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Forward

This International Conference was unique in that it attempted to bring together from around the globe those interested in a special aspect of short rotation forestry. The organizers were extremely pleased with the interest and participation in the conference. The meeting provided an arena to exchange scientific and technical information, to learn the current status of such activities, to identify additional resources and collaborators, and to stimulate a growing interest in the problems and opportunities associated with mechanization in short rotation forestry. The meeting successfully accomplished the intended objectives of fostering exchange and promoting new interests. A total of 69 persons attended, representing seven countries.

The co-chairmen would like to recognize and express appreciation to many people and organizations for their assistance. Several sponsors contributed funds and support. Major sponsors were the International Energy Agency/Biomass Agreement Task IX, Activity 1, and the Southern Forest Experiment Station of the USDA Forest Service. Other sponsors were Oak Ridge National Laboratory -US Department of Energy, Electric Power Research Institute, Southeastern Regional Biomass Energy Program, and the Southern Forest Engineering Center. We are deeply grateful to Scott Paper Company for hosting the conference and field tour, and to Morbark Industries for supplying the equipment for the demonstration. The employees of the Engineering Research Unit, USDA Forest Service in Auburn worked hard to make the meeting a success, and their efforts are sincerely appreciated.

We owe our thanks to the moderators and speakers who gave excellent informative presentations and provided papers for the proceedings. We also want to extend our thanks to the presenters' sponsoring organizations and recognize the support they provided to the conference. Most of all, thanks are due to the conference attendees for their interest in the meeting.

At the conclusion of the conference, it was obvious that interest in the subject was widespread and that several issues remained unresolved. During the final session, there was discussion on continuing the exchange of information and improving collaboration in short rotation mechanization. It was resolved to begin the process of establishing an informal working group of those interested in research in short rotation mechanization. Hopefully, in the long term, this group can sponsor additional conferences and provide for increased technical exchange and collaborative research. If you would like to have your name added to the mailing list for this working group, please reply to the co-chairs at the enclosed address.

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MECHANIZATION IN SHORT ROTATION, INTENSIVE CULTURE (SRIC) FORESTRY



Industrial Short Rotation Intensive Cultural Operations

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Mobile, AL USA**

*Paper presented at the Mechanization in Short Rotation,
Intensive Culture Forestry Conference, Mobile, AL, March 1-
3, 1994*

INTRODUCTION

This paper presents a brief history of Scott Paper Company in Mobile, Alabama in general and an outline of our work with Short Rotation Intensive Hardwood Culture in particular. The Mobile plant began as Hollingsworth and Whitney in the 1930s and was purchased by Scott Paper in the 1950s. Scott Paper Company manufactures personal care products and printing media at the Mobile site. Two hundred thousand ha of timberland in the southeastern United States supply 40 percent of the fiber needs for this plant. Presently all pulpwood is chipped at the Mobile site for consumption in our pulp mill. Final transportation of pulpwood to our Mobile site is done primarily by water with 90 percent all solid wood delivered by company-owned river boats and barges and the balance trucked into the gate. Our co-generation facility produces 100 MW of electricity (mill's demand) on site. In producing this electricity, the co-generation plant uses 110 t per hour of wood waste, among other energy sources. Four in-woods biomass harvesting crews produce 225,000 t of this wood waste from non-merchantable biomass in stands of timber scheduled for harvest. The balance comes from our chip plants, and is also purchased from other wood-using industries in this area.

Fiber Resource Strategy and Operations

As stated earlier, fee land produces approximately 40 percent of our fiber needs and constitute our most cost-efficient source. This land base is comprised of about 60 percent pine plantations managed on even-aged 25 to 30 year rotations primarily on pine uplands and flat sites. Loblolly and slash pine dominate formerly planted species. The remaining acreage of our fee land base is managed for hardwood production. These stands are predominately bottomland hardwood sites that are regenerated naturally by "silvicultural" clearcuts. A relatively small amount of our land base is dedicated to short rotation intensive culture hardwood plantations. These stands are predominately sycamore plantation intensive cultured on 5 year rotations. SRIC plantations are placed on upland pine sites in order to

provide a source for winter season hardwood fiber.

