come from use of different machinery or production practices inherent in that region. Producers tend to use equipment and practices they are familiar with. Species-specific differences are best illustrated by Swedish double-row spacing used in willow production, compared to single-stemmed hybrid poplar, sweetgum, or sycamore production.

There are many spreadsheet or program-based models in existence. These models use economic assumptions and projections of costs or average costs of production operations. These models are very useful in determining what projected costs of production are across an aggregate of production regions. Actual production costs from working field sites augment data used in these economic models, and contribute to an understanding of why cost projections differ among models.

From a bioenergy crop production perspective, a baseline of production economics data is needed as more land is established in, or converted to bioenergy crops. These raw data seldom exist from private landowner experience. These baseline production numbers will contribute to an understanding of prioritization of research and development with the eventual goal of reducing costs nationally, regionally, and across species.

Finally, actual production economics cost data will be used to provide a basis with which to develop markets for bioenergy and biobased products, and for understanding better the eventual use of these crops in an existing fiber industry.

The Economics of Agroforestry in Saskatchewan

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ABSTRACT

In recent years, prairie farms have been plagued with diminishing commodity prices, increasing instability, and escalating transportation costs. Faced with a series of farm crises, many producers are realising that they must diversify their crop portfolios, as it becomes increasingly difficult to make a profitable living relying solely on the production of traditional crops such as wheat and barley. Agroforestry represents one sector of agricultural diversification that could improve the economic sustainability of prairie agriculture.

Aside from improving the economic sustainability of prairie agriculture, the environmental benefits of agroforestry are also receiving increased attention. At the forefront of the environmental benefits is the practice's potential to sequester carbon, thereby reducing the concentration of carbon dioxide (CO_2 – the most common greenhouse gas) in the atmosphere. This potential has been recognised in the inclusion of some forestry practices in the Kyoto Climate Change Protocol. The purpose of this paper is to broadly discuss the practice of agroforestry, and assess its economic feasibility in Saskatchewan and carbon sequestering potential in the context of Canada's efforts to reduce its greenhouse gas emissions.

Keywords: agroforestry, Saskatchewan, economic feasibility

INTRODUCTION

In recent years, prairie farms have been plagued with dwindling commodity prices, increasing instability, and escalating transportation costs. Faced with a series of farm crises, many producers are finding that they need to diversify their crop portfolios to include more value added products as it becomes increasingly difficult to make a profitable living by relying solely on the production of traditional crops such as wheat and barley. Agroforestry is being recognised as one sector of agricultural diversification that may represent an improvement to the economic sustainability of prairie agriculture.

The environmental benefits of agroforestry are also receiving increased attention. Foremost among these benefits is the potential to sequester carbon in forested soils and plant matter, which would reduce the concentration of carbon dioxide (CO_2 – the most common greenhouse gas) in the atmosphere. This potential was recognised in the inclusion of some forestry practices in the Kyoto Climate Change Protocol. Within the Protocol, the Conference of the Parties "agreed to limit land use change and forestry sectors sink activities to reforestation, afforestation, and deforestation,[1] specifically excluding CO_2 removals in agricultural soils" (Boehm, 1998). Since agricultural soils are not included in Canada's emission reduction accounts, attention has been given to forestry and agroforestry as a means of reducing atmospheric stocks of CO_2 through carbon sequestration. This article will discuss the practice of agroforestry, and assess its

[1] *Reforestation* refers to the planting of trees on denuded forest land; *afforestation* to the planting of trees on agricultural land.

economic feasibility and carbon sequestering potential in the context of Canada's efforts to reduce its greenhouse gas emissions.

What is Agroforestry?

Because of its long and diverse history, its broad range of uses, and its interdisciplinary nature as an emerging science, *agroforestry* is a difficult concept to define. Attempting to moderate between a number of competing definitions, the International Council for Research in Agroforestry defines it as

> a collective name for land use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etcetera) are deliberately used on the same land management unit as agriculture crops and/or animals, either in some form of spatial arrangement or temporal sequence. In agroforestry systems, there are both ecological and economic interactions between the different components. (Gordon *et al.*1997)

Succinctly stated, agroforestry is the practice of keeping or growing trees on farmland for the benefit of the producer or landowner. Essentially, it is the combination of forestry and agricultural practices.

In recent decades, agroforestry has gained the interest of North American researchers and practitioners as an alternative land-use suitable for the temperate region of the United States and Canada. Researchers have found that when used appropriately, agroforestry technologies can:

- provide protection for valuable topsoil, livestock, crops and both aquatic and terrestrial wildlife;
- increase productivity of agricultural and horticultural crops;
- reduce inputs of energy (physical, chemical, or biological) and chemicals;
- increase water-use efficiency of plants and animals
- improve water quality;
- diversify local economies; and
- enhance biodiversity and landscape diversity. (Rietveld and Irwin, 1999)

Due to such environmental factors as climate and precipitation, and such economic restrictions as high transportation costs and small markets, many agroforestry practices are not currently feasible in the Canadian prairies. However, as the need to reduce net greenhouse gas emissions increases in the coming years, formerly unprofitable agroforestry practices may become profitable. To ensure that Canada meets its commitments to emission reductions, and to ensure that producers possess the technology and the know-how to assist in the sequestration of carbon, both the feasibility and the carbon-sequestering potential of agroforestry must be better understood. This article will focus on one specific agroforestry practice, fibre farming, looking at its economic viability and carbon sequestration potential.

Carbon Sequestration and Agroforestry

Although substantial emission reductions must eventually come from the major fossil fuel-burning sectors, forests offer the greatest immediate potential to stabilise CO_2 concentrations, as carbon is stored in the forest soil, the growing tree, and any forest products that are used in long-term residence products, such as buildings.[2] Many countries have already begun to investigate their forest policy and its role in meeting Kyoto emission targets. Canada, for one, expects a large portion of its emission reduction to come from forestry, with perhaps 25 to 40 percent of its Kyoto commitment to come from tree planting (Canadian Forest Service, 1998). Van Kooten (1999) investigated Canada's ability to meet its carbon uptake commitments and found that if tree planting could be extended to marginal agricultural land across Canada, some 70 percent of its commitment could be attained through forest policy.

A tree is a large storehouse for carbon; it converts atmospheric CO_2 into oxygen, which it releases, and carbon, which it turns into wood (close to one half of the dry weight of most wood is made up of carbon). For every tonne of carbon sequestered in wood or forest biomass, 3.667 tonnes of atmospheric CO_2 are removed from the atmosphere (Van Kooten, 1999).

The land upon which a tree grows is also a large carbon sink. Forested land contains 20 to 100 times more carbon per unit area than conventionally tilled agricultural land (Houghton, 1990). Together, this vast potential to remove CO_2 from the atmosphere through tree planting on agricultural land represents a substantial opportunity to counteract global warming.

Canada in particular is in a position to exploit this potential. Studies have shown that between 1.1 and 1.4 million hectares of Canadian land is realistically available for afforestation (Williams and Griss, 1999). The largest portion of this land is in Canada's three prairie provinces, with (according to another estimate) approximately 5.7 million hectares biophysically available for afforestation, although the actual figure is likely substantially lower (Nawitka Renewable Resource Consultants Ltd., 1999).[3] A large-scale afforestation program that would potentially afforest 800,000 hectares annually for ten years would likely offset 29.6 Mt CO_2-equivalent, or 21 percent of Canada's target reduction (Lempriere and Booth 1998).

The storage of carbon in forested land, however, is not permanent. Changes in forest management land use, and climate can quickly reverse the sequestration process (Rolfe, 1998). Deforestation activities, for example, release most of the sequestered carbon, either rapidly through burning, or more slowly through decay (Houghton, 1990). If the end use of harvested wood is fuel, any carbon that has been sequestered will be returned to the atmosphere. If, however, the wood is converted into a durable product such as paper, pulp, fibre, or veneer, no additional carbon is released for the duration of the product's life span. Nevertheless, close to 20 percent of the tree bole becomes waste and is burned during the production of durable wood products (van Kooten, 1999). Forests, thus, can act not only as sinks, but also as sources of carbon, depending on how

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[2] This substitution of tree planting for cleaner-burning and alternative fuels must be seen as a short-term/long-term trade-off. Forested lands cannot continue sequestering carbon indefinitely – soils will begin to approach a new equilibrium after a few decades. The time this finite carbon bank buys must be used to full advantage, so that when the bank begins to fill up (i.e. when forested lands approach a new carbon equilibrium), the technologies and mechanisms are in place to significantly reduce the emissions of larger sectors, such as transportation and energy.

[3] Nawitka acknowledges that this estimate may not be entirely accurate. The figure given consists of land with "good," "medium," and "poor" productivity ratings, suggesting that not all of this land may be suitable for tree growth. As well, the authors list "several key limitations" of the estimate, including "relative lack of public lands in the agricultural part of the prairie provinces that would be suitable for large blocks of afforestation, with the result that an ambitious program would require the participation of thousands of private land owners; uncertainties whether it makes economic sense for an individual land owner to grow trees in place of current crop or livestock land uses; uncertainty about private land owners' interest in establishing and maintaining plantations; presence of saline soils which place some constraints on tree establishment; and a current lack of nursery capacity to mount a massive afforestation program" (1999: 8).

and for what purpose they are managed. Any attempts to calculate (and to encourage) the sequestration of carbon on forested lands must take into account the effects of harvesting the trees, if they are eventually to be harvested.

Other Environmental Benefits of Agroforestry

Essentially, agroforestry can be used to accomplish two primary goals: to improve economic gains, and to improve resource conservation. This latter goal is critical to the agriculture sector since conventional agriculture systems have, over time, led to excessive erosion and subsequent soil deposition, as well as a general degradation of the natural resource base. Agroforestry can protect the quality of the environment by reducing on-site degradation processes, reducing soil erosion, and improving soil structure (Rietveld and Irwin, 1999).

Unfortunately, the economic gains from many of these environmental benefits are often difficult to measure or simply cannot be expressed in monetary terms. "Non-market" benefits are often ignored in decisions of whether or not to introduce agroforestry (Barbier *et al.* 1991). The benefits, however, are substantial. They include the value of forestry conservation for scenery, ecotourism, existence values, landscape amenity, cultural heritage, environmental protection (such as watershed protection and microclimate control), hunting, recreation, and wildlife habitat (Burgess, 1993, Hoen and Solberg, 1995, Koch and Kennedy, 1991, Barbier *et al.* 1991). Additional non-market benefits include reduced soil degradation, reduced summerfallow acreage, and reduced fossil fuel use per unit of output. These substantial benefits must not be overlooked in assessments of agroforestry practices.

Fibre Farming in Focus

In order to assess the potential viability of agroforestry on the prairies, this article will look at one particular agroforestry practices, fibre farming, assessing its current and potential economic viability, as well as its carbon sequestration capabilities.

Fibre farming plantations consist of intensive production systems of fast growing trees on agricultural land to produce chips for pulp and paper or higher value solid wood products. Typically, short-rotation woody crops, such as hybrid poplar (*Populus spp.*) species, are used in fibre plantations. Hybrid poplar plantations closely resemble a forestry crop, but are grown and managed very intensively like an agricultural crop. According to Kuhn and Rietveld (1999), "fast-growth, convenient propagation, and compatibility with conventional farming methods make short-rotation woody crops suitable for use in agroforestry practices to provide multiple benefits such as solid wood and wood fibre products, water quality improvement, crop and soil protection, wildlife habitat, and buffers for agricultural/community interfaces."

Fibre farming in Saskatchewan is not of high priority (Peterson *et al.* 1999). There have been no serious attempts to grow trees as an industrial source primarily because the economic viability of fibre farms is questioned by the degree of competition from natural tree fibre sources. Until native growth tree species such as aspen become more depleted, there will likely be no significant demand for private land wood (Lyle, 1999). However, Bruce Lyle, a woodlot extension specialist at the Farm Woodlot Association of Saskatchewan, estimates that native aspen may become depleted within the next 10 years. If these estimates are correct, the need for afforestation and reforestation activities (such as fibre plantations) is considerable, and immediate action is necessary in order to meet it adequately. The need for fibre farm plantations will be further amplified should the Kyoto Protocol become ratified and Canada begin to implement strategies to reduce greenhouse gas emissions.

Some research has been done into the relative ability of different tree species to sequester carbon, since the rate of accumulation will largely determine the viability of carbon-sequestering fibre plantations. Kort and Turnock (1997) predicted carbon contents after a 40-year period for several shelterbelt species, and found that hybrid poplars (trees that are typically grown in fibre plantations) have the largest carbon accumulation. This occurs primarily because of their fast growth rates, resulting in larger biomass stocks after 40 years of growth.

Economic Model

Conceptual Framework

The economic feasibility of an agroforestry rotation in Saskatchewan is investigated using the Farming Systems Model (FSM). Two scientists at the University of Saskatchewan, Ken Belcher and Marie Boehm, designed the FSM. This model is a dynamic model that incorporates both environmental and economic components of a farming system.

Within the FSM, three rotations are studied: an annual rotation (a six year zero-till rotation of spring wheat, barley, oats, canola, flax, and peas), a forage rotation (a 15 year rotation in which brome and crusted wheat grass are grown for the purposes of backgrounding livestock), and an agroforestry rotation (a 16 year hybrid poplar plantation).

The FSM utilises a fixed proportions framework to model all economic decisions. Land is allocated to each rotation based on a profit maximisation condition. In any given year, the rotation with the greatest net hectare revenues will be allocated land that is available (that is, land that is in transition between rotations).

A more detailed description of the model can be reviewed in Lindenbach (2000), Belcher (1999), and Belcher and Boehm (1999). The remainder of this section will focus on the empirical analysis specific to the agroforestry rotation in the FSM.

Empirical Framework

The economic component of the FSM is comprised of output and input relationships. The nature of revenues and costs for the agroforestry rotation are reported as an annual net present value (NPV). In reality, the majority of costs associated with an agroforestry rotation are incurred long before any revenues are realised. However, to make the rotation competitive with the annual and forage rotations, an annual NPV is applied. Within this calculation, a discount rate of 6 percent and an inflation rate of 2 percent are used. In the past, there has been a lot of debate over chosen discount rates. The results presented in this paper will differ under different discount rates.

Output

Output, calculated as the hectare revenue from each rotation, was determined using:

1. A rotation length of 16 years;
2. An average yield of 8 dry tonnes per hectare per year. The study assumes that this yield captures all site characteristics, growing conditions, and proper management regimes;
3. An average mortality rate of 4 percent; and
4. A price of $37.00 per cubic metre, or $33.37 per tonne. [4]

Given these assumptions, total hectare revenue for the agroforestry rotation translates to $256.44 per year.

Input

Inputs include land, fertiliser, transportation, and an "other" category. The cost of land in the initial year is $69.00 per hectare (a land investment cost reported by Saskatchewan Agriculture and Food for the black soil zone). After this initial year, a market-clearing price for land is calculated for each subsequent year using the derived demand for land for each rotation. The market-clearing price for land is determined by the quantity of non-land inputs demanded and the quantity of output produced by the fixed proportions assumption (Lindenbach, 2000; Belcher, 1999).

The cost of fertiliser was determined using BIOCOST (Walsh, 1996). Fertiliser is applied at a rate of 0.1 tonnes per hectare every second year (to account to a delayed nutrient uptake), beginning in year 5 after the tree canopy has widened, and ending in year 13. The NPV of this input is $11.56 per hectare per year.

Transportation costs involve transporting harvested wood to a pulp and paper mill located north of the study area. Using an average trucking radius of 100 kilometres, the NPV of this input is $24.03 per hectare per year.

The "other" input category includes all other inputs not explicitly included in land, fertiliser, and transportation inputs. These inputs include labour, maintenance, buildings, depreciation, risk, fuel, management skills, etceteras. The cost for this category is calculated using the supply curve for "other" inputs, which is an upward sloping curve, and generates producer surplus for this input. For the agroforestry rotation, it was assumed that this input category must include, at the minimum, establishment (year 1), maintenance (years 2, 3, and 4), and harvesting costs (year 16). The NPV of this input is $189.00 per hectare per year. Because this supply curve is upward sloping the cost of this input will increase as more land is moved into the rotation.

Simulation Scenario: The Introduction of a CO_2 Payment

An important simulation scenario incorporated into the FSM takes into account Canada's actions to meet their commitment to the Kyoto Protocol. As trees are large

[4] The price of the fibre (sold for the purpose of pulp and paper manufacturing) is assumed to be Weyerhaeuser's (an international forest company with one location situated in northern Saskatchewan) average cost of obtaining wood from crown lands.

storehouses of carbon, this scenario assumes that producers will receive another component of revenue aside from fibre revenue for their carbon sequestering activities.

To calculate this additional component of revenue, 80 percent of dry tree biomass is converted to a CO_2-equivalent using conversion factors from Peterson *et al* (1999). It was assumed that 20 percent would be lost during processing. Once the amount of sequestered CO_2 is calculated, it is then multiplied by the NPV of the CO_2 payment. Three CO_2 payment levels were modelled in this study: \$10.00, \$15.00, and \$20.00 per tonne of CO_2 sequestered.

An additional modification to the FSM in this scenario is a harvesting penalty. At the time of harvest, sequestration ceases. However, it is not known with certainty how long the atmospheric CO_2 will remain sequestered in the cut wood, as there are a number of factors that will affect the duration of sequestration. Therefore, a harvesting penalty of 50 percent of the total CO_2 payment made to producers is assumed.

DISCUSSION

The findings presented in this article state that in the absence of a CO_2 payment or subsidy for the landowner, fibre farming is not currently economically feasible. Essentially the costs associated with the agroforestry rotation are too high, particularly the "other" input costs. However, the fact that agroforestry as a cropping rotation is potentially feasible with the introduction of a CO_2 payment carries significant implications for future climate change policy. Essentially, trees could be used as a relatively inexpensive CO_2-mitigating instrument. There is an opportunity to establish a market for CO_2 in which businesses that need to reduce their CO_2 emissions could purchase emission credits from landowners employing carbon-sequestering practices such as zero-tillage and agroforestry. Furthermore, Recommendation 2 of the Agriculture Table's *Options Report* states that governments should provide public incentives for the adoption of greenhouse gas-reducing technologies and practices, particularly the provision of some kind of economic incentive to entice adoption and acceptance of climate-friendly practices. These public incentives would have to stay in place until such time as markets for emission reductions can be established in the agricultural sector. The technical report to the *Options Paper* and the findings presented in this article both suggest that policy makers interested in encouraging agroforestry and reducing greenhouse gas emissions face somewhat of a paradox: fibre farming is not currently economically feasible making large-scale adoption of agroforestry extremely costly and difficult to encourage at this time. At the same time, because of the significant time delay between the planting of the trees and the large-scale sequestration of carbon (which only begins to occur once the trees have matured a number of years), a failure to adopt fibre farming or other agroforestry practices in the very near future will mean that the agricultural sector will be simply incapable of sequestering much carbon when it is most likely to be needed – during the 2008-2012 Kyoto accounting period. Steps must be taken very soon if agroforestry can be expected to contribute to Canada's climate change policy.

Currently, agroforestry *is* expected to play a major role in Canada's climate change policy. As already mentioned, the Canadian Forest Service (1998) expects perhaps 25 to 40 percent of Canada's Kyoto commitment to come from tree planting – a figure that becomes increasingly unlikely as time passes. If these trees are not planted soon, agroforestry will simply cease to be a substantial option in Canada's Kyoto strategy. Thus, any new policy measures that encourage landowners to plant trees are urgently needed.

Policy Recommendations

The viability and carbon-sequestering potential of agroforestry in Canada have not been adequately researched, crippling the sector's ability to take advantage of the anticipated demand for carbon credits. There have been no attempts to grow trees on agricultural land at a large scale, and few attempts to increase the viability of such an undertaking. Because of this knowledge gap, the primary recommendation of this chapter is that further research be conducted into the future use of agroforestry. Specifically,

1. Further research must be initiated investigating the inclusion of other forms of agroforestry, such as alley cropping, riparian buffer strips, and Christmas tree plantations. In addition, the economic feasibility of integrating various combinations of agroforestry practices with one another should also be studied.
2. Further investigation should be carried out comparing the effects of introducing small-scale versus large-scale agroforestry plantations in terms of consumer demand and industry development in Saskatchewan.
3. The value of non-market benefits of agroforestry (particularly in relation to climate change policy) has not been extensively researched. The inclusion of the positive externalities of environmental benefits in economic analyses may indeed offset some of the market costs. However, the primary reason that non-market benefits are typically excluded from economic analyses is the lack of information related to the monetary values of these benefits. With no monetary values, the precise outcome of including non-market values such as carbon sequestration, soil conservation, and habitat protection is therefore unknown. Further research is needed to refine the value of these benefits so that they may be incorporated into future agroforestry research.

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Poplar Silviculture: Converting from Pulp Logs to Saw Logs

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ABSTRACT

Responding to increased environmental regulation and declining public timber supply, Potlatch began farming short rotation hybrid poplar in 1993. Over the last seven years, 17,200 acres (7,000 hectares) of plantations were established, focusing on the production of pulp logs. In 1998 Potlatch began to examine the use of poplar in higher value solid wood products. We have identified opportunities to market poplar for use in plywood, furniture stock, molding, and other non-structural applications. Realization of these opportunities presented silvicultural challenges that have not been applied extensively to poplar in North America.

Potlatch is converting the farm to saw log production, emphasizing thinning in the dense plantations, branch pruning to maximize clear lumber recovery, and longer rotations to increase tree size. Future development will be planted at wider spacing (3.1 by 4.6 meters) and managed for longer rotations (10-11 years).

This paper presents conversion activities and early results of tree performance in response to thinning and pruning. Management practices for saw log production are also described.

Keywords: hybrid poplar, thinning, pruning, saw logs.

INTRODUCTION

Potlatch Corporation acquired two contiguous center-pivot irrigated farms totaling 22,000 acres (9,000 ha) near Boardman, Oregon for intensive farming of hybrid poplar. A declining supply of economically available residual chips motivated Potlatch to aggressively develop hybrid poplar to augment its fiber supply. Some 17,200 acres (7,000 ha) of plantations were developed to help meet the chip fiber requirements of Potlatch's Lewiston, Idaho pulp mill. These plantations were densely planted and managed for a six to seven year pulp rotation. As the early plantations approached harvest age it was apparent that the anticipated regional shortfall in fiber was not materializing. This created an opportunity for Potlatch to examine the use of hybrid poplar in higher value solid wood products.

Over the last two years extensive mill trials have been done with several processors throughout the Pacific Northwest. The trials and processor response have indicated a great potential for using hybrid poplar in plywood, furniture stock, molding, and other non-structural applications. One concern among the processors was the small piece size and lower grade of the pulp logs used in the mill trials. After an extensive analysis of the opportunity to grow high quality saw logs on the Boardman farm, a business plan was developed and received Board of Directors approval in 2000. This paper discusses the silvicultural challenges in converting the farm to saw log production, including thinning in the dense plantations, branch pruning to maximize clear lumber recovery, and lengthening the rotation to increase tree size.

Transition to Saw Log Production

Market Influence

Supply

The Potlatch Hybrid Poplar Program was started in 1993 in a period of increased environmental regulation and declining public timber supply. Planners had evidence of a shortage of pulp fiber beginning in the late 1990's and continuing to the foreseen future. However, three factors combined to actually increase the availability of fiber on the market and reduce the need for the hybrid poplar chip fiber. First, the high price of logs made it financially attractive for smaller landowners to harvest their timberlands. The increased saw log volume placed additional residual fiber on the market. Secondly, the increased regulation and declining public timber supply caused a contraction in the industry and several mills closed further adding to the available fiber. Finally, the fiber market is now a global enterprise and supply from international sources are now influencing the North American markets.

Economics

In the current market environment, supply exceeds demand and the price for chips has actually declined over the last few years. While this is beneficial for the industry as a whole, it lowers the economic viability of fiber farming. When considering the farm's costs of production, the current market price exceeds our costs of production and makes farming for pulp chips unattractive. However, through our mill trials and marketing activities, higher value uses of hybrid poplar have been identified in solid wood products. This opportunity would not have presented itself had the market for pulp chips been strong.

Thinning

The objective of the thinning program was to release the dense pulp plantations to allow the trees to grow larger over a longer rotation. The process included an evaluation of the current growing stock and a prioritization of the varieties and age classes to thin. Some of the varieties planted were not suitable for longer rotations due to various types of environmental and pest damage. Others had poor form for a saw log product. Ultimately, the thinning was concentrated in the varieties that would maintain their productivity over the longer rotation, had good straight form, and were young enough to respond adequately before they were to be harvested.

The residual spacing varied among the thinning age. The growing conditions at the Boardman farm include periodic high winds. Further, drip irrigation confines the root system to a shallow volume of soil. Blow-down, resulting from opening a dense plantation too quickly, was a concern. Thinning was done on 9,000 acres (3,600 ha) of two- to four-year-old plantations. The three- and four-year-old plantations were thinned by 33%, removing every third tree down the row. The two-year-olds were thinned by 50%, removing every other tree down the row. In both cases the removed trees were staggered in adjacent rows to open the residual trees on as many sides as possible.

The four-year-old trees were thinned with a tree shear mounted on a skid steer loader. This required removal of the drip irrigation hose prior to thinning. The shear cut the trees on each adjacent row and placed them in the center of the tree row as it worked in reverse down the quarter mile long rows. The loader was highly maneuverable, was able to cut flush with the ground line, and resulted in very little damage to the leave trees. Approximately 1,700 acres were thinned in this age class.

The two- and three-year-old trees were chainsaw thinned with the sawyers leaving a low stump, but avoiding the drip irrigation hose. The sawyers worked in two man crews with one chainsaw operator and one person placing the cut trees between adjacent tree rows. Approximately 2,500 acres of three-year-olds and 5,000 acres of two-year-olds were thinned.

Initially, a trial was done on the four-year-old trees to determine the economics of removing the thinned material for pulp chips. The trial indicated negative returns for the operation and the decision was made to chip the downed trees in place. This was accomplished by moving a Morbark chipper with an in feed attachment through the tree blocks. The same process was followed in the three-year-old trees also. The two-year-old trees were small enough to chip with a Meri-Crusher attachment mounted on a farm tractor.

Pruning

The series of mill trials conducted over the last year have reconfirmed the premium value of clear, knot free wood. Branch pruning is one of the key requirements to reduce defect and maximize the production of clear wood. Last winter several pruning trials were installed to focus on the costs of this activity and their affects on tree growth. The trials included hand pruning, use of hydraulic shears, a gas powered mechanical pruner, and a wagon designed to get workers higher off the ground. Observations from these trials have developed into a best management scenario for operational pruning. This will include hand pruning done from the ground in a series of three annual lifts.

Pruning will begin after the trees have completed their third growing season. The first lift will be done with hand lopping shears. The second and third lifts will be done with pole saws. Branch sprouts will likely develop in response to the pruning and increased light on the stems, and they will be removed soon after emergence. Increased monitoring and control activities of insects attracted to the pruning scars are anticipated, and trials to refine products and rates for control are being investigated.

Growth Response to Silvicultural Treatments

Thinning

Thinning trials were installed across the farm in the winter of 1999-2000. The purpose of the trials is to evaluate the growth response to the various thinning intensities across different hybrid varieties. Preliminary results indicate all tree varieties responded to thinning and the greater thinning intensities resulted in greater response. Table One shows the one-year diameter growth response to thinning in a P. deltoides x P. nigra (DxN) variety thinned at age four. The 50% thinning level resulted in a 74% increase in diameter growth the year following thinning, and the 33% thinning level resulted in a 32% increase in diameter growth.