Scott employee timber buyers negotiate and purchase about 60 percent of the timber coming off land not owned by Scott Paper Company both by dealing directly with other landowners or purchasing timber from other wood producers directly at out yard gates.

Uniquely, Scott Paper Company's Southeastern Timberland is dedicated to the concept of company harvesting crews. Scott Paper Company operates 40 company logging and 4 energy harvesting crews throughout Mississippi and Alabama USA. We are now probably the largest logging operation in this country.

History of Short Rotation Intensive Culture Plantations

Prior to 1975, a small amount of wood waste was used in our boilers, primarily mill shavings and bark. We would also have sawdust brought in from cabinet shops, a clock factory, etc. In 1975, Dick Snider, our mill manager, turned procurement of biomass fuel over to the woods division in order to increase the volume and quality of fuel being used. This was when fuel prices had rocketed up and wood waste was a much cheaper alternative fuel. We visited a whole tree chipping crew that supported the fiber board plant of Masonite Corporation and decided to give it a try. We purchased a 25 cm Morbark<2> chipper, a Melroe Bobcat which had been converted into a feller-buncher, and 3 chip vans and started our first energy harvesting crew. We started out harvesting after the logging crew had removed merchantable timber, but quickly found out that it was more economical to pre-harvest stands for biomass. In 1984, we expanded the utilities complex and started up 5 more energy crews based on the experiences of our start-up crew.

Also during the period of the mid- to late-1970s, Scott entered into the North Carolina State Hardwood Research Cooperative and, with Dr. Bruce Zobel and Dr. Bob Kellison, established several long rotation hardwood plantations, primarily in bottomland hardwood stands. In the late 1970s, the idea of short rotation hardwood plantations gained notoriety, and we began establishing a sweetgum and sycamore orchard. Also, a sycamore mother tree test was established and thinnings at age 3 and 4 years yielded 10.5 tons/ha/yr and 12.8 tons/ha/year. We were in the midst of an oil crisis again at this time and Tom Kelly, our woodlands manager, calculated that this represented about the BTU equivalent of 16.1 to 19.8 barrels of oil/ha/yr. This began to increase our work on short rotation intensive culture and a biomass study was initiated at our Wildfork Seed Orchard in Monroe County, Alabama.

In the mid-1980s, the oil crises subsided and the project was almost dropped. Hardwood pulp prices similarly started to climb, particularly in the wet winter months when a majority of the hardwood in this region was inaccessible. Some chips from one of our biomass plantations were sent to our fiber quality lab in Philadelphia and the results were promising that we could whole-tree chip these 5-year-old sycamore stands and produce good quality chips for fiber.

These two programs - the biomass harvesting and the Short Rotation Program -

have come full circle as they are connected together in the harvesting of these SRIC plantations. Having the resources of the company operating harvesting crews has allowed us to experiment with some harvesting schemes and get good harvesting data and experience, even during the experimental stages of our SRIC program.

We began installing operational plantations in 1988 and currently plant 300 to 400 acres per year. These plantations are located on soils conducive to tree growth but that can be operationally harvested in wet weather. We are also planting some longer rotation sweetgum plantations.

Present Harvesting Operations

We are presently harvesting these stands with our conventional biomass crews, which consist of three 411 Hydro-Ax feller-bunchers, two 450 Timberjack skidders and a 69 cm Morbark mobile chipper. This crew will harvest approximately 250 tons per day. All chips are transported to our Mobile site in closed-top, lightweight wood chip vans by a private trucking contractor.

The Future

The flexibility of small green sycamore creates a problem. Our chipper, with its anvil set at 1.9 cm, generates small twigs 1.9 cm in diameter and 25 to 51 cm long. This doesn't seem to be a big problem for the pulpmill; however, our screen room is fed by volumetric metering bins, and these stems cause choke-ups. We feel the manufacturer of our chipper can help us solve this problem during our present harvest.

On wet ground conditions, our equipment (which use 58 cm tires designed for pre-harvesting tracts) have trouble operating. More needs to be done on larger accumulation-capacity feller-bunchers and pre-haulers or single grip machinery in order to increase efficiency with extremely small stems. Sycamore seems to be very site specific and operational yields do not meet our expectations presently.