Table 1. One-year diameter growth following thinning at age four.

Thinning Level	Diameter Growth (cm)	% Increase Over Control
Control	1.9	
33%	2.5	32
50%	3.3	74

Height growth in the thinned trees followed a predictable response. Height growth was reduced in the thinned trees as they allocated more resources to diameter growth in their new wider spaced growing environment. The non-thinned control plots continued to put on height growth as a strategy to get their crowns into the sunlight. Table Two shows the one-year height growth response following thinning in a DxN variety thinned at age four.

Table 2. One-year height growth following thinning at age four.

Thinning Level	Height Growth (meters)
Control	3.0
33%	2.0
50%	2.1

One observation worth noting was the lack of a delay in thinning response. Typically, a thinning shock is observed in conifer species grown in a natural forest setting. This generally occurs for a period after thinning as the residual trees expand their root systems into the space vacated by the trees removed. Further, a period of crown leaf area accumulation occurs on the leave trees adding to the response delay. These physiological responses are the mechanism for the tree to eventually accelerate diameter growth. It’s possible that in an irrigated and fertigated system, where the tree is given all the resources needed for growth, that a delayed thinning response does not occur to the extent found in natural forest settings. The trees simply do not need to grow more roots when all the resources are readily available.

Pruning

In addition to the thinning trials, several pruning trials were installed to look at various intensities and schedules of pruning. The objectives of these trials were to determine the maximum amount of branches that could be removed without negatively impacting tree growth. When pruning, the defect core is recommended to remain less than four inches (10 cm) in diameter. In the Boardman growing environment this requires pruning to begin at age 2-3. Table three shows the diameter growth response of two-year-old trees the year following a six-foot (2 m) pruning lift.

Table 3. One-year diameter growth following pruning at age two.

Hybrid Pedigree	Pruning Lift (meters)	Diameter Growth (cm)
TxD	Control	4.3
TxD	2	4.2
DxN	Control	5.5
DxN	2	4.8

As table three shows there was a slight decrease in diameter growth when a six-foot (2 m) lift was done on the two-year-old trees. While the slight growth loss is acceptable when trying to maintain the small defect core, moderate stem breakage was observed in the thinned plots. The trees were unbalanced with a heavy canopy above and when high winds occurred, stem breakage was observed at the base of the live crown. The breakage was greater in the P. trichocarpa x P. deltoides (TxD) variety. These observations have led to a recommendation to avoid pruning to six feet after the second growing season, and a delay in the start of pruning to age three.

To help guide the pruning activities after the trees are three-years-old, trials were installed to look at six-foot (2 m) and 15-foot lifts (4.5 m). When compared to the non-pruned control plots, no loss of diameter growth occurred with the six-foot lift. However, severe growth loss occurred with the 15-foot lift. Table Four shows these results for a TxD and DxN variety.

Table 4. One-year diameter growth following pruning at age three.

Hybrid Pedigree	Pruning Lift (meters)	Diameter Growth (cm)
TxD	Control	4.3
TxD	2	4.1
TxD	4.5	3.0
DxN	Control	4.2
DxN	2	4.1
DxN	4.5	2.8

The trees in the 15-foot lift (4.5 m) were over-pruned. At this young age a large number of live branches are removed in a 15-foot lift. The result was reduced photosynthetic capacity and decreased growth in the year following the pruning. Excessive tree lean was also observed in this treatment. These results also indicate no negative affects from a six-foot lift at age three.

Pruning trials were also installed in the four-year-old trees. Again the objective was to determine the safe level of pruning where no loss of growth occurred from removing the crown. Table five shows the results from a DxN variety lifted to 15-feet (4.5 m) in comparison to a non-pruned control. No decrease in growth was observed in the 15-foot lift. The branches removed at this age were mostly declining in vigor, as the tree was in the process of naturally pruning it’s lower branches.

Table 5. One-year diameter growth following pruning at age four.

Pruning Lift (m)	Diameter Growth (cm)
Control	3.3
4.5	3.5

Future Saw Log Management Program

Pruning

Trial results have provided a framework for operational pruning. The current program will include three annual lifts to a height of 24 feet (7 m). Pruning activities will begin at age three with a lift to six-feet, followed by a lift to 15 feet (4.5 m) at the end of the fourth year. The final lift to 24 feet (7 m) will be made after the fifth growing season. Epicormic branches will be removed in a single operation done annually if necessary. Crews will use hand tools for all of the pruning activities until an acceptable mechanical pruner can be developed. Pruning quality is excellent when done by hand and the cost is in line with expectations. Crews have a diameter limit in each age class where trees below the limit are not pruned. They also omit trees with damage or poor form. All branch material will be left on the ground and allowed to decompose. Following a catch up year in 2000-2001 in which all of the thinned acres will move into the program, approximately 1600 acres will be pruned each year in each of the three age classes. All pruning will be done in the dormant season.

Further research may modify the current operational program. One adjustment may be to begin pruning at age two with a three-foot lift. This will remove the larger branches on the lower stem when they are still small enough to be easily cut with lopping shears. The larger branches seem to slow down the crews and removal at age two is unlikely to dramatically increase the cost of pruning. Further, trials to determine the best season to prune are underway. Several rows of trees will be pruned monthly to determine the number of epicormic branches and the activity of insects that may be attracted to the pruning scars. This will be done on two hybrid varieties.

Tree Spacing and Rotation Length

The farm configuration for drip irrigation sets the row spacing at ten feet. Irrigation risers from the underground submain system are fixed at ten-foot intervals. Rather than modifying the risers to place the new rotation on a square spacing, trees will be planted at a 15-foot spacing down the tree row. The planting layout across the field will be in a diamond pattern, attempting to open the tree on all four sides. The 150 square feet of growing space per tree will optimize the volume per acre with a 10-11 year rotation. While individual tree size may be slightly compromised at this spacing, volume will be maximized. If the market favors larger trees we will modify the planting spacing in the future.

The Potlatch farm operates under an agricultural exemption from the State of Oregon. To be considered agriculture, and not forestry, the plantations are required to be harvested in less than 12 years. The benefits of the agricultural exemption far out-weigh those of being able to extend the rotation. The 10-11 year rotation provides some flexibility if market conditions warrant a delay in harvest for one year. Under this scenario, all trees will be harvested during their eleventh year and will be a minimum of ten-years-old.

Variety Selection

Moving to a saw log product changes the variety selection and deployment strategy. As the Potlatch HPP has developed, selection strategies concentrated on the stem biomass, pulp yield, and environmental suitability of the varieties chosen for operational use. To date, less importance has been placed upon stem form, branch size and number; and wood quality associated with solid wood use. The current list of operational clones has been refined to include those that will produce the best saw logs. Selection protocols for the many varieties in various stages of testing will be modified to emphasize traits consistent with solid wood products. Future breeding work will concentrate on selecting parents with good form and branch characteristics and access of breeding materials from European cooperators that have proven to produce offspring with good solid wood characteristics.

SUMMARY AND CONCLUSIONS

Potlatch is transitioning the fiber farm to produce high quality saw logs. Poor market conditions for pulp logs and a recognition that hybrid poplar can be used in higher value solid wood products motivated the change in focus. Through extensive mill trials, potential markets for the wood have been identified in furniture stock, molding, plywood core, and other non-structural materials.

As part of the conversion process the younger plantations on the farm have been thinned to promote the growth of larger trees. First year results from the thinning trials have demonstrated a growth response from thinning. All future plantings will be at a wider spacing and allowed to grow for a longer rotation. Growth and yield projections for the wider spaced plantations indicate that a 10-11 year rotation for saw logs is feasible. In addition, Potlatch has 4,000 acres (1,600 ha) of center pivot farmland remaining to convert to hybrid poplar. Management strategies for these acres are currently being evaluated.

An integral part of the saw log management regime will be branch pruning to optimize the quantity of knot-free clear wood. Pruning research trials over the last year have identified the best management program for this activity, and have indicated the threshold where excessive pruning results in growth loss. Application of the operational pruning program is continually updated and improved.

Finally, the market has identified a premium for certified wood for processing. Potlatch is investigating Forest Stewardship Council certification for the Boardman poplar farm. Certification looks promising given the environmentally friendly and sustainable production aspects of the operation.

Minnesota Wood Energy Scale-Up Project: Hybrid Poplar Research on CRP Lands an RC&D Project Providing Multiple Benefits to the State of Minnesota

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ABSTRACT

The year 2000 marks the seventh year of research being conducted on privately owned Conservation Reserve Program (CRP) plantings of hybrid poplar near Alexandria, MN. These plantations cover approximately 1,800 acres and are located within fifty miles of the city of Alexandria in West Central Minnesota. The "Minnesota Wood Energy Scale-up Project" is unique in many ways. Data are being collected on larger-scale farmer-owned sites rather than normal small study research plots. These larger sites provide an excellent opportunity to compare seventeen variations of soils, clones, topography, and management.

Through this project economic data is being collected from planting to harvest that will be useful to the wide and varied farming operations found in West Central Minnesota. Although no trees have been harvested in the project, many benefits have already been received. This project is being conducted in cooperation with a Resource Conservation and Development (RC&D) Council. Through this organization many benefits have been received since the formation of the Wood Energy Scale-up Project.

Keywords: Minnesota Wood Energy Scale-up Project, Minnesota Agro-Forestry Cooperative (MAFC), economic development, renewable energy, hybrid poplar

INTRODUCTION

The Wood Energy Scale-Up Project

The Minnesota Wood Energy Scale-up Project is a cooperative project between the Bioenergy Feedstock Development Program at Oak Ridge National Laboratory with the Department of Energy, WesMin RC&D Council, the Minnesota Department of Natural Resources-Forestry, the USDA Forest Service, private landowners, and numerous other partners. Beginning in 1993, hybrid poplars were planted on approximately 1,800 acres of privately owned Conservation Reserve Program (CRP) land within a fifty-mile radius of Alexandria, MN. The CRP Program offered a five-year extension for producers to plant trees and extend their CRP contract for five years beyond their original contract. Data is being collected on these trees each year including the maintenance, weed control, and pest control costs and amounts. On each plantation there are yield plots set up that are measured yearly for dbh (diameter at breast height) and height to be used for determining yearly growth and wood production.

This Project provides many opportunities to the participants, especially the farmers. They receive cost share for maintenance and pest control, expert technical forestry assistance, constant checks by qualified individuals, and economic benefit. Many studies are being conducted in conjunction with the Project that will yield valuable data to current and future growers of hybrid poplar. Currently clone trials and fertilizer studies are taking place in the Project.

Minnesota Focus—Current Events Affecting Hybrid Poplar

Not only do those immediately involved with the project benefit, but also the entire state of Minnesota has benefited from the growing of hybrid poplar that first started with the Wood Energy Scale-up Project. In Minnesota there are many changes occurring in forestry, energy, and farming. Landowners continue to plant hybrid poplar in an effort to position themselves to take advantage of a shortage of pulp, fiber, and energy in the next seven to ten years.

Northern States Power (NSP), a large power company in Minnesota, has been mandated to use renewable sources of energy as part of an agreement that they may store nuclear waste in Minnesota from their Prairie Island Nuclear facility. The mandate requires that 125 megawatts of energy from biomass be produced in Minnesota (825 megawatts of wind energy must also be produced over the next twelve years). The Renewable Development Fund (RDF) has also been created by NSP. For each cask of nuclear waste stored in Minnesota NSP must designate $500,000 per year towards developing renewable energy. In 1999, $4,500,000 was designated as part of the Renewable Development Fund. For year 2000 it is estimated that there will be $6,000,000 designated. It has been estimated by a member of the Renewable Development Fund Group that the request for proposals to use this money and the guidelines will be in place sometime after January 1, 2001. This mandate opens new doors for hybrid poplar growers as it assures them of a market. Although the renewable resources agreement is still in its beginning stages, we see great potential in the future for projects using hybrid poplar biomass for energy.

According the Minnesota Department of Commerce, as stated in their recent public meetings entitled “Keeping the Lights On”, Minnesota faces a possible shortfall of energy in 7 to 8 years, estimated at 5,000 Mega Watts. With the energy shortage, the RDF emphasis on biomass energy, and the public distaste for large coal and nuclear plants, Minnesota landowners have a tremendous opportunity to grow hybrid poplars for energy. In addition, a whole tree burning plant is being proposed in Southern Minnesota.

Another use for hybrid poplar in Minnesota is for pulp and paper. Currently, the mills are using native aspen stands to meet the demands for these products. Hybrid poplar fibers are very similar to those of aspen. Therefore, hybrid poplar can be used in place of aspen for most of these products. In Minnesota, there is also an age class imbalance in the aspen stands that will soon be realized starting in approximately the year 2014 (Streed et al. 2000). Aspen in Minnesota will either be too old and not suitable quality for harvest or too young to harvest. Therefore the paper companies in Minnesota have been looking for alternatives, and hybrid poplar fits the bill. The prices for native aspen have risen sharply in the last few years. Mark Downing, Agriculturist Economist with DOE, and Center for Natural Resource and Agriculture Management (CINRAM) has used $30/cord stumpage price as an average anticipated price for hybrid poplar in their economic studies. However, recently a sale was made in Mille Lac’s County in September of 2000 at $60.00/cord stumpage according to a MN Department of Natural Resources Forester. The maximum distance a harvester will travel to cut aspen used to be considered about 100 miles from a mill, but recently sales have occurred at distances of up to 480 miles. Since hybrid poplar can replace aspen, it is possible to assume that the prices for hybrid poplar will also increase. This creates economic opportunity for farmers in Minnesota.

There are also many current events in Minnesota that have created a climate for change from normal annual crops of wheat, corn, soybeans, etc. Commodity prices are low, floods have plagued areas, and the farm economy is depressed. Growing hybrid poplar on agricultural lands provides farmers with an alternative agricultural crop. Also not considered in economic formulas is the anticipated increased stumpage price due to ease of access and year round harvesting opportunities. Mills short on summer wood supply may pay a premium price for hybrid poplar. Trees growing on cropland in rows will be easier to obtain.

Minnesota Agro-Forestry Cooperative (MAFC)

The State of Minnesota has demonstrated its support for alternative farming (growing hybrid poplar) by providing financial assistance to the Minnesota Agro-Forestry Cooperative (MAFC) in the legislature this year (2000).

The state legislature provided $200,000 grant money (to be matched 1:1) and $200,000 loan fund money for a cooperative to develop a hybrid poplar program. The MAFC has about thirty-five members across the state that formed their group in 1995 to collectively promote and facilitate the production and marketing of hybrid poplar in Minnesota. The MAFC has created economic development throughout the state. More acres of hybrid poplar are being established across the state. The MAFC is also looking at even higher economic returns for landowners by recapturing some of the costs associated with harvesting and transportation to market (i.e. difference between stumpage price and gate price). WesMin RC&D has been incubating the MAFC, largely due to public interest and expertise gained from the Wood Energy Scale-up Project. The MAFC has created a public need for technical assistance, research, funding, and support.

Public Inforamtion and Education

WesMin RC&D and the MAFC have already hosted many hybrid poplar workshops throughout the state for farmers, landowners, and others interested in growing hybrid poplar. They have mailed many packets of information on hybrid poplars to interested persons in the state. The MAFC also sets up booths at local events including county fairs, alternative agriculture workshops, etc. They have brochures on their program to hand out at all events and they spend considerable time talking to others interested in growing hybrid poplar. The MAFC spent a considerable amount of time at the capitol lobbying for funding; they educated many political leaders about the advantages to the farmer and to the State for growing hybrid poplar. In 1999, presentations were made to over 2,000 persons in Minnesota regarding economic opportunities for growing hybrid poplar.

This project has also gained international notoriety. Public and private enterprises in the Alexandria area hosted two foresters from the Indian Council of Forestry Research and Education in Dehra Dun, India in March 1999. The foresters traveled around the Alexandria area and viewed International Paper and the Wood Energy Scale-up Project plantations. These Indian Foresters came here to learn about our methods of forestry with short rotation woody crops (SRWC). Also, the Poplar Council of the US (with members from the US and Canada) held its 1999 annual meeting here in Minnesota. A consultant from Canada came to visit with the staff at WesMin RC&D and International Paper this fall to discuss hybrid poplar and the program we have here. The Wood Energy Scale-up Project has become more than a research study, it has become an educational tool and means to provide the public with information on hybrid poplar.

Each year staff from WesMin RC&D, the MN Department of Natural Resources-Forestry, USDA Forest Service and other agencies and organizations staff a booth at Farmfest, a large farm show held yearly in Redwood County, Minnesota. At the site there is about _ acre of different hybrid poplar clones established by WesMin RC&D and the MN Department of Natural Resources for the public to view. This summer the University of Minnesota Extension Service created and filled a new position in Staples, MN for a forester to work specifically with agroforestry. In August 2000, the new University of Minnesota Extension Service Agroforestry Specialist, Mike Demchik, and WesMin RC&D sponsored an Agroforestry Bus Tour of the Alexandria area. International Paper also participated in the tour as well as hybrid poplar growers who are not in the Minnesota Wood Energy Scale-up Project. This tour gave about forty professionals from around the state the opportunity to see different projects and the impact hybrid poplar has in our area.

Another way that the public is informed about hybrid poplars is through newspaper articles that have been published. Recently, there have been two articles written in Agri-news, a broadly circulated farm magazine. After an Agroforestry bus tour of the Alexandria area the article *Trees seen as income-producing alternative* (Gunderson, 2000) was published. Another news article, *Poplars may grow among corn, bean fields* (Gunderson, 2000) was written about a landowner, Dennis Gibson, in Chippewa County who grows hybrid poplars for timberbelt windbreaks, also a WesMin RC&D Project.

Dennis' farm was the site of another tour held in August 1999. This tour demonstrated the use of hybrid poplars for crop windbreaks. Many agencies and organizations were brought together to sponsor this tour. The speakers at the tour included Dennis Gibson, landowner; Erik Streed, Center for Integrated Natural Resources and Agriculture Management (CINRAM); Steve Vongroven, RC&D/DNR Forester; and John Felton, Centrol Crop Consultant. Attendees traveled around Dennis' farm on a trailer pulled by a tractor to view the timberbelts, a living snow fence, and many other projects. WesMin RC&D, Prairie County RC&D, Willmar, MN, and the Chippewa Soil and Water Conservation District (SWCD) sponsored the tour. This Timberbelt Project continues to be at the forefront of hybrid poplar activities in Minnesota. The trees are measured yearly and data is being compiled on crop production adjacent to the timberbelt.

Other Economic Development That Has Occurred

Even though no trees have been harvested yet, there has already been economic benefit to the Alexandria Area. In January of 1999, a Biomass Technical Roundtable with over fifty attendees was held at the Holiday Inn in Alexandria. This brought in a vast amount of business to the Alexandria area for the hotels, restaurants, and shops. A subcontractors meeting, held in October 1999 for those involved with biomass and the Department of Energy, also brought business to the surrounding lakes area of Alexandria.

In August of 1999, the Poplar Council of the United States held its annual meeting in Alexandria and participated in a tour sponsored by WesMin RC&D and International Paper (formerly Champion International). On the same day a tour of the Herman Rosholt Farm in Pope County was held. These preceding conferences and tours have put Alexandria on the map for hybrid poplar and have brought in money for local business in town.

Renewable Energy

The public outreach and education initiatives through tours, Farmfest, conferences, and visits with people from other countries are only part of the benefit from the hybrid poplar programs. Hybrid poplar can also be part of the solution to Minnesota's energy crunch.

Northern States Power has been mandated to use renewable energy in exchange for storing its nuclear waste in Minnesota. Hybrid poplar can be used as a whole tree fuel for renewable energy. A whole tree burning plant by Energy Performance System/Beck Power has been proposed for the St. Peter area in Southern Minnesota. The tops and branches of the poplars, which are not used for paper (assuming paper and pulp are the highest bidders), could provide energy for Minnesota residents by burning in small-scale wood energy plants. Minnesota, at the legislative level, is considering deregulation of energy. This would provide opportunities for the hybrid poplar grower and smaller energy plants, to negotiate with large power companies for power contracts. Political groups have been formed to discuss and gain support for renewable energy issues. Most environmental groups like renewable energy; most citizens in Minnesota do not want a new coal plant in their backyard. We have already created several jobs and other economic benefits in the area because of the interest in hybrid poplar.

Currently, in the Alexandria area the highest end use for hybrid poplar (where the grower receives the best economic return) seems to be for pulp and paper. In Minnesota there are many large industries; International Paper, Potlatch, Boise Cascade, Truss Joint McMillen. Again, even though we have not harvested the hybrid poplar, the Minnesota Wood Energy Scale-up Project became a catalyst for several jobs in the Alexandria area. International Paper built an office building near Alexandria and has purchased and planted about 9,500 acres to date. They have plans to plant up to 25,000 acres in the next few years. They have also set up a nursery stool bed and building near Rose City, Minnesota. Since the beginning of the Project a Department of Natural Resources Forester in Alexandria has since moved to a new position with International Paper as the Hybrid Poplar Project Manager. A former employee of WesMin RC&D has moved to a new position at International Paper. A total of four full-time positions were created at International Paper, plus there are several planting crews and others hired to plant and maintain their trees. WesMin RC&D, through this Project, have hired a part-time staff person. Other jobs have been created; planting crews are needed each spring to get the sticks in the ground, aerial sprayers have begun to spray poplar, etc. It is estimated that ten full-time jobs have been created in the Alexandria area related to the planting, maintaining, and growing of hybrid poplar.

Research

Hybrid poplar projects have created jobs, enhanced economic choices, created pulp and paper alternatives to native aspen, offered renewable energy choices, informed the public about the trees, and provided opportunity for research to be conducted on these trees. Many organizations and agencies are involved in improving hybrid poplar. The following list includes some of the partners. University of Minnesota Extension at Staples, CINRAM, Iowa State University, USDA Forest Service, International Paper, Natural Resources Research Institute, Bioenergy Feedstock Development Program with the DOE, Minnesota Hybrid Poplar Research Cooperative, and landowners. Research projects are currently being conducted on fertilizer methods and types, clones and their survival, growth on different soils, and economic cost analysis. These research results are available to the farmers and other people interested in growing hybrid poplar. The research done for the Wood Energy Scale-up Project benefits the landowner too. They receive cost share for tree planting, insect and disease control, maintenance, etc. In addition, all the citizens in Minnesota and throughout the world can use the information gathered in the Project. The Project has several diverse partners, many of whom are with agencies and therefore pose no bias in the data collection. The research component of the Wood Energy Scale-up Project is a great benefit to Minnesota.

RC&D Perspective

WesMin RC&D has seen the Minnesota Wood Energy Scale-up Project bring many partners together to provide energy and pulp/paper for the future using a renewable resource. RC&D's work on creating partnerships, educating the public, coordinating efforts, and sustaining our natural resources. This Project is an outstanding example of how RC&D's can be involved in coordinating the many new directions that hybrid poplar has taken in Minnesota. This Project has created many new opportunities for people, for industry, for farmers, for researchers, and for the future.

ACKNOWLEDGEMENTS

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Delimbing Hybrid Poplar Prior to Processing with a Flail/Chipper

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ABSTRACT

We compared the performance of a flail/chipper for processing a) whole poplar trees and b) poplar trees that had been roughly delimbed with a pull-through delimber. Production rate was about 10% higher for the delimbed trees. The reduced cost of flail/chipping would not cover the additional cost of delimbing with the machine mix tested, but changes to equipment might improve the situation. In the test configuration, the delimber processed 175 trees per productive hour, about half as many as the single delimber/debarker/chipper (DDC). Delimbing separated about 16 dry kg of limbs per tree, which may have higher value than the mixture of limb and bark residues produced by the flail from whole trees.

Keywords: Short-rotation forestry, delimbing, debarking, chipping.

INTRODUCTION

Several paper companies in the Pacific Northwest are growing hybrid poplar in plantations on short rotations (less than 10 years) to supply some of their fiber needs. In the normal harvest sequence, these trees are mechanically felled and bunched, then forwarded to a landing with either a large front-end log loader or a grapple skidder. At the landing, the trees are delimbed and debarked with a chain flail processor, then chipped with a disc chipper. In most cases, the flail and chipper are combined into a single delimber/debarker/chipper (DDC).

Numerous studies have investigated the production rates of flails and/or the quality of the chips produced, including bark content (Araki, 1994; Creelman, 1992; Franklin, 1992; Stokes et al. 1989). One of the limitations to a chain flail's productivity is the volume of residues (limbs, leaves and bark) that must be separated from the bole wood and handled, especially during the summer months when fresh foliage is present. The residue takes up space in the flail's in-feed and thus reduces capacity. In DDCs, the residue frequently bridges over the waste discharge chute, slowing production, reducing chip quality and occasionally requiring that the machine be shut down and cleaned out.

The waste stream from the flail is of low value; it may be utilized for fuel or compost, or if the value is too low it is piled and burned on site. If limbs can be separated from the bark portion of the residues, they may be suitable for a higher value use such as feedstock for the neutral sulfite semi-chemical (NSSC) pulping process that furnishes pulp for corrugated cardboard.

Given the possible increase in value if the limbs can be separated, and the potential to increase flail/chipper productivity if the trees are delimbed prior to flailing, we decided to investigate alternatives to separate the activities. The possibilities included single-grip processors, irongate delimbers, and pull-through delimbers, among others. A pull-through delimber was selected for this study because it was inexpensive and an excavator was available to feed it. Irongates are also inexpensive, but must be fed by skidders, rather than by the front-end loaders that have been found to be effective for forwarding short-rotation trees (Spinelli and Hartsough, submitted).

The objectives of this study were to:

1) Determine the productivity of a pull-through delimber for removing limbs from six-year-old hybrid cottonwood trees.
2) Determine the effects of delimbing prior to flail debarking on:
   A) flail delimber/debarker/chipper productivity,
   B) costs of delimbing, debarking and chipping,
   C) chip quality, and
   D) recovery of clean chips, limb material and other residues.

The study was conducted at Boise Cascade Corporation's Sand Lake Fiber Farm near Boardman, Oregon, during 13-17 September 1999. Trees were felled seven to nine days before they were processed, to promote partial drying and dropping of the foliage. On 13 and 16 September, a Peterson Pacific DDC 5000 processed whole trees. On the 15th and 17th, it processed delimbed trees.

A Danzco PT20H pull-through delimber was placed in the precut unit, about a hundred meters from the road. A Volvo BM L150C front-end loader delivered bunches of whole trees to the delimber, moved delimbed trees to the DDC or to a storage deck, and cleared limbs from in front of the delimber. A Link Belt 2700 excavator with log grapple picked up the whole trees and pulled them through the delimber. Delimbing productivity was only about half of that of the DDC, so the excavator and delimber ran the whole week to prepare enough trees for the two days of DDC processing tests.

The Volvo loader was capable of keeping both the DDC and the delimber supplied with trees. A Cat 966D front-end loader equipped with a Shamrock slash grapple moved residues from the DDC's bark discharge, chipper reject, and infeed areas, and piled them for processing or burning at a later date.

An experienced and capable operator ran the DDC with similar settings on all days (with one exception, noted later). Only two of three flails were run: the bottom drum and the front top drum. Both were set at the minimum speeds (approximately 80% of max speed). The operator used the same speed on the delimber feed roller and the chipper feed roller throughout the test. He changed chipper knives at the end of each day (or earlier if they became dull), and honed them halfway through the shift. Every day, all chains on the upper drum and half of those on the lower drum were changed.

Study Approach

Delimbing Productivity and Quality

We used time-motion study to evaluate delimbing productivity and quality. We divided the delimbing cycle per grapple load of trees into the following elements:

pick up trees and place them in the delimber
limb (pulling through the delimber)
deck stems after they have cleared the delimber
move the loader when it is not carrying stems
pile residue
other productive time.

We also recorded delays by type, trees per cycle by DBH (eyeball estimates), and eyeball estimates of the percentages of limbs removed. For the latter, we recorded classes of removal: 1 = 0-20% removal, 2 = 21-40%, 3 = 41-60% 4 = 61-80%, 5 = 81=100%.

DDC Productivity and Chip Quality

We recorded chipping and other productive times per van, delay times by type, number of stems per van, and number of DDC grapple loads per van. Net green weight per load was taken from load tickets. A chip sampling tube was fabricated out of PVC pipe and elbows. Samples were collected from each van load by placing the tube under the chipper's discharge spout for a fraction of a second at four or five times throughout the chipping of the load. All the sample chips (about 5 kg) from a load were placed in a bucket, which was topped and then rolled to mix the chips. Two sub samples of approximately 800 g each were taken from the bucket and analyzed for moisture content, bark content and size distribution.

Recovery of Clean Chips, Limbs and Other Residues

We collected material removed by the delimber by having the Volvo operator set aside most of the residues from eight batches of counted stems. The numbers of stems per batch ranged from 76 to 166. (The residues on the output side of the delimber were not collected; they represented about 10 percent of the total delimber residues.) The residues from each batch were loaded into a trailer or dump truck, and weighed on a truck scale. For each batch, we then calculated the delimber residue weight (green) per tree.

For three van loads of whole trees and four loads of delimbed trees, the bark discharge material and the chipper rejects were separated and set aside. These were hauled by dump truck to the scale and weighed. From the tree counts for each van load, we calculated the following weights per tree: chips into the van, bark discharge, and chipper rejects.

RESULTS AND DISCUSSION

The study observations are summarized in Table 1.

Table 1. Summary of study time and production.

	Delimbing	Debarking/Chipping of Delimbed Trees	Delimbing/Debarking /Chipping of Whole Trees
Total Study Time, hrs	19.9	18.0	19.8
Productive Time, hrs	16.6	14.7	16.0
Trees/PMH	175	382	318
Van loads produced		28	28
Chipping ODT/PMH		26.1	23.7

Delimbing Production Rate

The Link Belt operator spent two-thirds of the total productive time in two activities: picking trees out of the pile of whole trees, and pulling them through the delimber arms (Table 2). The operator delimbed between one and five trees per cycle,

Table 2. Danzco delimber productivity statistics
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Variable	Mean	Std. Dev.	Range	n
Trees	3.50	0.84	1-5	826
DBH, cm	16.5	2.2	11-28	826
BA, cm^2	742	168	181-1320	826
Removal class	3.54	0.81	1-5	821
Cycle elements, cmin/grapple load				
Pick	38.5	17.4	0-141	826
Limb	37.3	17.6	12-171	826
Deck	22.5	8.0	0-57	826
Move	17.9	5.7	0-46	826
Other	2.0	17.3	0-802	826

averaging 3.5. This contrasts with the case where trees are being processed for sawlogs, where generally only one tree is processed at a time.

On average, the Link Belt/Danzco combination delimbed 175 trees per productive hour. The regression relationships developed from the data are displayed in Table 3. With the exception of pick ($p = 0.015$), all the relationships were highly significant ($p < 0.01$), but they only explained small fractions of the variation in the data. On average, fewer trees were delimbed with each pull if the trees were larger in diameter. The time to pick up stems increased with the number of trees grappled, as did the time to deck delimbed stems. Most of the decking time involved moving the tops of the trees laterally, away from the line of the delimber. It appeared to be a motion that could be avoided by clearing the delimbed stems more frequently or by adding an angled ramp that would cause the tops to slide laterally. Delimbing took longer if more basal area was processed at the same time, and if the removal quality was higher.

Because the excavator's reach was limited, it had to travel about ten meters each way on each delimbing cycle to index the butts of the trees to a common point, determined by the length of the tallest trees. Travel by the crawler undercarriage is considerably slower than swinging, so a longer boom would be preferable.

Delimbing Quality

On average, delimbing removed approximately 60-70 percent of the limbs, based on our visual estimates. Removal percentage was highly variable and decreased slightly as total basal area per grapple load increased (Table 3).

Several factors limited the delimbing quality. Handling multiple stems simultaneously obviously prevents the delimbing knives from fully removing branches between the stems, but three other aspects also contributed to the problem. The loader grappled stems two to four feet above the butts to prevent them from slipping out of the grapple. The delimber knives were another four feet or so beyond where the grapple could place the trees in the delimber. As a result the delimber could not remove the limbs on the lowest six to eight feet of each stem. The trees from the edge of the plantation, especially, had many low branches. Many of these limbs were dead and brittle, however, so they probably contributed little to the flail's burden.

Table 3. Regression relationships for pull-through delimbing.

Variable	Relationship	R^2	n
Trees per cycle	7.0 – 0.21 * DBH	0.30	826
Removal class	3.91 – 0.00085 * Basal area	0.03	821
Cycle elements, cmin/grapple load			
Pick	32.3 + 1.76 * Trees per cycle	0.01	826
Limb	28.8 + 0.0036 * Removal class * Basal area	0.02	821
Deck	16.7 + 1.66 * Trees per cycle	0.03	826
Move	17.9	(s = 5.7)	826
Other	2.0	(s = 17.3)	826

Where: Trees per cycle = trees per grapple load
Removal class = delimbing removal class (1 to 5)
Basal area = total basal area of the trees in the grapple load, cm^2
DBH = mean diameter at breast height of the trees in the grapple load, cm

Single tops of many trees were too light to hold the delimber's activating treadle down, so the knives opened prematurely, resulting in poor delimbing of these tops. Tree malformations – crooks, forks and the occasional heavy limb – could not be pulled through the knives. The Link Belt operator had to lift the stems off the treadle to open the knives, pull the bad portion through, set the stems down again and continue pulling. But there was a delay between setting the stems down and full closure of the knives, so the sections just beyond the crook or fork were not delimbed either.

DDC Production Rate

Statistics for the DDC are shown in Table 4. The independent variables for the whole tree and delimbed cases were very close on average; bone dry content averaged 54.1 percent for both, and chip weight per tree averaged 75 and 72 dry kg for whole and delimbed trees, respectively, giving a fair comparison of chipping rates.

The production rate (ODT/chipping hour) for delimbed stems was eight percent higher than that for whole trees, and the difference was significant ($p = 0.02$). The DDC operator fed 13% more delimbed trees than whole trees with each grapple load, and this difference was also significant ($p = 0.02$). It appeared, however, that feeding of the delimbed stems was less uniform than for whole trees. This was caused by a) the difficulties with handling stems that were broken during delimbing and subsequent decking, and b) extra handling to pull in stems whose butts were not indexed with the others. We noticed both of these problems on the first day of chipping the delimbed stems, but they diminished on the second day. The Link Belt operator did a better job of indexing the stems as the trial progressed, and the Volvo operator stacked the delimbed trees in decks of less height, which seemed to reduce breakage.

Chipping rate increased with average tree size, calculated from the load weight and tree count for each load. The rate decreased throughout the day, probably due to operator fatigue and dulling of chipper knives. We developed a regression relationship that reflected the effects of time of day, type of tree and tree size. All terms were highly significant ($p < 0.01$).

Table 4. Peterson-Pacific DDC 5000 productivity statistics.

Variable	Mean	Std. Dev.	Range	n
Chip, cmin/load				
Whole tree	3251.	340.	2674-4123	28
Delimbed	3047.	428.	2378-4082	28
Switch vans, cmin/load	99.	63.	0-267	56
Other productive delays, cmin/load	34.	102.	0-662	56
Move between landings, min/move	45.	-	-	1
Trees per load				
Whole tree	181	22	134-226	27
Delimbed	189	18	161-235	28
Load weight, oven dry tons				
Whole tree	13.5	1.0	12.0-15.4	28
Delimbed	13.6	1.2	12.2-16.7	28
Grapples per load				
Whole tree	65.4	6.8	53-78	14
Delimbed	62.9	9.7	47-80	17
Trees per grapple				
Whole tree	2.66	0.39	1.97-3.23	14
Delimbed	3.10	0.44	2.27-3.87	17
Production, ODT/chipping hr				
Whole tree	25.3	2.7	19.2-30.7	28
Delimbed	27.3	3.5	19.4-34.0	28

$$\text{Chipping rate} = 15.1 - 0.57^{*}\text{Hours} + 2.3^{*}\text{Delimb} + 0.162^{*}\text{Chip weight per tree}$$
$$R^2 = 0.31 \qquad n = 55$$

where: Chipping rate = oven dry tons produced per chipping hour
Hours = chipping hours, at the start of the load, since the beginning of the shift
Delimb = a dummy variable with value of 1 for delimbed trees, 0 for whole trees
Chip weight per tree = oven dry kg of chips per tree.

As noted earlier, trees were cut a week or more before processing to allow the foliage to dry. If the trees were pre-delimbed, the drying period would not be necessary. Bark is considered easier to remove on fresh trees because the wood-bark bond is weaker (Duchesne and Nylander, 1996; Kubler, 1990), so fresh trees could probably be processed at a faster rate.

Chip Quality

Fewer of the chips from delimbed trees were classified as acceptable by size: on average, 56% for delimbed trees versus 59% for whole trees ($p < 0.01$, $n = 109$). The additional non-acceptable chips showed up as more oversize (12% vs. 10%), overthick (15% vs. 14%) and overlength chips (2.4% vs. 1.7%). This might be due to the additional breakage of delimbed trees. There was essentially no difference in pins or fines contents. Bark contents averaged 2.6% for both delimbed and whole trees, so the higher production rate for delimbed trees did not come at the expense of an increase in bark.

Delimber and DDC Residues

The average weights per tree for each of the three whole tree loads and four delimbed loads for which residues were weighed are tabulated in Table 5.

Delimber residues, adjusted upwards by 10 percent to account for the uncollected residues on the output end of the delimber, averaged 15.9 green kg per tree. Delimbing prior to flailing reduced bark discharge residues by approximately half. Other than the obvious differences in the amounts of bark discharge and delimber residues, the average values for whole trees and delimbed trees were not significantly different, but the number of observations was small.

The pull-through delimber may remove some whitewood that the flail would not, lowering the recovery of high quality chips. It is not clear if pre-delimbing caused any loss; some wood was obviously broken off at the delimber, but the flail might also have removed much of this if the stems had not been delimbed. The Volvo operator noticed more breakage due to multiple handling of the delimbed stems, but he delivered all of the broken pieces to the flail.

Assuming the average tree size was the same for both operations, the difference in chip weight per tree would represent the delimbing losses. For all 56 observed loads, the chip weight per tree was three OD kg less for the delimbed trees, representing four percent of the average chip weight, but this difference was not significant.

Table 5. Green weight per tree, kg, based on one observation for each of the seven van loads for which residues were weighed.

Material	Whole trees	Delimbed trees
Chips	131	131
Residues		
Bark discharge	41	18
Chipper rejects	4	5
Delimber residues (adjusted)		16
Total residues	45	38
Total	176	170
# of observations	3	4

Economics

An economic comparison of the delimbed and whole tree cases was run for a typical tree size: 18 cm DBH, 74 OD kg of chips, and 9 OD kg of limbs recovered at the delimber). Two scenarios were included for the delimber, one with the observed excavator and production rate, and a second with a larger excavator and twice the observed production rate (Table 6). Hourly costs were calculated with the machine rate approach (Miyata, 1980), based on year 2000 purchase prices for current equipment models. The hourly costs of the Volvo and Cat loaders were included with those of the DDC, as the DDC limits these loaders' production rates. The calculated DDC production rates per chipping hour were reduced by the observed five percent productive delays such as changing vans. A balanced system with the small excavator would include two delimbers with one DDC, whereas only one delimber would be needed if using the larger excavator.

Table 6. Costs for delimbing prior to processing versus processing whole trees.

	Whole Tree	Delimbed – observed	Delimbed – w/large excavator
Purchase prices, $1000			
Danzco PTH		27	27
Link Belt 2700		160	
Link Belt 3400			220
Peterson Pacific DDC 5000	610	610	610
Volvo L150	270	270	270
Cat 966	240	240	240
$/PMH			
Delimb		79	95
Process with DDC	429	429	429
Productivity, ODT/PMH			
Delimb		12.2	24.3
Process with DDC	23.5	25.7	25.7
Cost, $/ODT of chips			
Delimb		6.5	4.0
Process with DDC	18.3	16.7	16.7
Total	18.3	23.2	20.7

Pre-delimbing increases the productivity of the DDC and therefore reduces the DDC cost per ton. The cost of pre-delimbing, however, is more than the savings for the DDC. Revenues must be considered as well, since net profit equals revenues minus costs. There are two possible differences in revenues. The increased DDC productivity would result in more revenue if the payment per ton and productive hours per year were both fixed. For the large industrial producers in the Pacific Northwest, however, it is more likely that the trees to be harvested each year would be fixed, so there would be no difference in revenue for chips. But if the separated limbs are of higher value, more revenue will be produced. The breakeven differential value for the limbs can be found from:

Differential = (TCD – TCWT) / (Limb Weight/Chip Weight)

where: Differential = breakeven increase in value for limbs, $/ODT of limbs
TCD = total cost of delimbing and DDC processing, $/ODT of chips
TCWT = total cost of DDC processing of whole trees, $/ODT of chips
Limb Weight/Chip Weight = ratio of recoverable limb weight to chip weight

For the observed loader and delimber, the breakeven differential is about $40/ODT of limbs. For the larger loader and higher productivity, the breakeven would only be about $20/ODT of limbs.

Recommendations

The Danzco delimber appeared to slab off portions of stems that were even mildly crooked, and broke some bigger tops if the grip was too tight and/or a big limb caused the delimber to rear up. After some initial tests, the operator reduced the pressure setting on the delimber’s hydraulic accumulator in order to reduce breakage, but some still occurred. A more stable base on the Danzco – an extended leg on the outfeed end or a weight on the infeed end – would help prevent the rearing motion and breakage.

In addition or alternatively, a remote override control of the delimber knives would help prevent slabbing and breakage, allow delimbing of light tops and improve delimbing beyond a fork or large branch. A top impactor such as on the old John Deere 743 harvester could knock off tops at a preset diameter, e.g. 5 cm, further reducing the “waste” material in the bark discharge and shifting the tops to the recoverable limb category.

The Link Belt operator felt that a larger excavator (22t instead of 15t) would probably double delimbing productivity because the longer reach would eliminate the crawler travel on each cycle, and the increased slewing torque would allow more trees to be processed with each swing. A telescopic extension might also help to rapidly index the butts of the delimbed trees.

The decking motion could be eliminated by using a ramp so the tops would slide laterally away from the delimber, or if the tops were removed by an impactor on the delimber.

It might be possible to place a pull-through delimber directly in front of the DDC and feed both with the DDC’s loader. It seems most efficient to couple the two activities in some fashion to eliminate the multiple pieces of equipment and the extra handling.

CONCLUSIONS

A grapple-equipped excavator and pull-through delimber processed multiple stems simultaneously, averaging 3.5 stems per pull in the trial. The delimber removed about two-thirds of the limbs from the hybrid cottonwoods, and these limbs would be available for a higher-valued market such as low-grade pulp. Productivity of the delimber was about half of that of the DDC, but the observed excavatorr was too small for the task. A larger machine might bring productivity up to near that of the DDC.

The DDC processed the delimbed trees 8% faster than whole trees, and might be able to increase that rate if trees were processed fresh and/or if the feed speed was increased. There were no significant differences in the amount of clean chips recovered per tree, but the accepts fraction was lower for the delimbed trees. This might be related to breakage during delimbing and related handling.

The projected costs of delimbing more than offset the savings in DDC costs, even if the delimber’s productivity was doubled by using a larger excavator with the delimber. The combination might be economical if a) the value differential for recovered limbs was high enough and/or b) the delimber could be integrated into the flail/chipper so that the separate feed loader could be eliminated.

ACKNOWLEDGEMENTS

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Planting and Harvesting Willows: A New York State Experience

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ABSTRACT

The Salix Project has planted more than 300 acres of willows in New York State using two types of planters. The Frobbesta planter plants a double row of 10-inch cuttings. The Step Planter plants two double rows of 7.5-inch cuttings that are cut from 4 to 6 foot whips at time of planting. Although, the Step Planter is much more efficient and economical there are conditions in which Frobbesta planter works well, particularly in small plots. A GPS with data acquisition has been used to collect planting data on the planters.

The Bender Harvester has been selected because of its portability and lower capital cost. The Bender will go into field trials in NYS in 2000 & 2001. A data acquisition system is being developed to record position, weight of harvested product and fuel usage.

Herbicide Screening Trial for Willow Biomass Crops: Applied at Pre-Emergence and Post-Emergence

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ABSTRACT

Control of weeds in the first growing season is essential for the successful establishment of woody biomass plantations. Currently, few herbicides are available due to labeling restrictions and broad phytotoxic susceptibility of willows and poplars. Two studies were conducted to explore the phytotoxic effects of six different pre-emergent herbicide treatments, (using both labeled and unlabeled herbicides) to find more viable weed control options. Currently, oxyfluorfen (Goal 2XL) is our standard pre-emergent herbicide used in biomass plantations and served as a reference to evaluate the other herbicide treatments.

In the first study twelve herbicide treatments, consisting of six different herbicides and two controls, were applied to one poplar and seven willow cultivars directly after planting in the spring of 1999. Percent covers of non-crop vegetation, phytotoxicity, survival, number of stems and wood production were measured. Azafenidin (Milestone 4 oz/acre), diuron and pendimethalin (Karmex, Prowl) mix, imazaquin (Scepter 70DG 2 oz/acre) and the imazaquin and pendimethalin mix were comparable in terms of wood production of oxyfluorfen. The ineffectiveness of weed control for diuron and imazaquin (1 oz/acre) and the phytotoxic damage of the sulfometuron (Oust), sulfometuron and azafenidin mix and azafenidin (8 oz/acre) led to reduced wood production.
The second study used the same research design, at the same field site with a subset of the herbicide treatments and was applied 30 days after planting. Azafenidin and both rates of oxyfluorfen had significantly higher wood production than the untreated control, while sulfometuron, diuron and imazaquin were not significantly different from the untreated control. All treatments achieved weed control but showed significant phytotoxic damage. Azafenidin and oxyfluorfen treatments were able to recover quickly without a serious loss in growth.

Key words: Post-flush, weed control, phytotoxicity, Salix, Populous.

Rust (*Melampsora epitea* var. *epitea)* on Short-Rotation Coppice (SRC) Willow

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ABSTRACT

Willow has been grown in short-rotation coppice in Northern Ireland since 1976. In 1986 there was a severe outbreak of rust caused by *Melampsora epitea* var. *epitea.* This disease is the single most limiting factor in SRC willow production. Although early work demonstrated that the disease could be controlled using fungicides, such a strategy was ultimately deemed non-viable. Over the past fifteen years investigations into the use of inter- and intra-species *Salix* mixtures as a means of reducing the impact of rust have been carried out. Varietal mixtures are effective in reducing the impact of rust on many varieties. A trial currently exists which is comprised of twenty willow varieties planted at three densities, 10,000, 15,000 and 20,000 plants ha-, in mono-culture and in five, ten, fifteen and twenty way mixtures. To date three particularly rust susceptible varieties have died out in both mono-culture and in each of the mixtures. In spite of this, mixtures are regarded as the best way of combating rust and of ensuring sustainability over the life of the plantation in situations of high disease pressure

Keywords: short rotation coppice, willow, rust, *Melampsora epitea*.

INTRODUCTION

A projected world shortage of wood pulp from conventional forestry (Stott *et al.* 1981) prompted an interest in growing willow (*Salix* spp.) as a short-rotation coppice (SRC) crop. The escalating prices of oil in the mid 1970s further stimulated interest in SRC willow as a potential energy crop in N. Ireland. Many of the *Salix* spp. varieties which were available at the time grew well under conditions of heavy rainfall and in the heavy, wet soils typically found in N. Ireland. One of the most important and best yielding varieties was *Salix burjatica* 'Korso' which was grown successfully for approximately ten years. However, in 1986 it was badly infected with a rust disease which, over 2 – 3 seasons, resulted in almost complete destruction of the variety to the point where it was no longer viable commercially. Since then rust has become the single most limiting factor in growing willow in many parts of the United Kingdom. This is also the case in some other parts of Europe.

The Disease and the Pathogen

The fungus *Melampsora epitea* var. *epitea* caused the disease. This rust is heteroecious and completes its sexual phase on European larch (*Larix decidua*) (Fig. 1). *M. epitea* var. *epitea* is primarily a foliar pathogen causing typical orange uredia on the underside of willow leaves, ranging in size from less than a millimetre to several millimetres in diameter. One specific type of *M. epitea* var. *epitea* referred to as the Stem

Infecting Form (SIF) is capable of additionally causing lesions on the stems and the mid-rib of the leaf on some *Salix* spp. varieties. The disease is primarily responsible for extensive premature leaf fall, which is then frequently followed by invasion by secondary pathogens such as *Fusarium* spp. and *Cryptodiaporthe* spp. These can kill rods and infect stools reducing flushing the following spring by as much as 60% (Dawson and McCracken 1994).

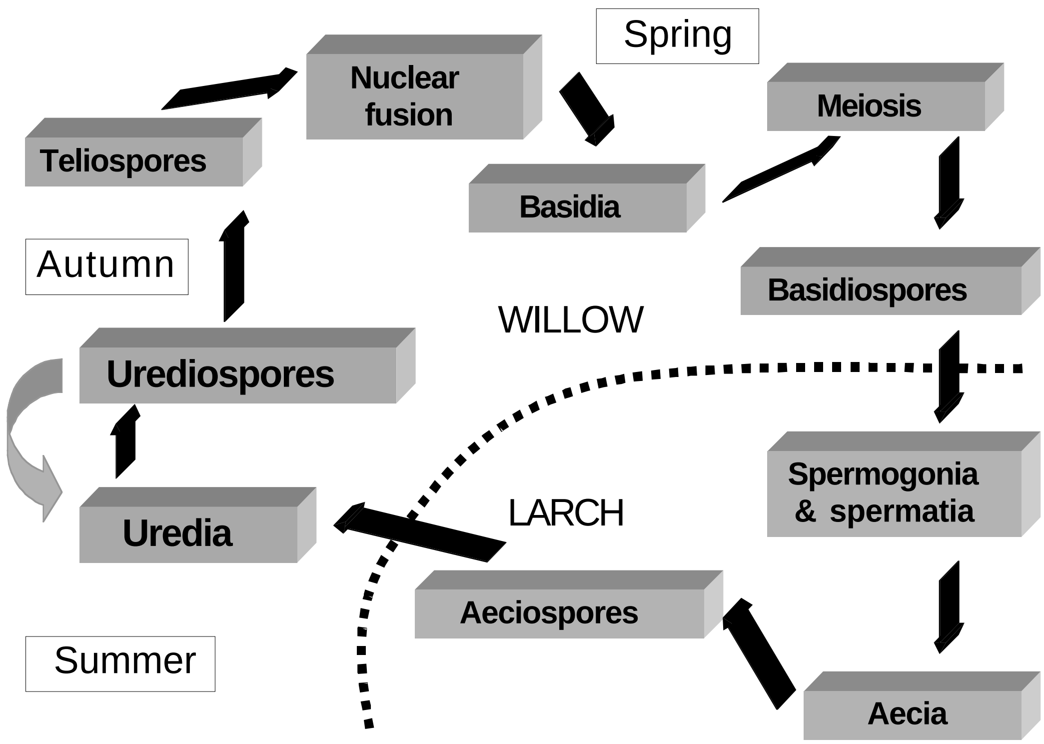

Figure 1. Life cycle of *Melampsora epitea* var. *epitea*, alternating between willow and European larch.

M. epitea var. *epitea* populations are complex, consisting of a range of pathotypes. The number of these pathotypes has been steadily increasing over the past 15 years with 14 having been identified to date (Pei *et al.* 1996; Pei *et al.* 1999). Individual pathotypes may have been present within the populations and choice of willow variety grown may have favoured the selection of particular pathotypes. The sexual stage also gives opportunity for more diversity to be introduced into the population.

Control Strategies

It has been demonstrated that the application of fungicides at 14-day intervals starting in early June can significantly reduce foliar rust and almost completely control stem dieback and subsequent stool death (McCracken and Dawson 1990; 1994). However the application of expensive chemicals to a low value crop was never considered to be a viable disease control strategy. There were also environmental considerations of applying chemicals to such a crop. Hence alternative methods were needed to reduce the impact of rust on the survival and growth of SRC willow. Wolfe

(1985) reviewed the effectiveness of using inter- and intra-species mixtures of cereals as a method of controlling diseases caused by obligate pathogens such as rusts and mildews. In this case, mixtures of as few as three cultivars gave significant reductions in disease levels. When choosing cereals for a mixture there are important issues to be considered such as compatible maturation dates, end usage etc. However, in contrast, this is not a problem when growing willows where the end product is only wood. Trials were therefore planted in the late 1980s to test the effectiveness of using varietal mixtures of *Salix* spp. to manage rust.

These initial trials incorporated four, five or six varieties in "organised random mixtures" (i.e. cuttings were planted A,B,C,D,E,A,B,C,D,E,A etc.). This in effect meant that any given variety was always growing between the same two other varieties. The development of disease on individual varieties within a mixture was monitored over three seasons on one, two and three-year-old growth and compared to the disease pattern of the same variety growing in a mono-culture at the same stage of growth. On most varieties it was found that (i) the onset of disease was delayed, often by as much as three weeks; (ii) the speed of build up of rust was slower and (iii) the levels of disease at the end of the growing season were significantly lower. The overall result was that premature leaf fall was either delayed or prevented, so that there was not a problem with rod or stool death (McCracken and Dawson 1997).

An important interaction was found between pathotypes, *Salix* spp. varieties and whether they were being grown in mixtures or growing as mono-cultures. Pathotype diversity was measured in 1994 and 1995 using the Shannon Weaver Index (Fowler and Cohen 1993). There was no significant difference between the mean diversity indices in each year. However, a significant difference ($P = 0.05$) was found between mono-varietal plots and mixtures, i.e. there was a greater diversity of pathotypes in mixtures (Fig. 2). There were also differences between varieties with the diversity index of pathotypes on *S. viminalis* 'Bowles Hybrid' being significantly ($P = 0.05$) less than on any of the other varieties (McCracken *et al.* 2000).

The Effectiveness of Mixtures

The results from these early trials raised a number of important questions relating to the planting and constitution of willow mixtures.

1. **Numbers of varieties within a mixture:** Mixtures with a small number (4 – 6) of components were effective in reducing rust (McCracken and Dawson 1997). However there was no information available on what was the optimum number of varieties within a mixture.

2. **Planting density:** All of the initial trials had been planted at a density of 20,000 ha^{-1}, although other trials had suggested that lower planting densities might be more cost-effective. However it was not known what impact this may have had on the growth of varieties or on the effectiveness of mixtures in reducing disease.

3. **Planting configuration:** The limitations of organised mixtures was recognised. In particular there was less potential for yield compensation of stools or even varieties,

which grew weakly in mixtures. Fully random, intimate mixtures were therefore considered to be potentially a better approach.

4. **Performance of new varieties:** Since the late 1980s there have been several new *Salix* spp. varieties originating from willow breeding programmes in Sweden and the UK, which had been specifically selected for growth in short rotation coppice. Most of these had at least some level of resistance to rust, but had never been tested in mixtures.

Following a consideration of these factors, a trial was planted in 1994/95.

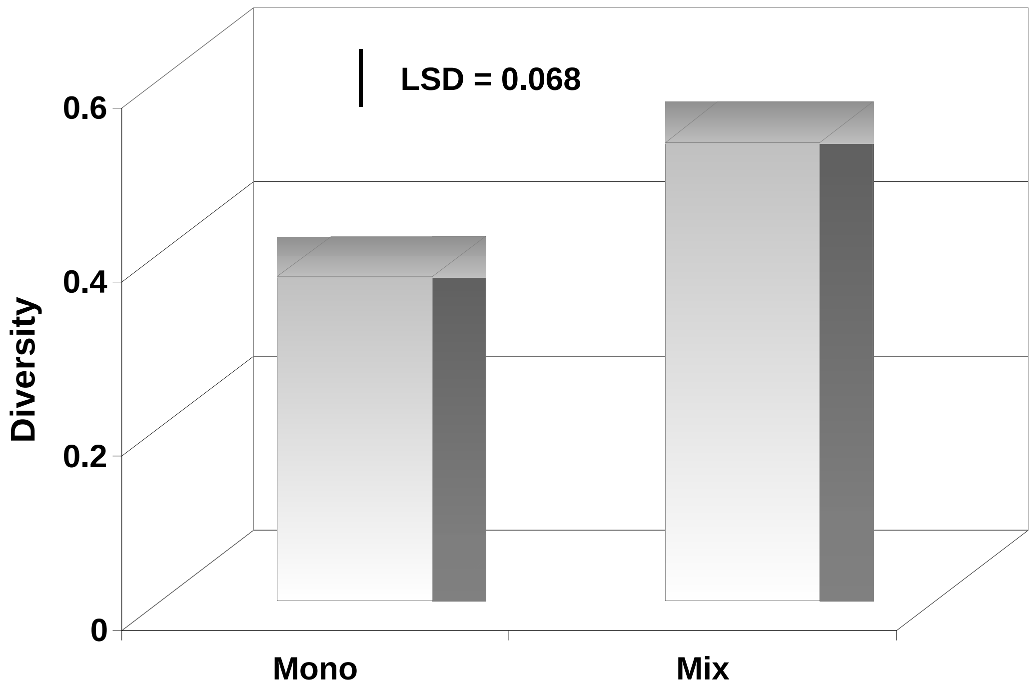

Figure 2. Diversity (Shannon-Weaver index) of *Melampsora* spp. and pathotypes on *Salix* spp. varieties grown in mono-culture and in mixtures (McCracken *et al.* 2000).

Castlearchdale Mixtures Plantations

The plantations were established at Castlearchdale, Co. Fermanagh, N. Ireland ($54^0$28'N $7^0$43'W), 60-70m above sea level and on a site with heavily gleyed soils with impeded drainage. The trial was planted in two replicate blocks. Block 1 was planted in spring 1994 and block 2 in spring 1995. Both blocks were cut back at the end of their establishment year and block 1 again in 1995/96 meaning that, in the summer 1996, both blocks were at the same stage of growth, (i.e. fresh regrowth from freshly coppiced stools). Twenty *Salix* spp. varieties (Table 1) were planted in large mono-plots (32 x 14m in Block 1 and 32 x 11m in Block 2) in double rows in a split plot design with three densities: 10,000 ha^{-1}, 15,000 ha^{-1} and 20,000 ha^{-1}. Four mixture combinations were employed comprising 5, 10, 15 and 20 varieties (Table 1). A map was prepared at the time of planting which enabled the identification of each individual stool within a mixture.

A number of criteria were used when selecting varieties for inclusion within the trial. Most were taken from a varietial selection trial having been chosen on the basis of yield and rust resistance, although not all were completely free of disease. *S. burjatica* 'Germany', *S. dasyclados x aquatica* 'V7511' and *S. dasyclados x caprea* 'V794' were infected with rust every season although they seemed to be able to carry a reasonably high level of rust with limited effect on growth (McCracken and Dawson 1998). *S.*

Table 1. *Salix* spp. varieties included in Castlearchdale mixtures trial

Included in 5, 10, 15, 20 way mixtures	**Included in 15, 20 way mixtures**
S. burjatica 'Germany' *S. mollissima-undulata* 'SQ83' *S. dasyclados x aquatica* 'V7511' *S. viminalis* '77082' *S. dasyclados x caprea* 'V794'	*S. viminalis x caprea* 'V789' *S. viminalis* '77683' *S. viminalis* '78101' *S. viminalis* '78195' *S. schwerinii x aquatica* 'V7534'
Included in 10, 15, 20 way mixtures	**Included in 20 way mixture**
S. viminalis x aquatica 'V7503' *S. viminalis* '78118' *S. viminalis* '78183' *S. schwerinii x viminalis x dasyclados* 'V7531' *S. viminalis* '870146 ULV'	*S. viminalis* '77699' *S. viminalis* 'Gigantea' *S. viminalis* 'Gustav' *S. schwerinii x aquatica* 'V7533' *S. viminalis* '870082 ORM'

mollissima-undulata 'SQ83' had a variable response to rust and *S. viminalis* '77082' was only slightly affected by rust. Hence varieties in the five-way mixture ranged from low to moderately susceptible to rust. These five varieties were then included in ten, fifteen and twenty-way mixtures with varieties that had a low to zero susceptibility to rust. Thus the more susceptible varieties were 'diluted' by less susceptible and resistant varieties.

Leaf samples were taken from individual varieties where they were growing in mixtures and from mono-varietal stands at two-week intervals, starting in late May. Samples were usually only taken from the highest density (20,000ha^{-1}.) although on three occasions at the start, in the middle and at the end of the season samples were taken from all densities. Sampling was carried out in 1996 (1 year old growth), 1997 (2 year old growth), 1998 (3 year old growth), 1999 (1 year old growth) and 2000 (2 year old growth).

Effect of Mixtures on Disease Development

<u>S. burjatica 'Germany', S. dasyclados x aquatica 'V7511', S. dasyclados x caprea 'V794'</u>

In 1996 all three of these susceptible varieties were severely infected by rust. In mono-culture plots, irrespective of density, the disease resulted in almost complete death of rods and stools. In all mixtures, at each density, disease development on *S. burjatica* 'Germany' was slowed down (Fig. 2), although it was still sufficiently severe to reduce growth significantly. A similar trend was observed with *S. dasyclados x aquatica* 'V7511' and *S. dasyclados x caprea* 'V794'. For these three varieties most of the stools had been killed with the remainder being very small. It was concluded that where a specific variety was, or became, highly susceptible to rust its inclusion in a mixture could at best slow down its eventual demise. However there was the benefit of neighbouring stools within mixtures compensating for those that had been lost, by occupying and colonising the space that had been left.

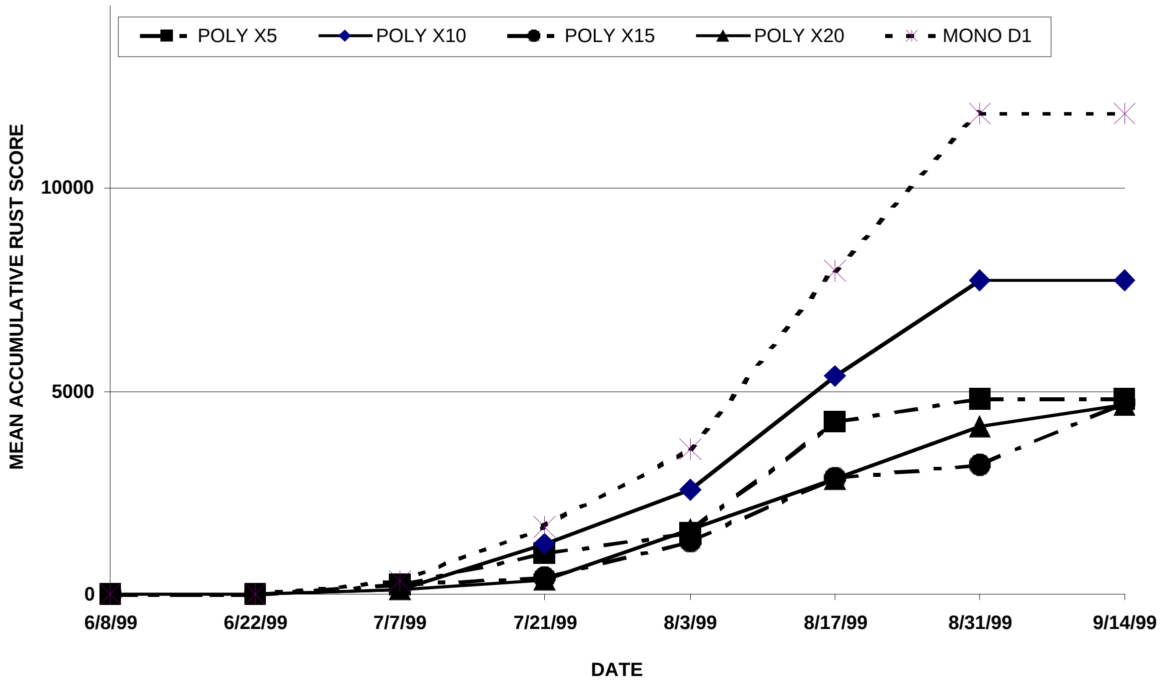

Figure 3. Disease progress curves of rust development on *Salix burjatica* 'Germany' grown in mono-culture and included in five, ten, fifteen and twenty way mixtures.

<u>S. mollissima-undulata 'SQ83'</u>

In 1996 *S. mollissima-undulata* SQ83 was severely affected by rust, which started early in the growing season and was followed by significant death of rods when in mono-culture. In that year its inclusion within a mixture, irrespective of size had a significant disease reduction effect. In subsequent years the disease pattern was different, tending to become evident much later in the season, often in late August, with consequently less impact on growth. In mono-culture when rust did occur later in the growing season there was a rapid increase, which was significantly less than in mixtures.

<u>S. viminalis: '77082', '78118', '78183', '870146 ULV', '77683', '78101', '78195', 'Gigantea', 'Gustav', and '870082 ORM'</u>

In each year from 1996 – 1999 *S. viminalis* '77082' carried low levels of disease, particularly earlier in the growing season, but even up until September. Significant levels of rust were observed only in July 1996. In none of the years were any differences observed in the pattern of rust between any of the mixtures or mono-cultures.

In all years *S. viminalis* '78118' had low levels of rust, which only became slowly evident as the season progressed. Inclusion of this variety in mixtures appeared not to affect the pattern of disease development.

S. viminalis '78183' had low levels of disease in all years and showed a general trend towards more rust being apparent on plants grown in mono-culture.

S. viminalis '870146 ULV' had virtually no rust in any of the years with the exception of 1996 when levels of disease observed on mixtures were less than in mono-culture.

S. viminalis '77683' had almost no rust in any year with pustules only infrequently being observed right at the end of the growing season in late September. There were no differences between rust on plants in mixtures or mono-culture. This may have been partly due to this variety being very variable and almost constituting a mixture in its own right.

S. viminalis '78101' tended to have a few rust pustules, even in early July. However there was only a slow increase in the amount of disease as the season progressed and at no point was there a difference between disease levels on this variety in either mono-culture or mixtures.

S. viminalis '78195' had low levels of disease, which only became apparent towards the end of August. No significant differences were observed between disease levels in mixtures or mono-culture.

S. viminalis '77669' had low levels of disease in all years irrespective of where it was growing in the trial.

S. viminalis 'Gigantea' never had significant levels of rust observed in mixtures or mono-culture in any year or at any stage during the growing season.

S. viminalis 'Gustav' had low to moderate rust levels in each year. In 1997 disease was observed early, whilst in 1998 and 1999 rust pustules were not recorded until much later. The general trend at each recording date was for reduced disease levels in mixtures compared to mono-culture.

S. viminalis '870082 ORM' had only very low levels of rust in any year.

In general each of the straight *S. viminalis* varieties grown in the trial had low susceptibility to rust, and often were only affected late in the season. There were, however, different patterns of disease development observed among the varieties. It can therefore be argued that even a straight *S. viminalis* mixture in which its components may be susceptible to the same *M. epitea* pathotypes will still act as a genuine mixture in terms of reducing disease and reducing the selection pressures on the pathogen.

<u>S. schwerinii x viminalis x dasyclados V7531, S. schwerinii x aquatica V7533, S. schwerinii x aquatica V7534</u>

Varieties with *S. schwerinii* parentage tended to display a high level of resistance to rust. Since planting the trial in 1996 rust has only been observed at minimal levels (occasional pustules on < 0.1% of leaves) in any year, irrespective of age of growth.

There was no immediate disease reduction advantage obvious in including such varieties within a mixture. However growing these varieties in mixtures reduces the potential disease pressure within each season, which ensures their long-term sustainability over the full 25 – 30 year life of a plantation.

CONCLUSIONS AND RECOMMENDATIONS ABOUT MIXTURES

Inter- and intra- species mixtures of *Salix* offer the only practical and realistic method of managing disease in plantations over the full life cycle (up to 25 years). Almost all of the varieties that are being commercialized from both the Swedish and the UK willow breeding programmes are currently resistant to *M. epitea* var. *epitea*.

However, experience in N. Ireland, where the disease pressures are high and climatic conditions are highly conducive to disease, has shown that often varieties which have previously been resistant breakdown after 8 – 12 years when grown in mono-varietal plots. Growing such varieties in mixtures reduces the selection pressures on the pathogen and so they have more chance to survive as productive varieties throughout the whole life of the plantation.

Salix spp. varieties that are susceptible to rust have a marked tendency to be less affected by the disease in mixtures. This can contribute to increased productivity in mixtures compared to mono-plots.

The number of varieties within a mixture appears to have little influence on the pattern of disease development on individual varieties. There are, however, advantages in having bigger numbers in mixtures. In the five-way mixture, where three of the varieties (60%) succumbed to rust, the remaining two (40%) were unable to compensate for their loss. In contrast, in the twenty-way mixture, where they only contributed 15%, their loss, was less important. Furthermore, larger mixtures give greater host diversity and hence less selection pressures on the pathogen. Concern has been expressed about the development of ‘super-races’ or ‘super-pathotypes’ within mixtures. Evidence has suggested that competition between pathotypes may prevent the development of such ‘super-pathotypes’ (McCracken *et al.* 2000).

Density had little or no impact on disease development, irrespective of age of growth. However density could be expected to affect competition between stools, compensation for lost stools and overall yield, particularly in the second harvest cycle.

Planting configuration of a mixture is probably not an issue in terms of rust dynamics throughout the season. The organised random mixture was not considered an ideal configuration, because each variety is always between the same two varieties and hence there is the potential to accentuate any negative effects they may have on each other. The completely random mixtures were considered best, especially for giving optimum compensation for varieties that are adversely affected by disease or other factors. However such mixtures are not practical for commercial plantations that are normally planted using step-planters, which are fed with rods from which four or five cuttings may be taken. As a compromise, rods can be mixed within the planter that results in short runs of the same variety. Line mixtures and mosaics will also give the beneficial effects of disease reduction, but are less effective in allowing for compensation.

Careful choice of varieties for inclusion within a mixture is vital. Low rust susceptibility is obviously important. Furthermore other factors, such as the fact that some varieties do not compete well within mixtures must also be considered. It should be noted that mixtures have little impact on the feeding patterns or the extent of damage caused by willow beetles (Bell *et al.* 2001).

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Yield Responses of Growing Inter- and Intra-Species Mixtures of Willow in Short Rotation Coppice (SRC)

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ABSTRACT

Willow can be grown in inter- and intra- species mixtures as a rust disease control strategy. Mixtures comprising five, ten, fifteen and twenty *Salix* species varieties have been investigated. The dry matter yield from such mixtures was normally higher than the yield from equivalent areas of the constituent varieties grown in mono-culture. There is a trend of increasing yield as the number of varieties increases. Some varieties e.g. *S. viminalis* 77082 and *S. schwerinii* x *aquatica* V7534 consistently produced significantly higher yields in mixtures. Other varieties e.g. *S. viminalis* x *caprea* V789, *S. viminalis* x *aquatica* V7503 and *S. viminalis* 78183 showed no yield benefit for being included in a mixture. There are however other benefits, and in particular the long sustainability of the plantation over twenty to thirty years and the reduced impact of rust on growth over this period.

Keywords: Short rotation coppice, willow, yield

INTRODUCTION

Willow (*Salix*) is frequently grown in inter- and intra-species mixtures as a rust disease control strategy (McCracken and Dawson 1998). A series of trials incorporating *Salix* spp. varieties into mixtures were planted in Northern Ireland in the late 1980s. It was observed that there were increased yields from the mixed-varietal stands compared to either the mean yield of the component varieties or even the individual yield of any of the component varieties when grown in mono-culture (Dawson and McCracken 1995). It was clear that at least some of this increased yield was attributable to the effect that mixtures have in reducing rust and its impact (Chin and Wolfe 1984, McCracken and Dawson 1997). Yield increases from mixtures only became evident towards the end of the second year of growth and were highly significant at the end of the three-year harvest cycle (Dawson and McCracken 1995; Willebrand et al. 1993).

There was a marked difference in the way in which individual varieties performed within mixtures. For example there were large positive response from *S. viminalis* ‘Bowles Hybrid’ and *S. burjatica* ‘Germany’. In contrast *S.* x *dasyclados* performed poorly in mixtures both in terms of increased stool death and in producing smaller individual stools.

Since 1990 many new *Salix* spp. varieties have become commercially available. These have tended to be higher yielding and less rust susceptible than the varieties used in the original work. This paper describes a trial in which twenty varieties were grown in different sized mixtures at a range of densities. While the primary objective of the trial was to investigate the impact on disease, observations were made and measurements taken of the effect of mixtures on survival, growth and yield.

MATERIALS AND METHODS

Plantations

The plantations and the *Salix* spp. varieties used have been described previously in detail (McCraken and Dawson 2001, McCracken and Dawson In Press). The *Salix* spp. varieties planted are listed in Table 1, along with their trial identification number.

Yield Measurements

Stools were harvested in the winter of 1998 / 99 when they were three-years-old. A map had been prepared at the time of planting which enabled individual stools to be identified. Stools were harvested individually and a fresh weight for each obtained. The dry weight of each stool harvested was calculated using a chipped sample, which had been oven dried. In both the mono and the mixture plots at least 40 stools of each variety were harvested. This enabled comparisons to be made between the growth and yield of each variety in each mixture or density in which it was growing. Comparisons could also be made between yield from a set area, which was normally calculated to $100m^2$.

Table 1. *Salix* spp. varieties with their trial identification number.

Var. 1	*S. viminalis* '77699'	Var. 21	*S. viminalis* '78101'
Var. 3	*S. burjatica* 'Germany'	Var. 23	*S. viminalis* '78118'
Var. 4	*S. mollissima-undulata* 'SQ83'	Var. 26	*S. dasyclados x caprea* 'V794'
Var. 6	*S. viminalis* 'Gigantea'	Var. 28	*S. viminalis* '78183'
Var. 9	*S. viminalis* 'Gustav'	Var. 29	*S. viminalis* '78195'
Var. 12	*S. viminalis x caprea* 'V789'	Var. 32	*S. schwerinii x vim. x dasyclados* 'V7531'
Var. 13	*S. dasyclados x aquatica* 'V7511'	Var. 34	*S. schwerinii x aquatica* 'V7534'
Var. 14	*S. viminalis x aquatica* 'V7503'	Var. 45	*S. schwerinii x aquatica* 'V7533'
Var. 17	*S. viminalis* '77082'	Var. 46	*S. viminalis* '870082 ORM'
Var. 18	*S. viminalis* '77683'	Var. 48	*S. viminalis* '870146 ULV'

At harvest it was possible to calculate accurately the space occupied by a particular variety. For example in the ten-way mixture each variety occupied 10% of the space. However because of differences at planting this often varied by a small proportion. In order to make comparisons between varieties it was assumed that each variety would contribute the same proportion to the yield as the proportion of the space it occupied. Difference from this 'predicted' value could then be calculated to give an indication of how a variety was performing within a mixture. A similar calculation was carried out for mono-plots. The contribution of a variety was calculated as a proportion of the total yield from each of the constituent varieties.

RESULTS

Mono-culture

The dry matter yield from varieties grown in mono-culture ranged from 283.3 kg 100 m^{-2} (*S. schwerinii* x *aquatica* V7534) to 51.2 kg 100 m^{-2} (*S. dasyclados* x *caprea* V794) (Fig. 1). For most varieties there was no significant differences (P = 0.05) between the yields from planting density 10,000 ha^{-1} and 20,000 ha^{-1}. The yield from the middle density, 15,000 ha^{-1} had a tendency to be lower.

Mixtures

The mean yield from 100 m^2 of each of the four mixtures was always significantly (P = 0.05) higher than the mean yield from an equivalent area of the constituent varieties grown in mono-culture (Fig 2). This trend was consistent across all densities, although the differences were not always significant.

The total yield from a set area of mixture, irrespective of the number of varieties within that mixture was always greater than the yield from the equivalent area of the components growing as mono-culture (Fig 2)

All varieties did not give a positive yield increase when included within a mixture (Fig. 3), nor was the response of an individual variety necessarily consistent in different sized mixtures.

S. viminalis 77082 contributed significantly greater dry matter yield than was predicted when included in the five and ten-way mixtures but these difference were not observed in the fifteen and twenty- way mixtures.

Salix burjatica Germany, *Salix dasyclados* x *aquatica* V7511 and *Salix dasyclados* x *caprea* V794 consistently gave significantly less than their predicted yield both when growing as mono-varietal plots and within mixtures. The difference from the predicted yield was usually greater in the mixtures.

In the ten-way mixture the best performing varieties were *S. schwerinii* x *viminalis* x *dasyclados* V7531, *S. viminalis* 77082 and *S. viminalis* 870146 ULV. These gave significantly greater dry matter yield than was predicted.

In the fifteen-way mixture *S. schwerinii* x *viminalis* x *dasyclados* V7531 once again gave improved yields with *S. viminalis* 78195, *S. viminalis* 77683 and *S. schwerinii* x *aquatica* V7534 all showing increased yields.

In the twenty-way mixture the four top yielding varieties were *S. viminalis* 870082 ORM, *S. viminalis* 78195, *S. schwerinii* x *aquatica* V7534 and *S. viminalis* 77683.

Where a *Salix* spp. variety (e.g. *S. burjatica* Germany) is, or becomes, particularly susceptible to rust then its inclusion within a mixture will not be beneficial in terms of maintaining its growth. Indeed such varieties, already weakened by rust may find it difficult to compete with the more vigorously growing varieties and die out even more quickly. Previously, before *S. burjatica* Germany had succumbed to rust, there were significant yield benefits when it was included in mixtures (Dawson and McCracken, 1995). Other varieties (e.g. *S. viminalis* x *caprea* V789 or *S. viminalis* Gustav) may not be particularly susceptible to disease but do not perform well within mixtures. In previous trials this phenomenon was also observed with *Salix* x *dasyclados* (Dawson and McCracken, 1995).

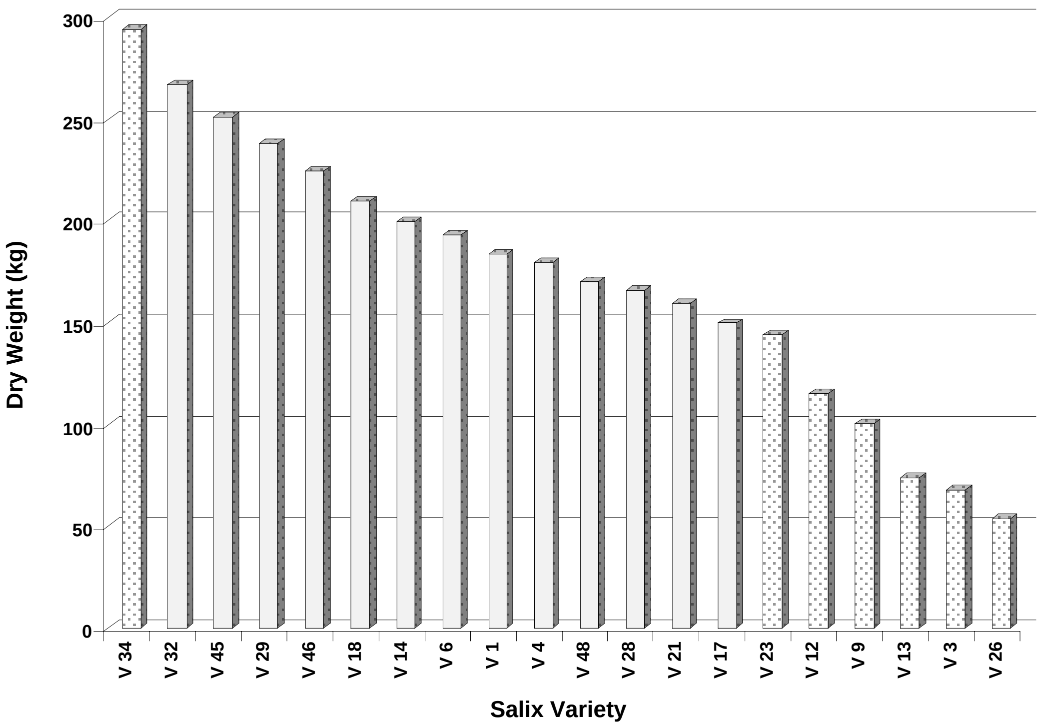

Figure 1. Three year dry matter yield (kg) from $100m^2$ of twenty *Salix* spp. varieties grown in mono-culture.

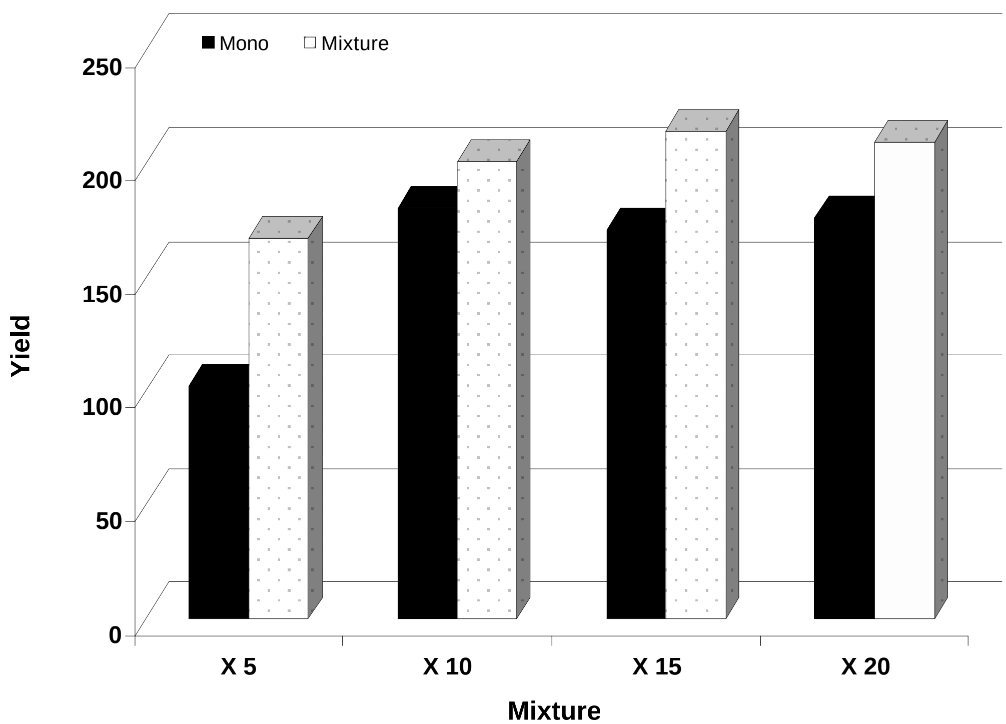

Figure 2. Yield (from $100m^2$) of each individual *Salix* spp. variety when grown in the ten-way mixture and as mono-culture plots.

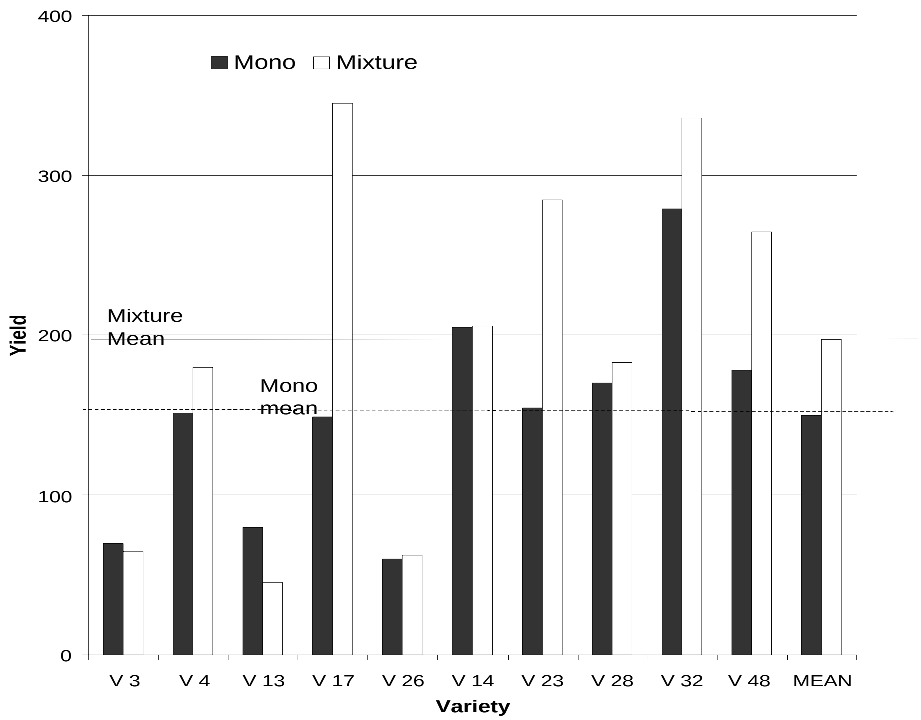

Figure 3. Yield (from $100m^2$) of each individual *Salix* spp. variety when grown in the ten-way mixture and in mono-culture compared to the mixture mean and the mean of the components grown as mono-cultures.

DISCUSSION

Planting configuration may be an important consideration when establishing mixed varietal plantings of willow. Fully random intimate mixtures, such as were employed in this current trial, give the best opportunity for yield compensation for stools or even varieties lost due to increased sensitivity to disease or other causes. In the same way the greater number of components within a mixture reduce the risk of loosing significant proportions of the planting. When 60% of the mixture was lost (as was the case in the five-way mixture) then the remaining two varieties were unable to compensate entirely, despite producing very greatly increased yields. However when these three varieties were lost from the twenty-way mixture, in which they contributed only 15% of the total number, the remaining varieties were able to compensate fully for their loss.

The results presented in this paper are for yields from the first three-year harvest cycle which are known to only produce around 70% of what can be expected in the second harvest cycle. Therefore, as site capture increases during the second harvest cycle it can be expected that these trends of competition and compensation will become more pronounced. It could also be expected that planting density may have a greater influence.

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Technical Session: Uses for SRWC

Establishing Willow, Poplar and Other Vegetation on a Brownfield Site in Utica, New York

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ABSTRACT

Abandoned and underutilized industrial lands, commonly referred to as brownfields, are common throughout New York State and the United States. Reclamation of these sites and possible remediation of soils contaminated with various pollutants may be accomplished through the establishment and growth of plants. Our study addressed the establishment of three vegetation communities on a brownfield site after one growing season, quantified in terms of percent vegetative cover, above and below ground biomass, and survival. Grasses are the standard community employed for the reclamation and remediation of brownfield sites. A randomized complete block design with four replications was used to compare establishment among three different plant communities: planted grass, planted willow and poplar, and a "volunteer" community, in which plants existing on the site were allowed to naturally revegetate the study area. Experimental units were 6 x 6 m plots. Unrooted cuttings of seven willow clones and one poplar clone were planted randomly at 0.3 x 0.3 m spacing in June 1999. The grass and willow/poplar treatment resulted in significantly higher percent cover, 90 and 62 percent, respectively, compared to the volunteer community at 29 percent. There were no differences in above or below ground biomass between the grass community and the willow/poplar community. Overall survival of willow and poplar clones was 90%; clone NM6 *(Populus nigra x P. maximowiczii)* displayed the highest survival at 97%, and S25 *(Salix eriocephala 16x S.erio* 276) survived at a rate of 81 %. Stem biomass production was 1.16 Mg/ha, which is consistent with first year growth on higher quality agricultural sites. Based on one growing season, the grass and willow/poplar communities appear promising for revegetating and remediating the brownfield site.

Phytoremediation of TCE in a Shallow Alluvial Aquifer — A Field Demonstration

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ABSTRACT

The efficacy of *Populus deltoides* planted as a short rotation woody crop to phytoremediate shallow ground water contaminated with trichloroethylene (TCE) has been evaluated at the field scale in a multiagency demonstration project in Fort Worth, Texas. This project was led by the Air Force and was conducted as part of the DOD's Environmental Security Technology Certification Program, as well as the USEPA's SITE Program. Planting and cultivation of eastern cottonwood (poplar) trees above a dissolved TCE plume in a shallow (< 3.6 m) aerobic aquifer took place in spring 1996. Data were collected to determine the ability of the trees to perform as a natural pump and treat system. Transpiration measurements indicate that the largest planted trees transpired approximately 14 liters per day during summer 1997; whereas a nearby 19-year-old cottonwood tree was determined to transpire approximately 275 kg per day (J.M. Vose, U.S. Forest Service, oral commun. 1997). Although the trees were transpiring water from the contaminated aquifer during the second growing season they were not hydraulically controlling the plume. Predictions of drawdown at the water table during peak growing season transpiration for mature plantations range from 12-25 cm at the center of the drawdown cone. The diameter of the predicted drawdown cone ranges from 140 to 210 m. These drawdown predications are associated with a predicated decrease in the volumetric flux of groundwater across the downgradient end of the planted area that ranges from 20 to 30 percent of the water that moved through the site before the trees were planted.

Percolation Reduction Using Short Rotation Woody Crops: Case Study – Schenectady, NY

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ABSTRACT

Water balance models are commonly used for long-term prediction of water movement within a hydrologic system. To assess the ability of native vegetation and short rotation woody crops to minimize percolation at a site in Schenectady, data were collected to quantify and model the water balance within shallow substrate. Components of the water balance were determined using instrumentation installed above and below ground within a stand of pioneer tree species and in an adjacent successional old field community. To measure precipitation, total solar radiation, relative humidity, temperature and wind speed, we installed a micrometeorological station in the old field area. From this we also computed potential evapotranspiration. Changes in soil water storage at both sites were calculated using an array of soil moisture probes installed in the fill. Water flux through the fill was measured using minilysimeters, while sap flow was determined using heat balance sap flow gauges. Surface runoff was estimated. Sap flow was measured on 2 cm diameter branches of a variety of tree species and then extrapolated to the stand level. Sap flow is species dependent and ranges from 2.4 to 2.8 Ga./tree.day. The results of preliminary modeling indicate that percolation is greatly reduced in areas under tree cover when compared with the old field areas. In addition, estimated average daily evapotranspiration from the stand ($380m^2$) ranges from 5.3 to 8.6 mm/day, which exceeds the average daily precipitation during the growing season of 2.7 mm.

Technical Session: Sustainability of SRWC

Birds Breeding in Short-Rotation Woody Crops in Upstate New York: 1998-2000

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ABSTRACT

This report on birds nesting in short-rotation woody crops is based on spot mapping and exhaustive nest searches in nine plots in Upstate New York. The largest number of different bird species was observed in season two (11 species), with somewhat smaller numbers in season 3 (nine species) and season 4 (eight species). In contrast to this result the total nest density increased with age of the willows and poplars: numbers of nests per acre, all species confounded, were 0.03 (season 1), 2.47 (season 2), 4.93 (season 3) and 6.56 (season 4). American Goldfinches seem to prefer clones S25 and SA2, while avoiding NM6. NM6 was also avoided by Red-winged Blackbirds and Willow Flycatchers, but clearly preferred by American Robins and to some extent by Grey Catbirds, two species that build large, bulky nests. S365 was strongly favored by Red-winged Blackbirds, and perhaps by Yellow Warblers.

Keywords: Aves, biodiversity, clone, density, nesting, willow, poplar

INTRODUCTION

As part of the study of the impact of short-rotation woody crops on biodiversity we studied which birds were observed breeding in plots of different ages, sizes and in which different clones were planted. All of these factors are known to have an effect on avian biodiversity (Sage and Robertson, 1996). The objectives of our studies were to determine: (1) which bird species breed in plots and at what density; (2) to what extent avian biodiversity changes with the age/size of the plots; (3) to what extent type of clone influences avian biodiversity; (4) to what extent the surroundings of a plot influence avian biodiversity; (5) if brood-parasitism by brown-headed cowbirds is a problem in the plots in Upstate New York; (6) compare birds breeding in willow plantations to those breeding in similar natural habitat

This report is limited to the description of the diversity and abundance of birds nesting in the “eastern” plots of Upstate New York and will also briefly address possible preferences of clone as a substrate for nest building in relation to branching patterns.

MATERIAL AND METHODS

The study plots on which this report is based were planted between 1996 and 1998. We analyze the results by growing season. Growing season 1P is the season in which the clones were planted. Before the next growing season the saplings are cutback by mowing with a sickle bar or brush saw, generating more side sprouting in the following growing season. The first season after cutback is called season 1. Later seasons are numbered consecutively. Although it was initially planned to cut the plantations after growing season 3, several plots were not cut then, so that we also report on the birds nesting during growing season 4.

The study plots included in this report, their location, size, year of planting and growing seasons during which data were collected are summarized in Table 1. The data for Lower Field in Lafayette are not included in the analyses, because to many trees died after planting.

Table 1. Short-rotation woody plots used in this report.

Site	Field	Area (ac)	Planting date	Growth Season				
				1P	1	2	3	4
King Ferry	Barn Site	5.5	1996			1998	1999	2000
	Weather Station	3.7	1996			1998	1999	2000
	Site Trial	2.7	1995		1999	2000	1998	
Tully	Area 4	0.1	1987			1998	1999	2000
	Area 12	2.7	1995		1999	2000	1998	
Lafayette	Lafayette Rd.	7	1997		1998	1999	2000	
	Upper Field	2	1998	1998	1999	2000		
	Lower field (1)	2	1998	1998	1999	2000		
Canastota	Canastota	20	1998	1998	1999	2000		

(1) Data not included because of heavy plant mortality.

The field methods were simple, though time consuming. From April to September each plot was visited every 7-10 days. We used spot-mapping techniques to census birds during each visit (Robbins et al. 1970; Bibby et al. 1992). For all the plots we walked the perimeter of the plot mapping any birds detected and afterwards we walked transects through the plot. This procedure was adopted to minimize, as much as possible, disturbances due to walking through dense and tall vegetation. All birds observed were identified and their location and behavior recorded on a map. Plots were also exhaustively searched for nest. When nests were found the content was recorded, the species determined and a flag with date found, species and nest content attached to a nearby tree. Nest fate and content was determined during later visits. A mirror attached to a pole was use to determine nest content of nests built above eye height. In late September and October after the leaves had fallen to the ground, the plots were revisited to determine if any nests had been missed during the growing season.

RESULTS

No birds were found nesting in season 1P. In season 1 only American Goldfinches *Carduelis tristis* were found nesting. Based on the behavior of the birds, though, we believe that Field Sparrow *Spizella pusilla* (King Ferry), Indigo Bunting *Passerina cyanea* (Lafayette) and Vesper Sparrow *Pooecetes gramineus* (Canastota) were also probable breeders.

Some species were only found nesting during season 2. These included Indigo Bunting, Common Yellowthroat *Geothlypis trichas* and Killdeer *Charadrius vociferus*. Nests of Song Sparrows *Melospiza melodia* were found in seasons 2 and 3, and young of the parasitic Brown-headed cowbirds *Molothrus ater* were only found in season 3. A single pair of the Wood Thrush *Hylocichla mustelina*, a declining Neotropical migrant, successfully raised young in a plot at King Ferry in its 4th season.

The largest number of different bird species was observed in season 2 (11 species), with somewhat smaller numbers in season 3 (nine species) and season 4 (eight species). In contrast to this result the total nest density increased with age of the willows and poplars: numbers of nests per acre, all species confounded, were 0.03 (season 1), 2.47 (season 2), 4.93 (season 3) and 6.56 (season 4).

Mean nesting density of Willow Flycatchers *Empidonax traillii*, Yellow Warblers *Dendroica petechia* and Cedar Waxwings *Bombycilla cedrorum* increased with age of the plantation. Nesting density of Grey Catbirds *Dumetella carolinensis* leveled off at season 3, and that of American Goldfinches and Red-winged Blackbirds *Agelaius phoeniceus* reached a maximum in season 2 and 3, declining in season 4. Although these trends seemed to hold for all species when comparing nest densities within the same plot, there was considerable variation between plots. This is illustrated for Grey Catbird and American Robin in Figures 1 and 2.

The extent to which birds preferred different clones for building their nests in is illustrated using the combined data from the King Ferry plots (Table 2). Across all species 41% of the nests were found in clone S365 and 24% in the poplar clone NM6. These numbers can be used as a reference to determine if certain species preferred or avoided any clones. The data suggest that American Goldfinches preferred S25 and SA2, while avoiding NM6. NM6 was also avoided by Red-winged Blackbirds and Willow Flycatchers, but clearly preferred by American Robins and to some extent by Grey Catbirds, two species that build large, bulky nests. Clearly the branching pattern of a clone influences the bird's choice of a nesting substrate. S365 was strongly favored by Red-winged Blackbirds, and perhaps also by Yellow Warblers.

CONCLUSIONS

Although based on a limited sample, bird species diversity and nesting density in short-rotation woody crops are quite high. Bird species diversity is highest in season 2 as some bird species that nest in shrubs are still found nesting in the plots, but some early successional forest species are already present. As trees grow and hence foliage volume (and therefore food abundance) increases nesting density also increases.

This study confirms results obtained in the USA, the UK, and Sweden that bird abundance is high in short-rotation woody crops. Our study also shows that brood parasitism by Brown-headed Cowbirds does not seem to be a serious problem. This might be related to the very dense foliage in the plots.

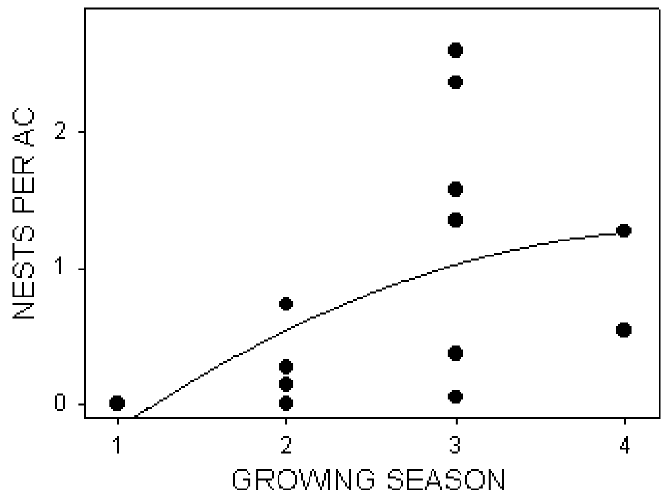

Figure 1. Nest density of American Robin.

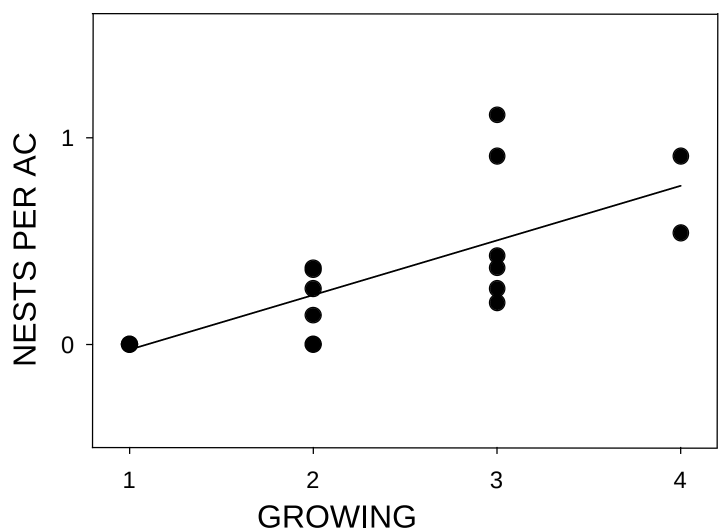

Figure 2. Nest Density of Gray Catbird.

Table 2. Nesting preferences differ between species in the King Ferry plots (growing seasons 2-4 summed). The numbers in the table represent the proportion of all nests of the species found in each clone. The lowest row gives the proportion of nests found in each clone combining all species. Bold values represent clones that are preferred or avoided by particular species.

CLONE	S365	NM6	SV1	S25	SA2	Total n. of nests
BIRD SPECIES		poplar				
American Goldfinch	0.39	**0.04**	0.09	**0.26**	**0.22**	23
American Robin	0.19	**0.55**	0.19	0.03	0.03	31
Cedar Waxwing	0.45	0.30	0.10	0.15	0.00	20
Gray Catbird	0.13	0.33	**0.47**	0.00	0.07	15
Red Winged Blackbird	**0.80**	**0.10**	0.05	**0.00**	0.05	20
Willow Flycatcher	0.45	**0.00**	**0.27**	0.09	**0.18**	11
Wood Thrush	0.00	0.00	1.00	0.00	0.00	1
Yellow Warbler	**0.83**	0.00	0.00	0.17	0.00	6
All species	0.41	0.24	0.17	0.09	0.08	127

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Sustainability of High Intensity Forest Management with Respect to Water Quality and Site Nutrient Reserves

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ABSTRACT

Ensuring sustainability of intensively managed woody crops requires determining soil and water quality effects using a combination of field data and modeling projections. Plot- and catchment-scale research, models, and meta-analyses are addressing nutrient availability, site quality, and measures to increase short-rotation woody crop (SRWC) productivity and site sustainability. Plot-scale (0.5 ha) research began in 1995 in MS, AL, and TN to compare woody and agricultural crops. In 1997, the plot scale expanded to catchment-scale SRWCs plantings (20-40 ha) on International Paper lands in South Carolina. Water quality, erosion, runoff, soil quality, and nutrient cycling are being quantified with production of SRWCs. Combined literature, meta-analyses, field data, and models (NuCM and WATRCOM) are identifying mechanisms to enhance soil carbon, fertilizer and water-use efficiency, and site sustainability, while minimizing nutrient and soil losses. Data and literature analyses demonstrate that soil cover, rates and timing of nutrient application, rainfall timing and intensity, and plant growth are keys to minimizing runoff, erosion, and nutrient transport while maximizing productivity. In SC, decreases in soil water potassium and phosphorus are indicative of previous agricultural fertilization; while increased extractable aluminum reflects increasing site acidification. Modeling simulations and water level management at the SC site are demonstrating mechanisms to enhance tree growth.

Keywords: soil quality, nutrient modeling, nutrient utilization, hydrologic modeling

INTRODUCTION

Dedicated short-rotation woody crops (SRWC) and perennial herbaceous crops, as well as residues, can provide significant feedstocks to support viable biomass to bioenergy and bio-products industries. Incorporating production of intensively managed biomass crops into agricultural systems can provide both economic and environmental benefits. Quantifying environmental benefits, risks and any mitigation measures that may be necessary to ensure sustainable establishment, management, and harvest of SRWC must occur if these benefits are to be realized. Growing perennial biomass crops on agricultural lands, particularly those producing marginal yields or established on more erosive soils, can provide soil and water quality benefits, dedicated feedstocks (Smith, 1995; Grigal and Berguson, 1998), and alternative economic return. The potential impacts from site preparation and production on more marginal lands are greater and the yields probably less than on more productive agricultural lands; however, the greatest gains in soil quality are expected on these lands. Determining management practices that can minimize on-site and off-site effects, e.g., erosion and chemical transport, and matching biomass crop types to appropriate sites, can maximize the environmental sustainability of biomass crop production for multiple end uses.

The combination of site-specific research, literature analysis, and modeling described here summarizes the ongoing research being supported by the U.S. Department of Energy's Offices of Transportation Technologies and Industrial Technologies. The goal of this research is to identify cost-effective management options to increase tree crop productivity while simultaneously enhancing site sustainability and long-term soil productivity. The combined approach evaluates measures to manage off-site movement of sediment and chemicals, develops water management approaches to increase productivity and reduce runoff, and evaluates nutrient budgets to assess nutrient use efficiency. The endpoint is to develop an integrated approach with user-friendly nutrient (NuCM) and water quality (WATRCOM) models that can be used to increase productivity and sustainability of short rotation woody crops. Thornton et al. (1998) and Tolbert et al. (1997, 1998) summarized some of the earlier surface water and nutrient transport results from the small field-scale studies that provided the first layer in identifying practices to increase sustainable SRWC production.

METHODS

Small-scale plantings have been used to quantify water and soil quality and productivity of sycamore compared with no-till corn for at a site in western Tennessee (TN), sweetgum with and without a cover crop compared with no-till corn at a site in northern Alabama (AL), and cottonwood in Mississippi (MS) since 1995. Earthen berm enclosures were used to exclude runoff from outside the plots and to quantify runoff, sediment, and nutrient transport from the individual plots. At the TN and MS sites the replicated plots were 0.5 ha and at the AL site 0.25 and 0.5 ha. This event-based monitoring will continue at least through 2001 at the TN and AL sites. Detailed descriptions of the plot-scale study methods are available in previously available publications (Joslin and Schoenholtz 1998, Thornton et al. 1998, Tolbert et al. 1997, 1998)

Catchment-scale (20-40 ha) plots and watershed scale (~500 ha) plantings were established on International Paper lands in SC to assess factors controlling off-site movement of nutrients, chemicals, and water, and long-term soil sustainability of larger scales. Replicated SRWC plantings [two using current management techniques for tree crop production (sweetgum with open drainage -SWO and sycamore with open drainage – SYO), and one incorporating agronomic water management practices for SRWC production (sycamore with controlled drainage structures - SYC)] were established in late 1996. The treatments represent commercially feasible systems of tree species, fertilization, weed control and water management regimes. The six catchments are instrumented to measure surface and subsurface water quality and surface water discharge. Soil nutrients, carbon, and tree productivity are measured annually. The combination of the small-scale, catchment-scale and two second-order watersheds (~500 ha) are providing the basis to evaluate the ability to use results from multiple scales to make predictions of effects of landscape-scale SRWC production. Field data from the SC site are providing input to the meta analysis on nutrient turnover and for models for hydrologic and nutrient cycling.

Existing information on nutrient reserves and nutrient amendments in short rotation biomass plantations is being compiled into databases for meta analyses using the method of Curtis (1996). These databases are being used to assess the factors affecting the sustainability of site nutrient reserves and the effects of nutrient amendments on water quality. Sources of information included are published reports obtained from literature searches and inquiries from forest scientists via the International Energy Agency.

Process-based hydrologic (WATRCOM) and nutrient based (NuCM) models are being used to develop an integrated modeling framework to assess the sustainability of SRWC with respect to water quality and site nutrient reserves. Data from the SC site are being used to parameterize the models to develop a user-oriented model platform for operational use by the forest products industry.

RESULTS AND DISCUSSION

Results from the plot-scale studies through 1997 have been reported in several publications (Bandaranayake et al. 1996, Thornton et al. 1998; Tolbert et al. 1997, 1998, Tolbert and Wright 1998). Establishing short-rotation tree crops on former agricultural sites has been shown to provide positive benefits for water and soil quality. At the AL research site establishing a 60-cm wide herbaceous cover crop centrally between tree rows significantly reduced sediment transport from the plots especially during the initial year of establishment (Green et al. 1996, Malik et al. 2000). Sweetgum productivity from 1995-97 did not show a competition effect of the 60-cm wide fescue cover crop.

Soil quality

Comparisons on small-scale plantings showed that soil organic carbon (SOC) increased by 19% in the upper 2.5 cm with conversion to cottonwood production; the total soil carbon mass (excluding stumps and coarse organic matter) was 15 Mg ha^{-1}. With stump and coarse roots included, the belowground biomass was approximately 18 Mg ha^{-1} (Tolbert et al. 1998). At the TN site SOC increased by 27% and 34%, respectively, under no-till corn grown with a winter cover crop and sycamore. The increased SOC storage under the sycamore was approximately 1.3 Mg ha^{-1} yr^{-1}. Soil carbon significantly increased ($p \leq 0.02$) under switchgrass, sweetgum with a cover crop, and no-till corn from 1995-1997 at the AL site. By contrast soil carbon under sweetgum without a cover crop decreased by 6% over the same period (Fig. 1). This carbon loss is consistent with Hansen's (1993) measurements showing soil carbon decreases during the initial years of tree crop establishment with use of cultivation.

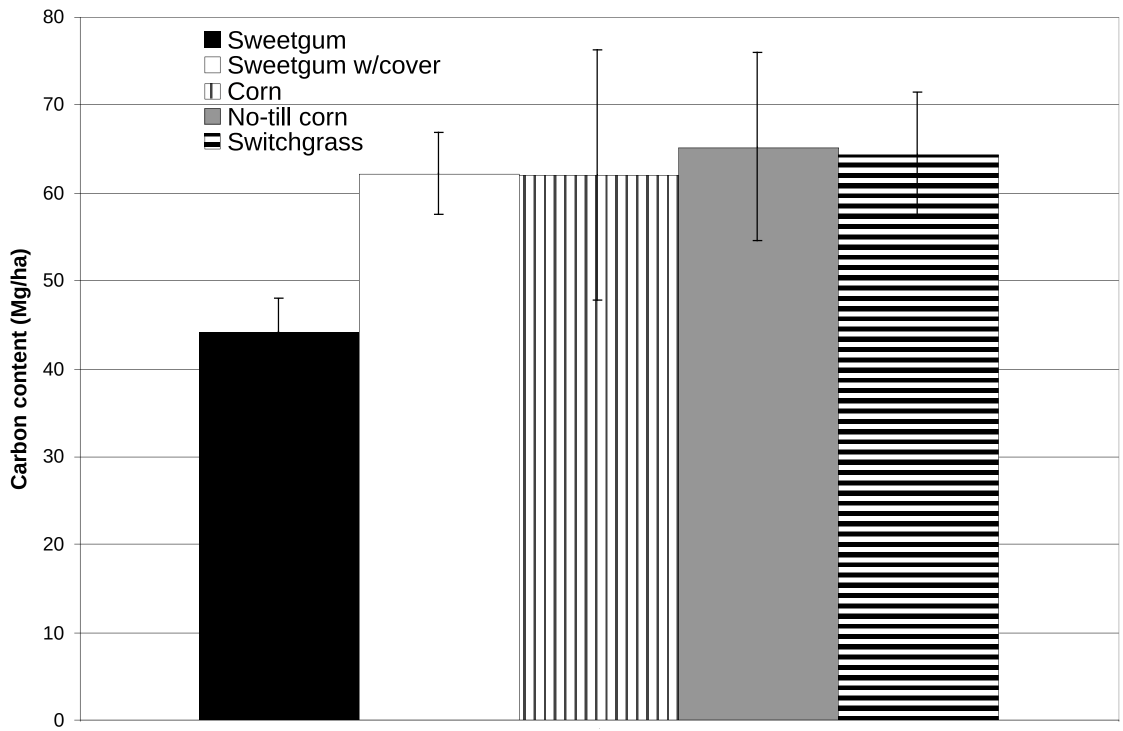

Figure 1. Mean soil organic carbon by treatment at the AL site after the fourth growing season.

At the South Carolina (SC) site, elevated extractable cation levels reflected differences in parent material and genesis between the Coxville and Goldsboro soils. Extractable K was greater in the upper 30 cm on the sweetgum plots than the sycamore plots. Phosphorus exhibited effects of past agricultural management, with the sycamore-open drainage catchments having significant higher levels than the other two treatments; all treatments had elevated levels in the upper 30 cm. Extractable K and P declined between 1997 and 1998 in the sycamore-open drainage treatment indicating a loss of P from the surface soil that is not being maintained by the current fertilization regime. Comparisons of carbon allocations into soil and aboveground components at the SC site show that there are dramatic differences in allocation between sycamore and sweetgum (Fig. 2) with sweetgum allocating significantly more carbon to the soil component over the first three years of growth.

At the TN site, soil samples taken from 1995 – 1998 showed the greatest changes in soil properties within the upper 30 cm. Initial comparisons showed bulk densities and penetration resistance to be lower under 13-year old sycamore than the newly established sycamore and no-till corn. Both penetration resistance and bulk density at 0-30 cm decreased significantly over time in the younger sycamore plots compared with the no-till corn plots. The hydraulic conductivity and infiltration rates in the cottonwood plots at the MS site were more than twice as great as in the continuous cotton plots (12.47 vs. 4.6 and 44.7 vs. 20.0 cm/hr, respectively (Tolbert et al. 1998). Bulk density in the upper 10 cm decreased over the 3-year cottonwood production (1.4 Mg m^{-3} in 1995 to 1.1 Mg^{-3} in 1998) as the result of increased incorporation of organic material and root penetration. Soil bulk density and infiltration at the SC site ranged from 1.42 Mg m^{-3} in the A horizon within the planting bed for treatment SYC to 1.79 Mg m^{-3} in the B- horizon, between

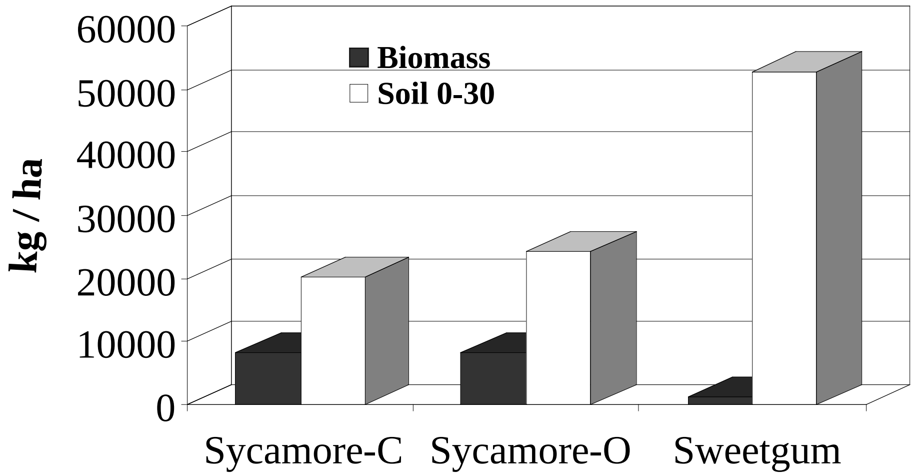

Figure 2. Allocation of carbon by sycamore (C – closed drainage, O – open drainage) and sweetgum at the SC site.

beds for treatment SWO. Sample infiltration rates ranged from 1.0-104.1cm per hour.

Runoff was reduced with production of SRWC relative to agricultural crops. The reductions, which were greatest with eastern cottonwood, then sycamore, and finally sweetgum match the species growth and site occupation rates and show the effect of higher rainfall interception and evaporative losses by tree foliage (Mitchell 1997) and increased litter cover. At the AL site, sweetgum plantings with a cover crop produced 25% less runoff than the no-till corn plots.

Hydrologic data are currently being collected at the SC site and provide the opportunity to compare water availability with and without use of flashboard risers to retain water on the site and to determine water availability for comparison with plant growth responses. Water level simulations are contributing to the WATRCOM simulations of water level management at the SC site (Fig. 3).

Water quality

Water quality comparisons overall for the plot scale sites show that runoff transport of nitrate was greater from the row crops than from the tree crops (at the TN and AL sites). As would be expected, nutrient transport was greatest when runoff events occurred soon after fertilizer application.

Soil water at the SC site is acidic, averaging pH 5.39, 5.21, and 5.63 for the SWO, SYO, and SYC treatments, respectively. In 1997-98 there were significant differences in pH but little difference in Ca and Mg among the SRWC treatments during this period. Calcium and Mg levels in the SRWC plantings were greater than in soil water collected in the agriculture reference plot, presumably a result of past management practices. Potassium exhibited variation among treatments with no discernible treatment effects or temporal patterns. Elevated NH4 -N following the spring 1998 application of fertilizer was evident in the soil water. The levels declined within a month, but remained elevated relative to the 1997-growing season. Overall, levels of NH4 -N have consistently been below 1 mg l^{-1}. Nitrate levels, across all treatments, have been low during the winter

(Nov. - March) and then increased in the spring probably a result of fertilizer application and nitrification. The strong temporal pattern suggests that nitrification (of both organic and fertilizer NH^4 -N) is the primary mechanism. Nitrate levels in the SRWC plantings exceeded those in the agricultural reference at all times. The NO^3-N levels in the SRWC plantings represents a mobile N pool, which is likely in excess of vegetation or microbial demand. This suggests that the N fertilization rates are too high for the present stage of stand development.

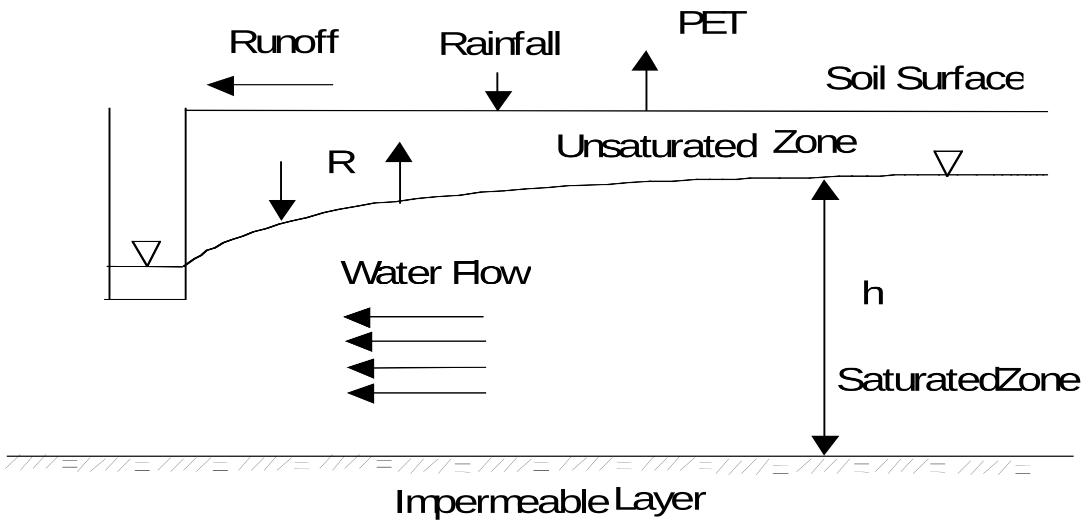

Figure 3. Schematic representation of the water flows simulated in the saturated zone along with linkages to the unsaturated zone for WATRCOM hydrologic model.

Literature Survey and Meta Analysis

Existing literature on nutrient losses and fertilizer recovery in forest systems has been compiled and summarized in separate databases on the effects of forest harvesting on soil carbon (Johnson and Curtis In press) and fertilizer nitrogen recovery. The meta analysis of the harvesting and soil C data base revealed no significant differences between whole-tree and sawlog harvesting, each producing an average soil C increase of approximately 22%. There were significant-time-since-harvest effects, where little differences in soil C (4-8%) were noted within the first five years of harvest and considerably more during years five to twenty. The analysis of depth effects revealed a perhaps spurious result: the greater accumulation of soil C in deeper horizons than in surface horizons. Further refinements of these analyses are being conducted.

The literature analysis of fertilizer recovery and allocation by trees was an update of a database previously reported by Johnson (1992). The developed database on fertilizer nitrogen recovery is being used to assess factors affecting the sustainability of site nutrient reserves, allocation of site available nitrogen, and effects of nutrient amendments on water quality. The comparisons to date of the fertilizer N recovery using the meta analysis show that the type of fertilizer applied effects the retention of the fertilizer applied (Fig. 4). For example, ammonium nitrate was retained approximately in equal proportions by soil, litter, and stem whereas applied urea was retained primarily in the soil and litter and NO_3 primarily in the stem and soil. Data from multiple studies show that single annual applications of fertilizer showed greater on-site retention of nutrients than from multiple fertilizer applications (Fig. 5). Application of less than 150 kg resulted in greater retention than 150-500 kg and particularly more than 500 kg. Linking these meta analyses with data from the catchment-scale studies, and nutrient models can begin to guide application of fertilizer to SRWC to maximize their productivity, environmental benefits for soil and water quality, and economic competitiveness.

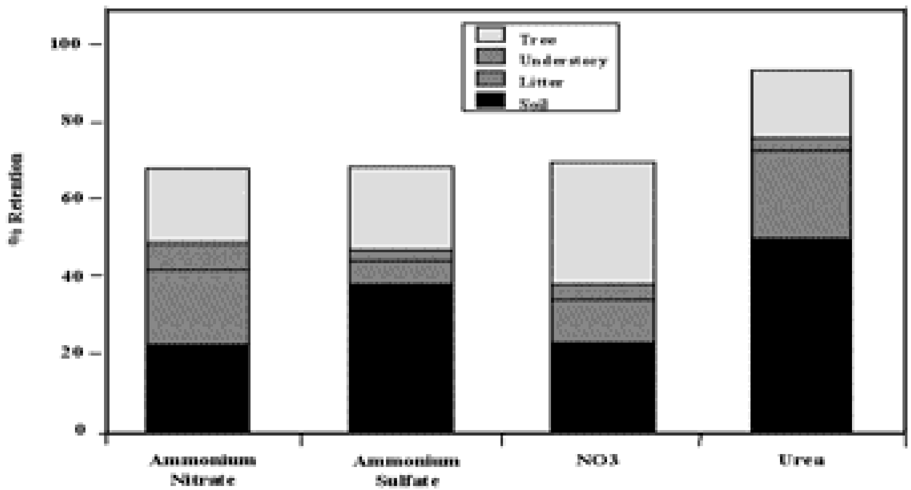

Figure 4. Comparison of retention of fertilizer show that the type of fertilizer applied influences the retention of fertilizer by forest components.

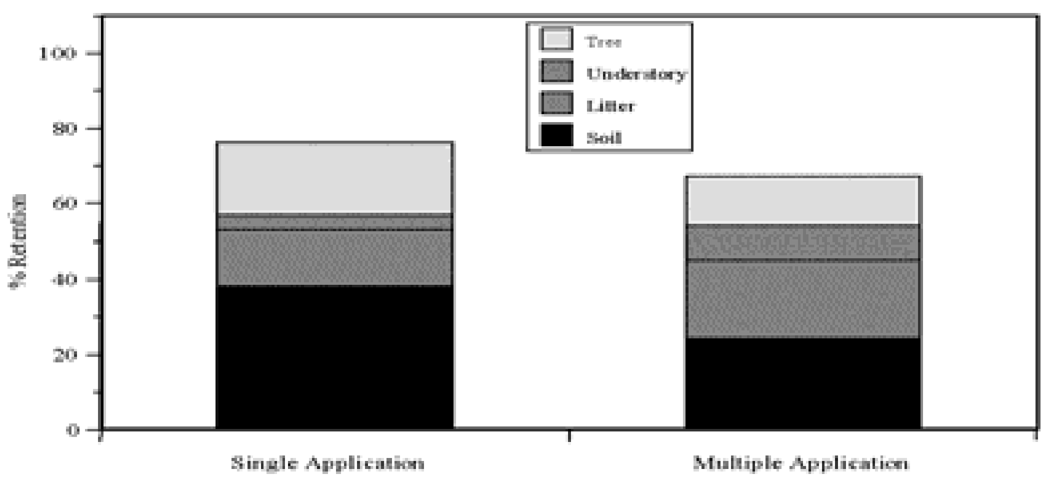

Figure 5. Comparisons of retention of fertilizer within different forest components based on single applications compared with multiple applications.

Calibration of the NuCM Model

The results of the meta analysis are currently being used along with the SC field data and the NuCM nutrient model to determine whether the timing of nutrient additions and their allocation within the system are reflected in the patterns of nutrient requirements and losses from intensively managed tree crops at the SC site. Meteorological data, including precipitation chemistry and air quality, and soils and vegetation data for the South Carolina site are currently being collected for calibration of the hydrological and chemistry sub-models of NuCM for the SC site.

SUMMARY

The combination of small field-scale and catchment-scale comparisons of productivity of woody crops in combination with hydrologic and nutrient models and databases summarizing information on SOC retention with different harvesting practices and nutrient management are providing powerful tools to help increase the sustainability of SRWC production. Conversion of agricultural croplands to SRWC production can have positive benefits for both soil and water quality. Production of SRWC on agricultural lands can also contribute to increased SOC. The combination of small- and catchment-scale research studies show that different SRWC respond to variations in soils and that nutrient requirements differ for different tree crops and different soil types.

Identifying appropriate management practices for nutrient additions can contribute to environmentally sustainable production of SRWC and to reducing economic costs for their production. Identifying changes in nutrient content and productivity with time and developing user-friendly models for nutrient and water use can also assist individual and operational scale growers to identify best management practices for nutrient content, application, and timing to maximize sustainable production. The combined projects will continue monitoring runoff, water quality, and soil chemistry, including SOC, at both small- and catchment- scales during the middle rotation years (5 – 8) of production cycles. Continuing to monitor these soil and water quality parameters will allow us to determine (and document) whether patterns change over time and whether the quantified benefits of cover crops for soil and water quality continue. At the AL site monitoring productivity and SOC over time will help determine whether SOC on the plantings with a cover crop will continue to outpace that of the sweetgum without a cover crop plantings. This has important implications for both soil and water quality with larger-scale production of woody crops. If productivity data from comparisons of the effects of different cover crops at the AL site show significant nutrient and productivity benefits for the tree crops from use of different cover crops, there could be increased interest and use of cover crops at production scales to increase sustainability and productivity. The AL and SC sites offer opportunities to determine if cover crop and water level management can provide enhanced nutrient availability and use efficiencies to enhance productivity. Management options under consideration for harvesting and replanting at the TN site can provide additional information for establishment, site management, and harvest to increase both yields and sustainable production. Monitoring changes, testing options, and documenting measures to increase economic and environmental potential of SRWC can increase their adoption for energy, bio-based products, and fiber.

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Soil Carbon Pool in a Short-Rotation Willow (*Salix dasyclados*) Plantation Four Years After Establishment

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ABSTRACT

Soil carbon (C) pools, i.e., whole soil (WSC), and particle size fractions; sand (SaC), silt (SiC), and clay (ClC), within 0-60 cm soil depth of willow [*Salix dasyclodos* (SV 1)] short rotation intensive culture (SRIC) plantation were compared with adjacent non-woody vegetation (control) plots four years after plantation establishment. The sites had similar management history and by assumption similar soil C levels prior to plantation establishment. Particle size fractions were obtained using physical fractionation procedures. Carbon, determined by wet oxidation, did not differ significantly ($P > 0.05$) between willow and non-woody vegetation plots in concentration (g/kg), mass (g C/kg fraction), and enrichment (E = % fraction C/% soil C). We hypothesized that SRIC systems could impact soil organic matter (SOM) pools differently. The general increasing trend for pool C concentration was SaC < WSC = SiC < ClC and for mass SaC < ClC < SiC. Sand was C depleted whilst silt and clay were C enriched. We conclude that four years of tree presence maintained or caused no decline in initial soil C pools.

Keywords: carbon concentration; carbon mass; carbon enrichment; willow (*Salix dasyclados*); short-rotation intensive culture.

Poster Presentations

The Development of a Small Scale Combined Heat and Power Plant Using Down Draft Gasification

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ABSTRACT

From the outset of the research and development programme on short-rotation coppice willow as an energy crop in Northern Ireland, the investigation of markets and utilisation formed an important and integral part of the project. Downdraft Gasification Technology was sourced from the University of Lourvain la Neuve in Belgium and 100 kW commercial prototype was installed at the Department's Agricultural College in Enniskillen, Co. Fermanagh. Developments in the design and operations of both the gasification system and its associated gas cleaning systems led to the consistent production of a high quality clean gas supply allowing continuous engine running and generation. At this point a new company, Rural Generation, was formed, charged with the full commercialisation of the plant. The first of these plants was installed at Brook Hall Estate in Londonderry where 42 ha of willow coppice had been established as the fuel source. A second has been commissioned at Boughton in Nottinghamshire where it has been installed in a renovated pumping station functioning as a conference centre. Currently, as well as the accumulation of operational data, future developments centre around the replacement of the conventional gas/diesel engine with small scale gas turbine. This turbine has been specially designed by Queens University Belfast to operate on gases with a low calorific value.

Keywords: down draft gasification, willow

INTRODUCTION

Work on short-rotation coppice willow began in Northern Ireland in 1974-5 in response to a projected European shortfall in cellulose for paper manufacture. The work was undertaken for the Paper Industry Research Association. In the late 1970s the focus of the work changed to its production and use as an energy crop following the oil crises in the Middle East. (McElroy and Dawson, 1986). Although recently the price of oil in Europe has shown a dramatic rise, it has not returned in real terms to the disastrous level of the late 1970s. However, the research and development input into short-rotation coppice willow has been maintained because of two significant developments.

The adoption by the United Kingdom of the 12.5% reduction commitment in carbon dioxide emissions by 2010 as part of the 'burden sharing' agreement within the overall European Union commitment of 8% reduction following the Kyoto agreement. Nationally the United Kingdom government has adopted a much more challenging target of 20% reduction in the same time frame (Anon., 2000a). Whilst to achieve these targets will require action on an extremely wide front including transportation, energy conservation etc. renewable energy sources will have a major part to play. In a United Kingdom context wind and energy from biomass are seen as the most mature technologies in the renewable portfolio. A recent review of the potential renewable technologies in Northern Ireland (Anon., 1999) indicates a maximum contribution of 160 GWh yr^{-1} for wind energy by 2025 with energy crops, including forestry residues and short-rotation coppice, contributing 256-279 GWh yr^{-1}.

The second significant development concerns the decline in agricultural income in the United Kingdom in general and Northern Ireland in particular since 1995 when they were at their peak. In Northern Ireland where agriculture is grass based, the crisis in farm income was particularly serious with its heavy dependence on an exporting beef industry. In the period from 1995-1997 total farm income dropped by 35% from a total in 1995 of £305m to £109m. In 1998 and 1999 further drops 52% and 22% respectively occurred reducing total farm income to £71 million, its lowest level since 1980 (Anon., 2000b). This drastic drop in profitability and changing priorities within the European Union's common agricultural policy require a major shift in agricultural production strategies. However, in Northern Ireland the mild, wet oceanic type of climate and its generally heavy moisture retentive soils limits the choice of alternative agricultural enterprises. Only 6% of Northern Irelands agricultural land is classified as arable. In these circumstances the production of energy from short-rotation coppice willow offers a significant opportunity to the agricultural industry, as a sustainable alternative agricultural system.

Development of a Utilisation Strategy

Most of the early research and development work involved the basic agronomy of the crop, pre-planting site treatment, varieties and planting densities, harvesting regimes etc. (Dawson, 1992). However, at the outset it was recognised that, in parallel with this agronomy-based research and development, end uses for the coppice product needed to be developed, if short-rotation coppice was to maximise its potential. In addition to the successful direct combustion route to produce heat, attention was focused at upgrading the energy output by conversion to electricity whilst at the same time maintaining efficiency by designing the system in a combined heat and power configuration.

As already indicated, farm structure in Northern Ireland is somewhat different than the rest of the United Kingdom. In addition to the small size of individual farms, approximately half the average size of the rest of the United Kingdom, individual field size is also extremely small. This imposes logistical limits on the size of any conversion unit developed. As a consequence the strategy adopted in Northern Ireland was one of small embedded or distributed generating facilities in the range 0.1-0.3 $MW_{(e)}$ where the electricity is supplied directly to the consumer.

Embedded power generation has a number of advantages. It can be installed where the grid is weak and it avoids the losses and/or investments related to the transmission and distribution of electricity. At this scale it also provides the opportunity of making use of the co-generated heat locally to the unit. In this way total efficiency figures of up to 85% have been recorded. In this situation where the farmer, or groups of farmers, takes ownership of the conversion facility, the problems encountered with most other agricultural commodities, where it is the raw material and not the final added value product is sold, are avoided.

However, even in this situation the economics are only marginal (Dawson, 1999) and a dual-purpose crop would enhance the economic sustainability. In this context the use of short rotation coppice willow as a bioremediation system for municipal wastewater/sewage sludge is being investigated. Here the avoided costs for chemical treatment or incineration by the utility can be considered as added value to the coppice system.

Gasification Technology

The downdraft gasification technology used in this development was sourced from a research project in Belgium in the University of Louvain in Neuve being carried out by Prof. J Martins. Initially in 1993 the Department of Agriculture and Rural Development installed a $100kW_{(e)}$ prototype in a small Agricultural College in Enniskillen, Co. Fermanagh, in the west of Northern Ireland. Over the next two years engineering changes and operational experience resulted in a system which was robust, easy to start up and shut down and which delivered a consistent flow of high quality gas to the dual fuel gas/diesel engine used in the system. (Dawson *et al*., 1996). At this stage proof of concept had been achieved and in 1996/97 the system was offered for commercial development and a company, Rural Generation, was established to effect full commercialisation of the system.

Brook Hall Rural Generation System

After initial appraisal, the first of a new generation of downdraft gasification based combined heat and power plants was designed and installed by Rural Generation as an on-farm system at Brook Hall in Co. Londonderry. This system was switched on in 1997 and since then has accumulated in excess of 11,000 hours operation time. Major engineering adjustments have been made principally to the hearth and to the early stage particulate removal element of the gas clean up system. This is the first on-farm generating plant, which has come on-stream and is operating under the United Kingdom 'Non Fossil Fuel Obligation'. This is a mechanism whereby the government offers a 15 year inflation proof contract for renewable energy technologies, which have not yet reached the market place, as a result of a competitive bidding process. In this case a minimum price of 6.95 p kWh^{-1} was awarded. This price can be further enhance by generating at advantageous times under the operation of a season and time of day tariff.

The production of the short rotation coppice takes place on set-aside land, a European Union support scheme which compensates farmers for taking land out of food production. As a result, in this instance in addition to an establishment grant of £400 ha^{-1} in year one, the enterprise also attracts five years compensatory payments of just under £300 ha^{-1} making a total support of approximately £1900 ha^{-1} over five years. For the $100kW_{(e)}$ system approximately 42 ha of willow coppice will be required assuming a yield of 12.0 tonnes oven dried wood per hectare per year. This will give an annual production of approximately 500 tonnes of dry wood by chip harvesting 14 ha on a three-year cycle. This production level will be sufficient to operate the plant for just over 6,000 hours per year and would represent a carbon dioxide saving of 1.4 tonnes per day or over 500 tonnes per year. Potentially this system can generate 600 MWh of electricity annually and it has been estimated that the net annual revenue taking into consideration the fuel and maintenance costs is in excess of £20,000 yr^{-1}. The heat recovered from the exhaust and cooling systems is used for fuel drying, space heating, and grain drying in the estates' cereal enterprises.

In addition to accumulating operational data, future developments of the Brook Hall plant will include the replacement of the engine with a micro-turbine. A turbine designed by Queens University Belfast to operate on low calorific value gas is already on site and testing with the gasifier has begun. The successful bringing together of these two technologies will have significant implications on capital costs, maintenance costs, efficiency of operation and other less tangible environmental benefits such as noise reduction. This latter point may well have important implication for these small embedded systems.

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Variety Mixing and Planting Density Effects on Herbivory by the Blue Willow Beetle *Phratora vulgatissima* (Coleoptera: Chrysomelidae)

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ABSTRACT

Willow and poplar are the most promising short-rotation coppice species grown presently in the United Kingdom as possible sources of bioenergy. Few invertebrate pests have a serious impact on the yield of these species. However, the chrysomelid beetle, *Phratora vulgatissima*, is the predominant invertebrate pest of willow in the UK causing significant damage and yield loss to willow clones presently being investigated for biomass production. In trials to investigate the effect of mono-culture, mixed variety and planting density on the rust, *Melampsora* spp., five willow varieties were damaged significantly more than others by *Phratora vulgatissima*, indicating preferential herbivory. Mixed variety planting retarded the build-up of rust and there was a trend towards reduced willow beetle damage in the preferred varieties in mixtures. Planting density had no significant effect on the incidence of willow beetle herbivory.

Keywords: Willow beetles; *Phratora vulgatissima*; herbivory; *Salix*; mixed varieties; rust; *Melampsora* spp.

INTRODUCTION

Research into the use of bioenergy and production of energy crops began in the UK in 1979. The interest at the present time in these crops is due, not only to their use for energy production, but also to the environmental benefits which they offer in terms of reduction of greenhouse gas and as an alternative source of income and employment to rural communities. The most promising energy crops in the UK are short rotation coppice willow and poplar since the mild wet climate is very suitable for this production system. Sage and Tucker (1997) conducted a survey of the invertebrates in the canopy of willow and poplar short rotation coppices in Britain and Northern Ireland. While they recorded over 50 invertebrate species or groups, the majority were found in the willow plantations, and the degree of defoliation was correlated most closely with the abundance of the leaf-eating beetles *Phratora vulgatissima*, and *Galerucella lineola*. High population densities of beetles (20 m^{-3}) were found at some sites and at one of these 68% leaf loss was recorded.

Rust, caused by *Melampsora epitea* var. *epitea*, is probably the greatest limitation to the growth of willow (*Salix* spp.) in short rotation coppice for biomass. The disease can affect a wide range of *Salix* species and varieties. In the most susceptible varieties rust causes heavy premature leaf fall followed by infection by a whole spectrum of secondary pathogens which can result in death of shoots and even stools (McCracken and Dawson 1992). Although rust can be controlled by the intensive use of fungicides (McCracken and Dawson, 1990; 1997) it was clear that this was not a viable approach to disease control. Early work reported by Wolfe (1985) indicated that mixtures of multilines or cultivars of cereals was an effective method of reducing the impact of diseases, especially those caused by obligate pathogens such as rusts and mildews. Therefore in the mid- 1980s trials were planted in Northern Ireland, which comprised mixtures of willow species and varieties, in order to test their effectiveness in reducing rust. These early trials indicated that when a susceptible willow variety was included in a mixture the first appearance of rust was delayed, the build up of the disease slowed and the final levels of rust significantly reduced compared to the same variety growing in a mono-culture (McCracken and Dawson, 1997). Subsequent trials were planted with a view to determining the effect of numbers of varieties within a mixture, the impact of planting density and the performance of some of the newer planting material within mixtures. This paper reports the effect of variety mixing and planting density on herbivory by the willow beetle, *Phratora vulgatissima*.

MATERIALS AND METHODS

Plantations were established at Castlearchdale, County Fermanagh, Northern Ireland ($54^0$28'N $7^0$43'W), 60-70m above sea level, on a site with heavily gleyed soils, and impeded drainage. The trial was planted in two replicate blocks. Block 1 was planted in spring 1994 and block 2 in spring 1995. Both blocks were cut back at the end of their establishment year and block 1 again in 1995/96 meaning that in the summer 1996 both blocks were at the same stage aboveground, i.e. regrowth from freshly coppice stools. Twenty *Salix* spp. varieties (Table 1) were planted in large mono-culture (32 x 14m in Block 1 and 32 x 11m in Block 2) in double rows in a split plot design with three densities - 10,000ha^{-1}, 15,000ha^{-1} and 20,000ha^{-1}. Four mixture combinations were employed comprising 5, 10, 15 and 20 varieties (Table 1). All mixtures were planted as fully random intimate mixtures. A map was prepared of the planting pattern at the time of planting so that subsequently each stool could be identified.

Leaf samples were collected in 1999 and 2000 from mid-June at two week intervals. At least 100 leaves were taken from approximately ten stools of each variety growing in mono-culture and in mixtures. The leaf samples were scored for rust and also assessed visually for willow beetle damage. Herbivory was scored as the percentage of each leaf removed and a mean score was calculated for each variety in mono-culture and in mixtures.

RESULTS

The levels of willow beetle damage to leaves from the various varieties in mono-culture are shown in Figure 1. Overall, damage levels were moderate. However, five varieties exhibited damage, which was significantly greater than the others. These were *S.viminalis* 78118, *S.viminalis* 870146 ULV, *S.viminalis* x *caprea* V789, *S.viminalis* 77683 and *S.viminalis* Gigantea.

When the results from the mixture plots were examined, these varieties showed a trend towards reduced damage with increasing numbers of other varieties in the mixtures (Figure 2). There was no significant effect of planting density on the degree of willow beetle damage.

Table 1. List of *Salix* spp. varieties planted in 5, 10, 15 or 20 way mixtures.

Variety No.	Variety	Mixture			
3	*S. burjatica* Germany	5	10	15	20
4	*S. mollissima-undulata* SQ83	5	10	15	20
13	*S. dasyclados* x *aquatica* V7511	5	10	15	20
17	*S. viminalis* 77082	5	10	15	20
26	*S. dasyclados* x *caprea* V794	5	10	15	20
14	*S. viminalis* x *aquatica* V7503	-	10	15	20
23	*S. viminalis* 78118	-	10	15	20
28	*S. viminalis* 78183	-	10	15	20
32	*S. schwerinii* x *viminalis* x *dasyclados* V7531	-	10	15	20
48	*S. viminalis* 870146 ULV	-	10	15	20
12	*S. viminalis* x *caprea* V789	-	-	15	20
18	*S. viminalis* 77683	-	-	15	20
21	*S. viminalis* 78101	-	-	15	20
29	*S. viminalis* 78195	-	-	15	20
34	*S. schwerinii* x *aquatica* V7534	-	-	15	20
1	*S. viminalis* 77699	-	-	-	20
6	*S. viminalis* Gigantea	-	-	-	20
9	*S. viminalis* Gustav	-	-	-	20
45	*S. schwerinii* x *aquatica* V7533	-	-	-	20
46	*S. viminalis* 870082 ORM	-	-	-	20

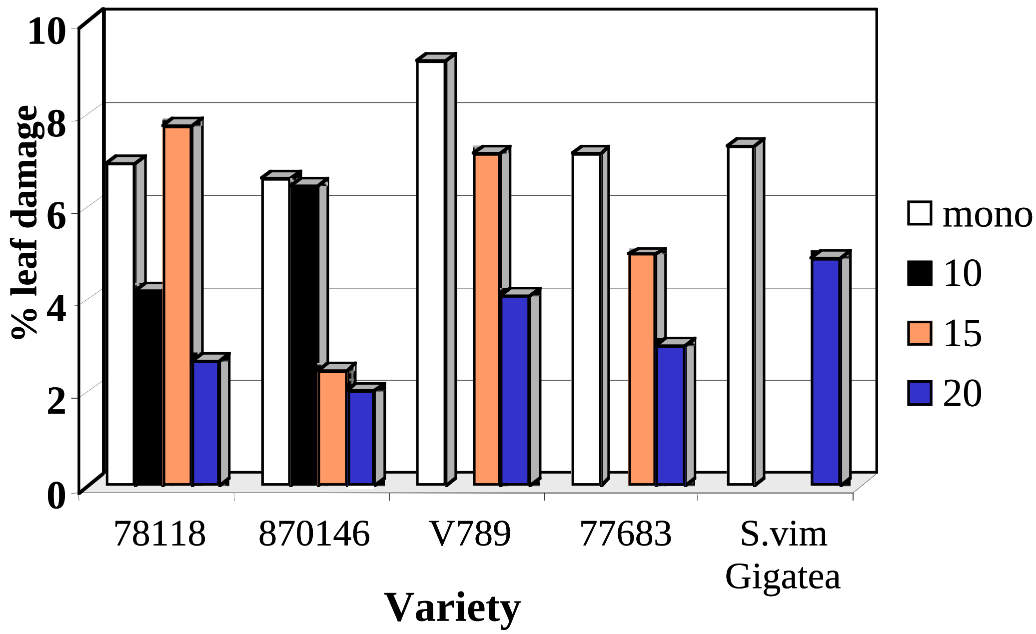

Figure 1. Willow beetle damage to varieties in mono-cultures. The dark bars indicate those varieties which show significantly higher levels of damage.

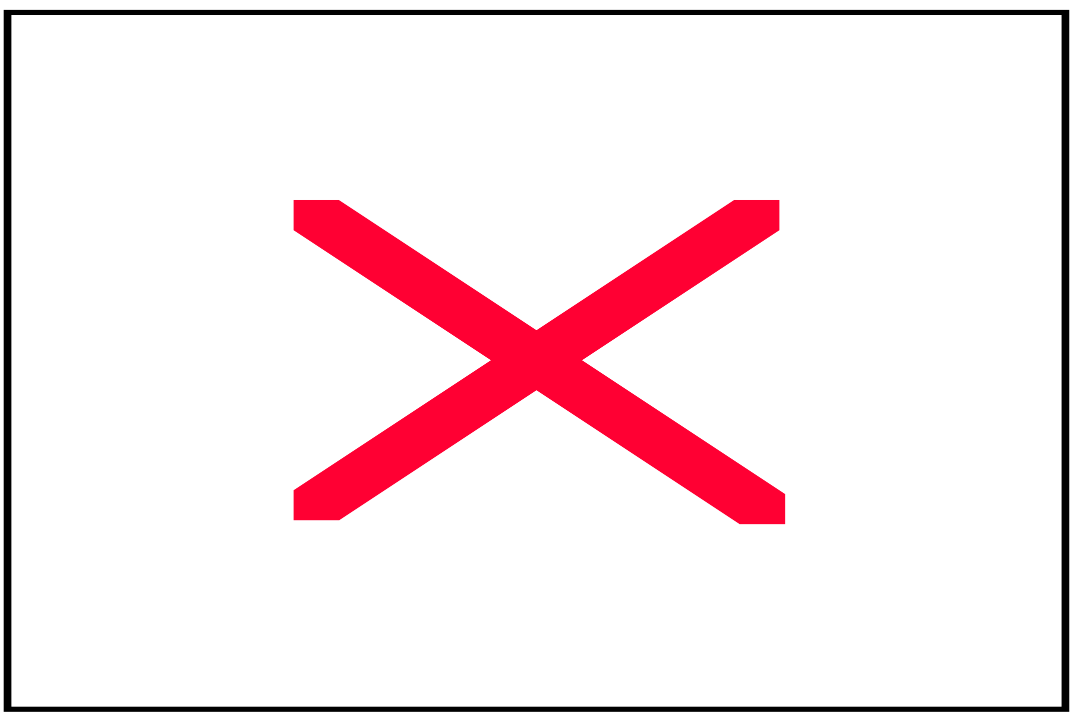

Figure 2. The effect of mono-culture and mixed variety planting on herbivory in five varieties selected preferentially by *Phratora vulgatissima.*

DISCUSSION

There was clear evidence of preferential feeding on some of the varieties in the mono-culture and mixed variety plots. Preferential feeding of *Phratora vulgatissima* on different varieties of willow is documented in the literature (Sage and Tucker, 1998;

Kearns, 1934), and the results in the present trial indicate that five of the varieties could be at risk of significant damage in years when willow beetle populations are high. Kendall, Wiltshire and Butcher (1996) investigated the effect of defoliation on willow yield. They manually defoliated plants at two times during the growing season, early defoliation in June and late defoliation in August, to simulate damage during the two peaks of willow beetle activity. Damage at both times caused significant reduction in biomass yield of *Salix viminalis*. There was some evidence that the plants could partially compensate and recover from the early damage but not from late defoliation. In a further publication (Kendall and Wiltshire, 1998) cited the figure of 10% defoliation as a threshold for significant impact on the yield of coppiced willows. Bell and Clawson (2000) reported that high levels of defoliation could lead to yield losses of around 45%.

There was a trend towards lower damage in the preferred varieties when they were included in mixed plantings. Although this result did not achieve statistical significance, it does suggest that the inclusion of damage-susceptible varieties in mixed plots may offer them some protection from willow beetle attack. It is likely that this would have become more obvious if beetle populations had been higher during the period of this study.

The conclusion from this work is that mixed variety plantings of willow offer useful benefits in terms of retarding the progress of rust within the plot, and this in turn has positive effects on biomass yield. Herbivory by willow beetles is selective and targets preferred varieties. However, there is a suggestion in the present results that mixed plantings may offer these varieties a degree of protection against willow beetle attack.

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Results of a Species Selection Trial on the Jos Plateau, Nigeria

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ABSTRACT

Reforestation efforts on the Jos Plateau in the late 1980s focused on raising and distributing *Eucalyptus camaldulensis* seedlings. The current study screened 34 other species and four provenances of *E. camaldulensis* that may be useful for reforestation and agroforestry efforts. Trees were planted on three marginal sites in the region. Survival after three growing seasons did not vary significantly across the three sites – Kai was 39.2 ± 8.0%, Wereng was 40.5 ± 5.4%, and Fobur was 56.8 ± 8.1%. Height growth varied significantly across the three sites. It was lower at the tin mine spoil site - Wereng (26.3 ± 3.8cm) - compared to the other two sites - Kai (76.3 ± 17.0cm) or Fobur (83.8 ± 16.7cm). The introduced provenances of *E. camaldulensis* had the greatest height growth on the non-tin mine spoils sites. *Acacia auriculiformis* and *A. holosericea*, at Fobur and Kai respectively, had height growth similar to the local provenance of *E. camaldulensis*. Results indicate that other species can be established as successfully as *E. camaldulensis* on these sites; however, the success of each species varies from site to site.

Keywords: Eucalyptus camaldulensis, savanna, reforestation, tin mining

INTRODUCTION

At the start 1900s open woodlands covered a significant portion of the Jos Plateau. Over several decades population increases related to the development of the tin mining industry increased pressure on these woodlands, resulting in almost complete deforestation of these areas (Wimbush 1963). The first reforestation efforts occurred in the late 1940's and were focused on revegetating the tin mining spoils, which cover about 321 km^2 on the Jos Plateau (Figure 1) (Alexander 1989a). Initial efforts included intensive site preparation of the spoils and were reasonably successful. However, it became increasingly costly to conduct this work and subsequent efforts on the tin mine spoils, with less site preparation, were not as successful (Wimbush 1963).

Despite the decline in the tin mining industry from the late 1960s onwards, demands on wood resources for wide range of products continued to be greater than the remaining resource. In response to this need, and the negative impacts of erosion and desertification associated with deforestation, the Plateau State Afforestation Project (PTPU) was initiated (Varelides 1993). Earlier trials with exotic tree species indicated that *Eucalyptus camaldulensis* was one of the fastest growing species for the savanna region (Otegbeye 1985), so it became the focus of PTPU's seedling distribution effort.

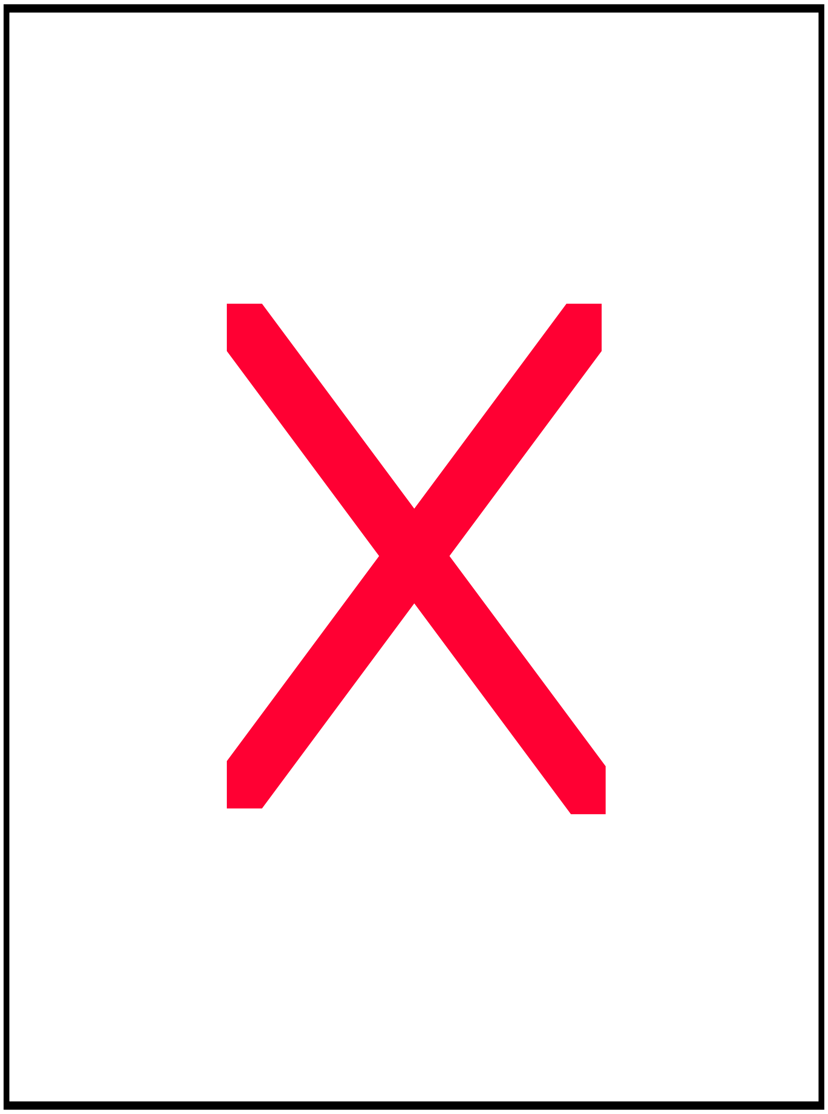

Figure 1: Location of study sites and the extent of tin mining on the Jos Plateau, Nigeria.

This species has the potential to address needs for firewood, poles and building timbers. Recently requests from the rural communities for multipurpose trees, and some of the potential negative effects that some *Eucalyptus* species have on soils, prompted an effort to locate other species that could be grown successfully in the area.

The objective of this study was to identify local and exotic tree species that would be biologically successful on the Jos Plateau. The biological component is only one piece of the puzzle involved in successful reforestation efforts. The species selected have to address the primary concerns raised by the local population and be accepted by them (O'Keefe and Munslow 1989). The scope of this project did not cover these latter components, but they were included in other projects carried simultaneously by the Jos Plateau Environmental Resources Development Programme. Input from these efforts and local PTPU staff was used to select a mix of species that represented a range of alternatives for meeting the needs expressed among rural residents. Needs vary from one community to another (RRA Workshop Participants Marit Team 1991, RRA Workshop Participants Wereng Team 1991) but generally include firewood, building timber, food sources, reforestation of mine spoils, medicinal purposes, and soil conservation (Kidd et al. 1992; Hunter et al. 1993).

Eucalyptus camaldulensis is one of the most widely planted species in the world. Its provenances are quite variable in terms of growth rates and site suitability. Considerable gains in production can still be made by matching particular provenances to specific sites (Eldridge et al. 1994, Jackson and Ojo 1973). The majority of seedlings distributed by the PTPU were *Eucalyptus camaldulensis* raised seed collected from existing stands without too much consideration for growth and vigour. Many of the local stands are thought to originate from introductions made during some earlier species and varietal trials (Buckley 1987, Kemp 1970). Indeed, it is suspected that many of the stands and most of the current plantings are of southern Australian provenances (Buckley, 1987). While northern provenances showed good growth compared with the southern provenances in some earlier trials, they were not selected for wide use (Jackson and Ojo 1973). The reasons for this are not clear. However, it does seem that after some early enthusiasm with tree trials there was little follow-up and the results produced did not find their way into practice. In light of this, and because *Eucalyptus camaldulensis* comprises the bulk of the species raised in PTPU nurseries, a small provenance trial was planted at one site.

MATERIALS AND METHODS

Seed for 38 different local and exotic species and provenances was obtained from various local or international organizations (Tables 1). Seed was planted at the PTPU Bukuru Afforestation tree nursery between December 18, 1991 and March 11, 1992 depending on the estimated time between planting and seedling maturity. Larger seeds were planted directly in to polyethylene pots. Smaller seeds were planted into beds and later transplanted into polyethylene pots. Species selected for each site depended on an assessment of the site conditions and the availability of an adequate number of seedlings. At each site a hole large and deep enough to hold all of the soil from the polyethylene pots was dug for each tree. Polyethylene pots were removed from each seedling before planting. Eighteen species/provenances were planted at Fobur on July 30, 1992; 21 at Kai on August 10, 1992; and 26 at Wereng on August 1, 1992. Seedlings were planted out at 2m x 2m spacing in a completely randomized block design with three replications at each location. Ten trees of each species were planted in each block, except in first block at Fobur where space only allowed for eight trees. A border row of the local provenance of *Eucalyptus camaldulensis* or *Eucalyptus torrelliana* was planted at the ends of each replication. Soil was collected from under some mature *Causaurina equisitifolia* trees in Jos where there was evidence of inoculation by *Frankia* speices. A handful of this soil was incorporated into the surface soil around all the *Causaurinas* species planted at Wereng and Fobur.

A trial consisting of three provenances of *Eucalyptus camaldulensis* from Australia (Table 2) and the commonly raised local provenance from Jos, Nigeria were planted at Fobur on July 30, 1992. Seedlings were planted in four by four tree plots at 2m

Table 1: Percent survival (mean and standard error) of species planted at Wereng, Kai, and Fobur, Plateau State, Nigeria, after three growing seasons and sources of seeds used for planting stock.

Species	**Wereng [a]**	**Kai [a]**	**Fobur [a]**	**Seed Source [b]**
Acacia auriculiformis	66.7 + 14.5	64.0 + 9.5	78.3 + 11.7	ICRAF
Acacia holosericea	10.0 + 10.0	50.0 + 5.8	np	ICRAF
Acacia nilotica	50.0 + 5.8	26.7 + 5.8	24.2 + 12.9	PTPU
Acacia tortilis	3.3 + 3.3	np	np	ICRAF
Adansonia digitata	np [c]	np	34.2 + 18.0	PTPU
Albizia lebbeck	56.7 + 8.8	90.0 + 5.8	64.2 + 3.0	ICRAF
Balanites aegyptiaca	10.0 + 0	3.3 + 3.3	np	PTPU
Casaurina cunninghamiana 13519	63.3 + 3.3	3.3 + 3.3	69.2 + 18.4	CSIRO
Casaurina cunninghamiana 15601	60.0 + 10.0	np	np	CSIRO
Casaurina cunninghamiana 16511	56.7 + 3.3	np	np	CSIRO
Casaurina equisetifolia	np	0.0	np	NFTA
Casaurina glauca 13128	53.3 + 8.8	3.3 + 3.3	np	CSIRO
Casaurina glauca 13141	46.7 + 14.5	np	np	CSIRO
Casaurina glauca 15217	70.0 + 5.8	np	np	CSIRO
Casaurina junghuhiana	10.0 + 5.8	np	np	CSIRO
Cedrela ordorata	np	10.0 + 10.0	np	PTPU
Dalbergia melanoxylon	np	56.7 + 8.8	np	PTPU
Enterolobium cyclocarpum	np	86.7 + 6.7	77.5 + 8.0	ICRAF
Eucalyptus camaldulensis 14338	30.0 + 10.0	40.0 + 17.3	np	CSIRO
Eucalyptus camaldulensis 14497	53.3 + 14.5	50.0 + 5.8	np	CSIRO
Eucalyptus camaldulensis 14537	33.3 + 12.0	16.7 + 3.3	np	CSIRO
Eucalyptus camaldulensis local	36.7 + 8.8	43.3 + 3.3	np	PTPU
Eucalyptus torrelliana	20.0 + 11.5	np	78.3 + 6.0	PTPU
Faidherbia albida	13.3 + 13.3	np	0.0	ICRAF
Grevillea robusta	46.7 + 12.0	56.7 + 6.7	96.7 + 3.3	ICRAF/PTPU
Leucaena diversifolia	40.0 + 10.0	13.3 + 6.7	26.7 + 12.0	NFTA/CRDP
Leucaena leucocephala	66.7 + 3.3	53.3 + 12.0	55.8 + 17.1	ICRAF
Moringa oleifera	np	np	0.0	PTPU
Parkia biglobosa	0.0	np	0.0	PTPU
Prosopis juliflora	26.7 + 6.7	0.0	0.0	ICRAF
Pterocarpus santalinoides	np	np	92.5 + 3.8	ICRAF
Senna siamea	36.7 + 8.8	83.3 + 16.7	60.8 + 11.5	PTPU
Tamarindus indica	np	np	27.5 + 11.4	PTPU
Ziziphus spina-christi	0.0	0.0	19.2 +9.2	PTPU

Notes: [a] The least significant difference using FPLSD (α = .05) is 17.92 for Wereng, 22.80 for Kai and 26.98 for Fobur.
[b] ICRAF – International Council for Research in Agroforestry, Ibadan, Nigeria; NFTA – Nitrogen Fixing Tree Association; CSIRO – Commonwealth Scientific and Industrial Research Organization, Forestry Division, Australia; PTPU – Plateau State Afforestation Project, Jos, Nigeria; CRDP – COCIN Rural Development Program, Jos, Nigeria.
[c] np means the species or provenance was not planted at this site.

Table 2: Source of Australian provenances of *Eucalyptus camaldulensis* tested at Fobur in Plateau State, Nigeria.

Seed lot No.	Provenance	Latitude	Longitude	Elevation (m)
14338	Petford, Queensland	17^{o} 7’ S	145 ^{o} 3’	120
14497	Ferguson River, Northern Terr.	14^{o} 4’ S	131^{o} 58’	120
14537	Isdell River, Western Australia	16^{o} 56’ S	125^{o} 35’	315

by 2m spacing. The trial consisted of three replications in a completely randomized block design.

Survival counts were taken at the end of each rainy season in 1992, 1993 and 1994. Height measurements, to the nearest millimeter, were taken at the end of the 1993 and 1994 growing season for all sites. Height measurements and survival counts were taken at all three dates for the *Eucalyptus camaldulensis* provenance trail established at Fobur.

For each site ANOVA was used to determine if the mean survival or heights were different among species and provenances after three years of growth. Due to unequal sample sizes caused by low survival of some species, Fisher’s protected least significant difference (FPLSD) was used to differentiate between means (Steele and Torrie 1980). For the *Eucalyptus camaldulensis* provenance trial an ANOVA was run for height and survival data collected at each point in time. A single linear contrast was tested to determine if there was any difference in height growth and survival between the local provenance and mean of the three introduced provenances.

The Jos Plateau covers an area of about 860 km^2 in north central Nigeria. The precipitation pattern is unimodal with rainfall beginning in April - May and ending in September - October. Total annual rainfall is 1,200 – 1,400mm. Altitude for all the locations in this trial is 1,000 – 1,100m. Mean maximum and minimum monthly temperatures for Jos range from 31.4 ^{o}C and 19.1 ^{o}C in April to 23.8 ^{o}C and 13.9 ^{o}C in January (Varelides 1993). The Wereng site is an old tin mine spoil, which are typically very deficient in phosphorus and have a high clay content. This site was selected in conjunction with the local community who had an interest in being able to make some productive use of the area (RRA Workshop Participants Wereng Team, 1991). Kai is an area adjacent to tin mine spoils that had most recently been used for grazing. The site was plowed one week prior to planting in order to break up the soil and control some of the vegetation that had become established on the site earlier in the growing season. Fobur is located adjacent to the Liberty Dam. The area had not been cultivated for several years, but was used for grazing by pastoralists.

RESULTS AND DISCUSSION

Wereng

After the third growing season there were significant differences in survival (p = 0.0001), which ranged from 70.0% (*Casaurina glauca* 15217) to 0.0% (*Parkia biglobosa* and *Ziziphus spina-christi*). Ten species had greater then 50% survival. Trees from the genus *Casaurina* dominated this group, with five representatives. Different species of *Casaurina* have been recognized for their ability to grow on harsh sites and have been used in other countries for reclamation work. Their ability to form symbiotic relationships with the actinomycete of the genus *Frankia* to fix nitrogen has often been cited as one reason for its success (von Maydell 1990). Four of the top ten species, *Acacia auriculiformis*, *A. nilotica*, *Leucaena leucocephala*, and *Albizia lebbeck* have all been identified as nitrogen fixing species. *Faidherbia albida* is another species that has been widely recognized for its ability to survive in harsh locations and has become naturally established on a number of mine spoils in the area (Alexander 1989b). However in this trial its survival was only 13.3%. The only other species that had a survival rate $\geq$ 50% was *E. camaldulensis* 14497. Survival of the other *E. camaldulensis* provenances ranged from 30.0 – 36.7%.

There were significant differences (p= 0.0001) in height between the species after the third growing season. Height growth on this site was very slow, with heights ranging from 10.7cm - 51.2cm (Table 3). The harsh site conditions, browsing and trampling by goats during the dry season, and some tip die back all contributed to this limited growth. Of the eleven species with the greatest height, five were from the genus *Casaurina* and three had the ability to fix nitrogen (*Acacia auriculiformis, Albizia lebbeck*, and *Prosopis juliflora*).

None of the species planted grew very well on this site. However, a number of species did better both in terms of survival and height growth than any of the provenances of *Eucalyptus camaldulensis*, which has been widely planted on mine spoils (Alexander 1989a, Adegbehin 1983). Early plantings of *Eucalyptus camaldulensis* on mine spoils were fairly successful as long as there was intensive site preparation. Subsequent efforts, with very limited site preparation, met with limited success (Wimbush 1963). Very little site preparation was done for this trial. This study suggests that other species, in particular those of the genus *Casaurina*, have the potential to out perform *E. camaldulensis* on spoils when the amount of site preparation is minimal.

Kai

There were significant differences in survival after three growing seasons (p = 0.0001), which ranged from 90.0% (*Albizia lebbeck*) to 0% (*Casaurina equisetifolia, Prosopis juliflora, and Ziziphus spina-christi*). Only three species had survival rates greater than 80% - *Albizia lebbeck* (90.0%), *Enterolobium cyclocarpum* (86.7%) and *Senna siamea* (83.3%). Survival of the remaining species was less than 65%. Nine species had better survival rates than any of the *Eucalyptus camaldulensis* provenances in the trial, which ranged from 16.7% to 50.0%. Over 25% of the dead *E. camaldulensis* trees showed clear signs of termite damage, indicating that they were very susceptible to termite attacks on this site. All three of the *Casaurina* species tried on this site, which was the only one not inoculated, had extremely poor survival, ranging from 0.0 – 3.3%.

There were significant differences (p = 0.0001) in height growth after three growing seasons, with a range of 228.7cm (*Eucalyptus camaldulensis* 14338) to 33.3cm (*Dalbergia malanoxylon*). Five additional species (*Acacia auriculiformis, A. holoserica, Eucalyptus camaldulensis* 14497, *E. camaldulensis* 14537, and *E. camaldulensis* local) had heights greater than 100cm. Seven of the top ten species in terms of height growth were also on the top ten in terms of survival.

Fobur

There were significant differences in survival after three years (p = 0.0001), which ranged from 96.7% for *Grevillea robusta* to 0% for four different species. Only one other species has greater than 80% survival - *Pterocarpus santalinoides* (92.5%). Seven others had survival of 55 – 79%. Nine of the top ten species in terms of survival were also in the top ten for height growth.

Table 3: Height (mean and standard error) of species at Wereng, Kai, and Fobur, Plateau State, Nigeria after three growing seasons.

	Wereng a	**Kai a**	**Fobur a**
Species	**Height (cm)**	**Height (cm)**	**Height (cm)**
Acacia auriculiformis	51.2 ± 10.5	108.0 ± 9.3	135.2 ± 18.9
Acacia holosericea	27.7 ± 10.0	165.3 ± 26.1	np
Acacia nilotica	16.3 ± 5.8	27.7 ± 1.2	25.0 ± 9.3
Acacia tortilis	16.0 ± 3.3	np	np
Adansonia digitata	np b	np	17.9 ± 3.0
Albizia lebbeck	31.3 ± 4.7	36.3 ± 4.4	29.3 ± 3.5
Balanites aegyptiaca	10.7 ± 2.6	22.0 ± 3.3	np
Casaurina cunninghamiana 13519	30.6 ± 1.5	24.0 ± 3.3	104.2 ± 14.9
Casaurina cunninghamiana 15601	30.9 ± 6.3	np	np
Casaurina cunninghamiana 16511	33.8 ± 5.7	np	np
Casaurina equisetifolia	np	0.0	np
Casaurina glauca 13128	24.8 ± 2.9	42.0 ± 3.3	np
Casaurina glauca 13141	30.9 ± 0.9	np	np
Casaurina glauca 15217	36.4 ± 1.9	np	np
Casaurina junghuhiana	33.3 ± 0.8	np	np
Cedrela ordorata	np	45.0 ± 10.0	np
Dalbergia melanoxylon	np	33.3 ± 0.9	np
Enterolobium cyclocarpum	np	57.7 ± 11.7	56.7 ± 7.2
Eucalyptus camaldulensis 14338	29.1 ± 9.6	228.7 ± 16.3	np
Eucalyptus camaldulensis 14497	45.5 ± 9.9	177.7 ± 10.4	np
Eucalyptus camaldulensis 14537	25.9 ± 9.5	158.0 ± 8.2	np
Eucalyptus camaldulensis local	31.6 ± 2.2	123.7 ± 26.8	np
Eucalyptus torrelliana	22.3 ± 2.3	np	137.0 ± 3.2
Faidherbia albida	14.0 ± 3.3	np	0.0
Grevillea robusta	43.6 ± 1.5	60.7 ± 8.6	94.0 ± 7.1
Leucaena diversifolia	18.5 ± 5.6	98.0 ± 57.0	69.7 ± 21.2
Leucaena leucocephala	20.9 ± 4.0	45.3 ± 4.1	58.7 ± 2.2
Moringa oleifera	np	np	0.0
P. santalinoides	np	np	40.7 ± 3.3
Parkia biglobosa	0.0	np	0.0
Prosopis juliflora	32.3 ± 3.9	0.0	0.0
Senna siamea	16.4 ± 1.5	75.7 ± 11.1	33.6 ± 6.7
Tamarindus indica	np	np	19.9 ± 1.2
Ziziphus spina-christi	0.0	0.0	27.0 ± 7.6

Notes: [a] The least significant difference using FPLSD ($\alpha = .05$) is 15.42 for Wereng, 54.66 for Kai and 24.75 for Fobur.

b np means the species or provenance was not planted at this site.

Height was significantly different (p = 0.0001) by the end of the third growing season, ranging from 137.0 cm for *Eucalyptus torrelliana* to 17.9cm for *Adansonia digitata*. Two other species were greater than 100cm - *Acacia auriculiformis* (135.2cm) and *Casaurina cunninghamiana* 13519 (104.2cm). Nine of the remaining species still had heights of less than 70cm at this point in time. Nine of the top ten species in terms of height growth were in the top ten in terms of survival.

Eucalyptus camaldulensis Provenance Trial at Fobur

There were significant differences (p = 0.045) in survival between the four provenances after the first growing season (Table 4). Survival of the local provenance was significantly lower than the other three varieties (p = 0.010). After the second and third growing seasons, the overall ANOVA for survival data was not significant (p = 0.2011 and 0.1623 respectively). The local provenances' survival was significantly lower than the other three provenances (p = 0.042) after the second but not after the third growing season (p = 0.058). However, from a practical point of view the difference was considerable. The local provenances' survival was 66.7 ± 11.0%. The mean and standard deviation of the other three varieties combined was over 20% above that at 89.6 ± 9.4%. For this site it appears that if these provenances become well established during the first growing season they will survive. There was no evidence of termite activity at this site, in contrast to the significant damage noted at the Kai site.

Table 4: Percent survival (mean and standard error)and height (mean and standard error) after the first, second, and third growing seasons for four provenances of *Eucalyptus camaldulensis* planted at Fobur, Plateau State, Nigeria.

	Survival (%)			**Height (cm)**		
Provenance	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
14338	93.8 ± 3.6	91.7 ± 5.5	91.7 ± 5.5	90.8 ± 7.9	130.2 ±17.9	184.6 ± 10.6
14497	97.9 ± 2.1	93.8 ± 3.6	91.7 ± 2.1	80.6 ± 3.2	142.4 ± 7.7	197.1 ± 7.9
14537	91.7 ± 2.1	85.5 ± 8.3	85.5 ± 8.3	87.6 ± 7.1	128.6 ± 12.6	177.9 ± 25.7
Local	79.2 ± 5.5	68.8 ± 10.8	66.7 ± 11.0	48.7 ± 3.5	101.2 ± 8.8	147.2 ± 12.6

Height was significantly after the first (p = 0.014) and second (p = 0.0183) growing seasons, but not after the third (p = 0.148). At each of the measurement periods the linear contrasts indicated that height growth of the local provenance was significantly less than the three introduced provenances (p-values after the first, second, and third growing seasons were 0.0026, 0.0043, and 0.0415 respectively). By the end of the third growing season, heights ranged from 147.2cm to 197.1cm. Provenance 14497 had slower initial height growth compared to the other two provenances. After the first growing season it was ranked third, but had become the tallest provenance by the end of the second growing season. It held this position through the third growing season as well.

A previous trial of *Eucalyptus camaldulensis* provenances in Nigeria found that increases in yield up to 30% could be obtained by planting the appropriate provenances on different sites. The provenances from the Northern territories (Katherine provenance) and from Queensland (Bullock Creek provenance) were the most successful on the Jos Plateau. Another provenance from Queensland (Petford) did well in trials in areas near the Plateau, but it was not actually planted on the Plateau (Jackson and Ojo 1973). Otegbeye (1985) confirmed these results in a reassessment of some of these plots about a decade later. The two provenances with the best survival and growth rates in the current study (14497 and 14338) originate from areas close to the source for the Katherine and Petford provenances. Survival of the Katherine provenance was 100% at all three plateau sites and mean height growth after three growing seasons was 200- 260cm (Jackson and Ojo 1973). Survival of the two best provenances in this trial was very good at Fobur, but rather poor at Kai due to termite activity. Average height growth on the two sites ranged from 177.7 – 228.7cm. Jackson and Ojo (1973) used other inputs, such as boron fertilizer, that may contribute to some of the differences with the current trial. At the time of establishment of their trial, Jackson and Ojo (1973) believed that the local provenance originated from southern Australia due to its morphology. This may well be the same source in use today, although the specific origin of the currently propagated local variety is unclear (Buckely 1987). The southern provenances were among the worst performing ones in their trial. Eldridge et al. (1994) also noted that southern Australian provenances have had poor growth when planted in areas with summer rainfall.

It is apparent from this trial that there are other provenances of *Eucalyptus camaldulensis* that are better suited for these sites in terms of both survival and height growth. Increases as large as 37% for survival and 33% for height growth were found at Fobur. Height growth at Kai was up to 84% greater for the imported provenances compared to the local provenance. However, survival for all the *Eucalyptus camaldulensis* was ≤ 50% at this site. Since this species is the most widely grown species in the PTPU program, it would be advantageous to do further provenance tests across a variety of sites to locate the best provenances for different areas of the state.

SITE DIFFERENCES

There were distinct differences in height growth between the tin mine spoil site at Wereng and the sites at Fobur and Kai. For the species in common across all three sites, height growth was lowest at Wereng (26.3 ± 3.8cm) followed by Kai (76.3 ± 17.0cm) and Fobur (83.8 ± 16.7cm). This is not surprising because site conditions at Wereng were much harsher than the other two sites. Height growth of the introduced provenances of *Eucalyptus camaldulensis* was dominant on the non-tin mine spoils sites. *Acacia auriculiformis* and *A. holosericea* at Fobur and Kai respectively had height growth similar to the local provenance of *E. camaldulensis*. These species have the potential to yield benefits, such as enhanced soil fertility, because they are nitrogen fixing species.

It was surprising that the overall survival was similar on all three sites – Kai was 39.2 ± 8.0%, Wereng was 40.5 ± 5.4%, and Fobur was 56.8 ± 8.1%. Survival at Kai was strongly affected by termite activity. Four species – *Acacia nilotica, Leucaena diversifolia, L. leucocephala and Parkia biglobosa* - actually had higher survival at Wereng than either Kai or Fobur. All of these species are capable of fixing nitrogen. However, average height growth for each of these species was lowest at the Wereng site.

SUMMARY

It is clear that no one species or provenance is suited for the wide variety of conditions that are found across the Jos Plateau. Preliminary results from this study suggest that the different species should be selected for different areas of the Plateau and according to the prevailing site conditions (for examples, whether the site is tin-mining spoil). If *Eucalyptus camaldulensis* is going to continue to be a widely planted species, other provenances should be tested. This, and previous trials, suggest that provenances originating from northern Australia are better choices than local provenances derived from southern Australia. However, longer-term growth results are required in order to solidify this result. In addition to the biological suitability of different species to the range of sites found on the Jos Plateau, the needs, interests, and input form the local populations needs to be factored in before large changes in species mixes are made in the program.

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Kraft Pulp from Plantation-Grown Biomass Willow

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ABSTRACT

A short experimental evaluation was done on the papermaking potential of willow grown on an ESF plantation for biomass energy. The growth rate was 5-7 (max. 13) o.d. gross tons/acre/year (~25-35 m^3/ha/a, max. 65 m^3/ha/a) rendering it competent in growth with the fast-growing eucalyptus. Three-year old willow pulped fully to kappa number 16.9 and bleached to Brightness 90.2 % with a total yield of 51.4 % from wood. In comparison with a commercial ECF-bleached eucalyptus pulp it was shown that the willow contained good paper properties despite of short fibers (~.54 mm). Willow was proven to be a viable commercial fiber source for fine papers. The favorable growth rate of willow and its homogeneous fiber length distribution along with easy delignification and beating might attract the industry's interest in willow as raw material source for pulping instead of energy due to its papermaking potential.

Mesa Reduction Engineering and Processing, Inc.

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ABSTRACT

Mesa Reduction Engineering and Processing, Inc. has developed technology capable of reducing any type of biomass to a desired size. Over the last three years Mesa has been supplying the Department of Energy with processed willow, swithchgrass, utility poles, railroad ties, wood chips, sawdust, as well as biomass/coal blends for analysis and testing. This led to the technology being deployed at a co-firing project where wood waste and coal are blended and fired to create electricity. Mesa has recently developed and tested a portable processing plant that can go from location to location processing biomass. The goal of the system is to bring the technology closer to where biomass is grown in order to reduce the cost of transportation, one of the major obstacles to widespread use of biomass. The system can handle a wide range of materials with varying moisture contents and is capable of processing dissimilar materials like wood and swithchgrass at the same time. Mesa stands ready to work cooperatively with those interested in exploring applications where short rotation woody crops and other biomass resources can be utilized.

Growth and Survival of Hybrid Willow and Poplar: Case Study – Schenectady, NY

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ABSTRACT

To evaluate their potential use in an alternative cover system hybrid willow and poplar were planted in four test plots on a landfilled site in Schenectady, New York. The plots, covering approximately 2 acres of upland areas of the landfill, were established among native vegetation, and were designed to compliment ongoing ecological restoration within the existing plant communities. Four factorial experiments were established in the plots to evaluate the main effect of clone (SV1, S301, and SA2 willow and NM5, NM6 poplar), planting depth (10 and 40 inches) and organic amendment (compost and mulch) on survival and growth. Ten-inch cuttings were planted by hand using traditional planting methods, while 40-inch cuttings were planted in 9-inch diameter machine-augered holes. Compost was rototilled into the top 8 inches of soil, and mulch was surface applied. All experiments were established as randomized complete block designs with three replications. First year data indicate that greater growth occurred for forty-inch cuttings of willow and poplar clones. Growth of up to 12 feet was recorded for some 40-inch poplars. Independent of treatment, average survival in the four plots exceeded 75%. Poplar (NM5 and NM6) had higher survival rates across all treatments. However, survival of the two cutting lengths varied by planting area. In all plots non-compost treatments unexpectedly exhibited higher survival and greater growth than compost treatments.

Effects of Short-Rotation Forestry Site Preparation Techniques on Mite Communities in Soil

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ABSTRACT

The effects of site preparation techniques associated with production of willow (*Salix* spp.) on density, species richness and community structure of two functional groups of soil mites (Acari): Oribatida (saprophages and mycophages) and Gamasida (predators) were investigated. The oribatid mites were largely unaffected by site preparation treatments, but tillage had significant effect on the abundance of several individual species. Gamasida showed more pronounced changes in density and diversity in response to the treatments. The success or failure of willow crop and resulting divergence in soil environments created by different plant communities best explains the differences in gamasid mite populations among treatments. The data suggest that 1) site preparation techniques have the most important direct effects on soil mites during the first year after planting, but then are superceded by other factors; 2) presence or absence of tillage contributes most to the differences in mite community structure, and 3) soil mite communities recover from the initial stress of site preparation.

Keywords: mites, Oribatida, Gamasida, tillage, short-rotation forestry, biodiversity.

INTRODUCTION

The State University of New York College of Environmental Science and Forestry (SUNY-ESF) is a center for research and development of short-rotation forestry as a source of fuel and fiber. Production of willow (*Salix* spp.), the principal tree being tested, is similar to any agricultural cropping system in many respects. Site preparation techniques, including tillage and herbicide applications, are potentially crucial factors determining soil biological activity and biodiversity in willow agroecosystem. Many experimental and theoretical studies suggest that higher community diversity is associated with higher stability and sustainability of the ecosystem (McNaughton, 1977; Crossley et al. 1989; Bardgett and Cook, 1998). Soil fauna is important for maintaining soil structure and fertility (Hendrix et al. 1990; Beare et al. 1992; Coleman and Crossley, 1996).

Our objectives were to determine the effects of site preparation methods on the density, species diversity and community structure of representative groups of soil organisms. The research focused on two taxonomic and functional groups of mites (Acari) - Oribatida and Gamasida. The oribatid mites (Acari: Oribatida) are saprophages and mycophages. These mites are regulators of the decomposition rate, and through interactions with microflora, they affect nutrient cycling, an important factor in soil fertility (Coleman and Crossley, 1996; Sulkava et al. 1996). Low abundance and low diversity of these mites may indicate unfavorable soil conditions, correlated to lower plant biomass production potential. The gamasid mites (Acari: Gamasida) are important predators that attack other microarthropods and both free-living and plant-parasitic nematodes (Koehler, 1999). The abundance and community structure of these mites reflect the availability of their prey.

METHODS

Experimental Design and Sampling

An experiment has been established by SUNY-ESF researchers in Lafayette, Onondaga County, NY for determining the effects of site preparation techniques on willow plants and soil. Study plots were laid out as a complete randomized block design with 6 treatments in 3 replications (Table 1). In June and October of 1998-1999 four random soil samples (125 cm^3) were taken within each plot, using a stainless steel corer. Mites were extracted by a Tullgren apparatus, counted and identified to species level.

Table 1. Willow Planting in Lafayette, NY: Site Preparation Experiment – the Description and Timing of Treatments.

Field Operations: Steps and Timing	Treatment					
	Machine planted		Hand planted			
	Standard	No Till	Standard	No Till	Cover Crop	No Weed Control
Post-emergent herbicide (Fall ‘96)	+ [a)]	+	+	+	+	+
Plowed and Disked (Fall ’96)	+		+		+	+
Cover crop planted (Fall ’96)					+	
Pre-emergent herbicide (Spring ’97)	+	+	+	+	+	
Willow Crop (as of 1999)	S [b)]	F [c)]	S	F	S	F

a) indicates presence of this particular field operation;
b) willow trees established successfully;
c) willow trees failed to reach commercial size.

Data Analysis

Soil microarthropods tend to have an aggregated distribution. To make the data appropriate for parametric statistical methods we applied rank transformation to the raw counts (Conover and Iman, 1981; Potvin and Roff, 1993). Over four sampling dates the coefficient of variation for two mite group densities ranges from 74.01 to 226.08 for the untransformed data, and from 51.70 to 56.04 after transformation. Transformed data were analyzed using two-way analysis of variance (ANOVA). To identify the effects of individual site treatments, the data were investigated as sets of planned comparisons (contrasts) (Kuehl, 1994). Correspondence analysis was used to analyze individual counts for the most abundant species of Gamasida and Oribatida and to display relationships between mite communities and treatments on a coordinate system (community ordination). Chi-square test was used to test the hypothesis of independence between mite community structure and experimental treatment. All statistical tests were conducted at the level of significance $\alpha = 0.05$ using SAS (Statistical Analysis System, SAS Institute).

RESULTS

Analysis of Variance

A total of 20 species of Oribatida and 22 species of Gamasida were represented in the samples. The highest density and diversity of both Oribatida and Gamasida in 1998 and Gamasida in 1999 were observed in “No till, Machine” treatment. The highest density and lowest diversity of oribatid mites in 1999 was in “No Weed Control” treatment. The results of ANOVA are summarized in Table 2 and Table 3. The mode of planting - hand or machine - had no effect on mite communities. No significant effect of post-emergent herbicide was detected in the year following its application. The negative effect of tillage was significant only for Gamasida in the first year after tillage was applied. Cover crop has significant negative effect on density and diversity of gamasid mites and was less important for oribatid mites. The success or failure of willow crop best explains the differences in density and diversity of Gamasida among treatments. Oribatid mites proved to be largely insensitive to the treatment factors.

Table 2. P-values for contrasts for Oribatida where the null hypothesis is rejected ($\alpha = 0.05$).

Contrast	Density (mites/sample)		Species Richness	
	1998	1999	1998	1999
Hand vs. Machine	- [a)]	-	-	-
Till vs. No till	-	-	-	-
Cover crop vs. No cover crop	-	0.019	-	-
Weed control vs. No weed control	-	0.026	-	-
Willow crop failure vs. Success	-	-	0.039	-

a) failure to reject null hypothesis of no treatment effect.

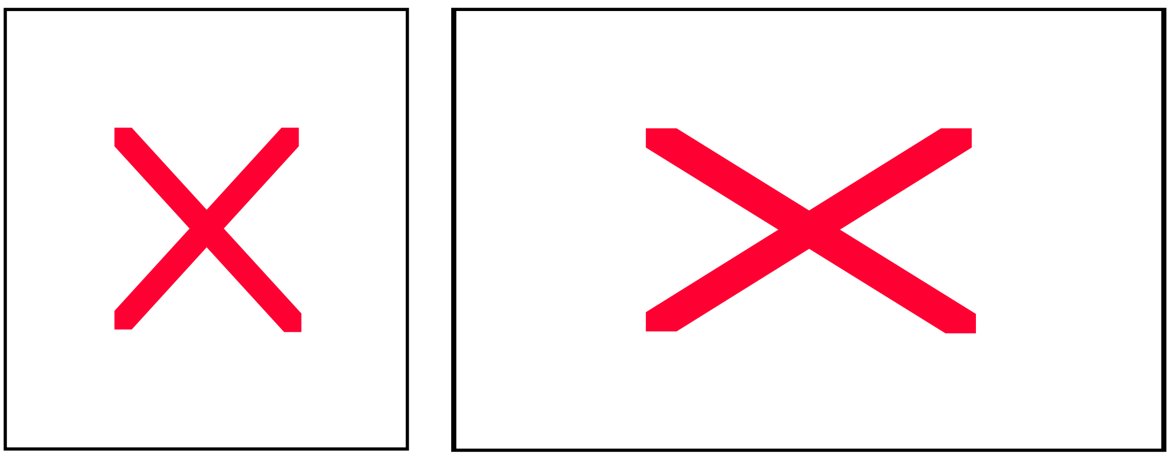
Table 3. P-values for contrasts for Gamasida where the null hypothesis is rejected ($\alpha = 0.05$).

Contrast	Density (mites/sample)		Species Richness	
	1998	1999	1998	1999
Hand vs. Machine	- [a)]	-	-	-
Till vs. No till	0.002	-	0.001	-
Cover crop vs. No cover crop	0.019	0.015	0.037	-
Weed control vs. No weed control	-	0.011	-	0.004
Willow crop failure vs. Success	0.0007	0.0004	0.001	0.002

a) failure to reject null hypothesis of no treatment effect.

Community Ordination

The χ^2 test showed that the site preparation technique significantly affects the community composition of both groups. Figure 1 presents community ordination based on correspondence analysis of individual counts for all species with relative abundance > 1%.



a) 1998 b) 1999

Note: the location of spheres indicates the degree of similarity between mite communities under different treatments; the sphere diameter corresponds to the total species richness of both Gamasida and Oribatida.

Figure 1. Community Ordination - mite communities in experimental establishment treatments of willow biomass crops in Lafayette, NY, 1998-1999.

This method allows us to display mite communities observed in different site treatments on a pair of Cartesian axes. The axes represent eigenvalues for the contingency table of mite species vs. site treatments. The two axes account for 84% of the total variation within the data set, and more than 65% is explained by axis 1 alone. The analysis enables us to distinguish between treatments that are merely correlated with the axis and those that make major contribution to it. The presence or absence of tillage during site treatment contributes most to the separation of mite communities along the first, most important, axis. The increase in species richness in 1999 suggests that mite communities are recovering from the initial stress of site preparation.

DISCUSSION AND CONCLUSIONS

In agricultural settings it is difficult to separate the effects of tillage and agrochemicals on soil mite communities. Both Oribatida and Gamasida were reported to be negatively affected by herbicides (Koehler, 1999; Moore et al. 1984), though Moore *et al.* (1984) found that the density of Oribatid mites returned to control level by the end of the season. The sensitivity of Gamasida to herbicide is influenced by the ground vegetation (Koehler, 1999). Under various conditions other authors observed negative (El Titi, 1984; Franchini and Rockett, 1996), positive (Loring et al. 1981; Moore et al. 1984) or no effect (Tomlin and Miller, 1987; Winter et al. 1990) of tillage on Gamasida and Oribatida. In our study Gamasida showed more pronounced changes in density and species diversity in response to site treatments than did the more sedentary oribatid mites. As predators, Gamasida integrate complex reactions of other trophic levels in soil and are often used as bioindicators (Koehler, 1999; Karg and Freier, 1995). Total density and species richness of oribatid mites were largely unaffected by site preparation treatments, but tillage had a significant effect on the abundance of several individual species.

The observed differences in soil mite populations can be attributed to two factors - effect of tillage and the divergence in soil environments created by different plant communities. The failure of the willow crop in no-till and no weed control plots resulted in markedly different vegetation cover from those plots where willow trees established successfully. The aboveground vegetation influences soil fauna by affecting soil structure, microclimate, water regime, microflora, and habitat diversity (Berg and Pawluk, 1984; Koehler and Born, 1989).

The biomass of soil microarthropods has been shown to correlate with pore size distribution and soil organic matter in soils under different land use (Vreeken-Buijs et al. 1998). Tillage dramatically alters soil pore network and often stimulates a sharp decrease in soil mite populations, followed by a rapid increase toward the end of growing season, presumably in response to favorable changes in nutrient availability and aeration (Loring et al. 1981; Moore et al. 1984). The studies generally conclude that tillage favors organisms with short generation times, small body sizes, rapid dispersal and generalist feeding habits (Andren and Lagerlof, 1983). Mite species found in tilled soil are those found in heavily disturbed or early successional habitats, whether natural or anthropogenic (Norton and Sillman, 1985). Reduced tillage creates a relatively more stable environment and encourages development of more diverse decomposer communities and slower nutrient turnover (Hendrix et al. 1990). Available evidence suggests that conditions in no-till systems favor a higher ratio of fungi to bacteria, and a predominantly fungivore-dominated fauna, whereas in conventionally tilled systems bacterial decomposers are favored (Beare et al. 1992).

Unlike conventional agroecosystems, willow plantations are maintained without additional tillage during the 17-21 year rotation period. Tillage and other site preparation techniques have the most important direct effects on soil mites during the first year after planting, but then are superceded by other factors. Because soil is minimally disturbed and plant residues are allowed to accumulate, the recovery of abundant and diverse soil mite communities is promoted.

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Coppice Effects on Willow and Hybrid Poplar Stem Attributes and Biomass Production

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ABSTRACT

Coppice short rotation intensive culture systems (SRIC) are being established over large areas in different parts of the world for the purpose of producing pulpwood, fuel, bioproducts or firewood. After establishment of the root system, the above ground portion of the trees is cut back to produce vigorous growth through a flush of multiple stems. Coppice systems are known to exhibit superior biomass production potential, which is primarily attributed to efficient photosynthate transport between root and shoot, rapid occupation of land through high leaf area deployment, and early bud break and late leaf senescence, resulting in a more efficient use of the growing season. While willows (*Salix* spp.) and hybrid poplars (*Populus* spp.) respond well to coppicing, differences may be expected in coppicing potential, and post coppice growth patterns, including biomass production. Although some studies have analyzed the phenomenon of coppicing and the associated biomass production potential in willow and hybrid poplars, little has been reported on their differential response to coppicing. In addition, it is of practical interest to study the changes in stem morphology through which post coppice growth vigor is expressed. A coppice rotation system selection trial of 38 poplar and willow clones was established in central New York State (NY) in 1997. In December 1997, at the end of the first growing season, the trees were cutback at 2-5 cm off the ground to promote coppice regrowth. A suite of tree dimension variables (diameter, height and number of stems), and stool biomass was monitored in 1997 and 1998. This paper presents an analysis of the effect of coppicing on individual stem dimensions, number of stems and stool biomass production, for willow and hybrid poplar clones and identifies the specific attributes that best explain the variation in post coppice biomass production rates.

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