Some suggested solutions are site selection and genetic work to provide yields that can be more predictable. Using equipment from one of our logging crews with lower ground pressure tires to harvest the SRIC plantations, while the energy crew equipment is used for logging could also be tried. New equipment designed to harvest small diameter stems on wet sites might be developed.

We are still in the early stages of this system and much work remains to be done. With more and more lands being taken out of production due to regulations (wetlands, endangered species, etc.), our productivity will remain static without coming up with new and innovative ways to increase yield and efficiency while maintaining long-term productivity of our land. We need to continue to ask why or why not?





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Harvesting Costs and Utilization of Hardwood Plantations

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*Paper presented at the Mechanization in Short Rotation,
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the exclusion of any other that may be available.*

INTRODUCTION

The use of short rotation, intensive culture (SRIC) practices in hardwoods to meet fiber supply needs is becoming increasingly widespread. Total plated area of short rotation hardwood fiber plantations is currently about 22,000 ha (McDonald and Stokes, 1993). That figure should certainly to grow in response to public concerns over loss of natural hardwood stands. With many of the plantations currently approaching first harvest, questions have been posed about the adaptability of conventional harvest systems to SRIC stands. Past efforts in development of specialized SRIC equipment have achieved some success (Stuart and others, 1983), but markets sufficient to justify commercialization of the concepts are not likely in the near future. Without SRIC-optimized equipment available, conventional harvesting machinery will have to be used. This study was initiated to test the use of harvest equipment common in the Southern United States in SRIC stands. Objectives were to determine productivity, costs, and recovery of felling, skidding, and processing short rotation sycamore (*Platanus occidentalis* L.) stands.

METHODS

The study was established on property owned by Scott Paper Company located in Escambia County, AL, approximately 80 km northeast of Mobile. The stand was planted in 1-year-old sycamore seedlings at a 1.5- x 3.0-m spacing (2,153 stems/ha) in March 1988. Average diameter at breast height (dbh) in winter 1993

(after five growing seasons) was 7.5 cm, and the yield from the plantation was 14.3 green t/ha/year. Understory vegetation was controlled as part of the silvicultural regime, thus it was not a hindrance during harvesting. The site was generally flat and poorly drained. A period of rainfall forced operations to halt during the study, but conditions at the time of testing were generally good.

In February, 1993, 10 trees from each dbh class in the 2.5 cm to 15.0 cm (2.5 cm increment) range were felled and weighed. A regression equation relating dbh class (cm) with weight (kg) was developed ($P < 0.001$, $R^2=0.9$) in the form $w=ad^2$, where w =weight, d =dbh, and $a=0.54$ was a regression coefficient.

Time Study

A Scott Paper Company crew that ordinarily produced whole-tree chips for fuel performed the harvesting. The harvest system consisted of three HydroAx 411B feller-bunchers with 40 cm shears, two TimberJack 450B grapple skidders, and a Morbark model 30 (76 cm diameter disk, 600 kW) chipper. Felling productivity was determined for one operator and skidding productivity was determined for two operators.

Fellers ordinarily cut two rows per pass through the stand. Bunches of approximately 40 to 60 stems were built, usually from four felling head accumulations. This bunch size represented a full load for the skidders. Building bunches that large required additional maneuvering for the feller-bunchers, perhaps resulting in lower overall felling productivity. In addition to testing these normal operating procedures, a special time study was also carried out on the system when the feller-buncher operator built bunches of two accumulations, forcing the skidder to assume some of the burden in making a full turn.

Individual machine productivities could not be established in 1993 because the harvest was halted by wet weather. Harvesting was resumed in late February, 1994, and all skidding, felling, and chipping productivity data were collected in March, 1994.

For time study purposes, felling cycles were broken down into the following elements: (1) move to first tree, (2) cut and accumulate a full felling head, (3) move to dump, and (4) dump.

Move-to-first-tree and move-to-dump distances were also measured and recorded. Before the tests, the trees in the rows to be cut were numbered and measured for dbh. The identification numbers of the stems accumulated during each cycle were noted.

Skidding cycles were broken down into: (1) travel empty, (2) position, (3) grapple, (4) intermediate travel, (5) travel loaded, and (6) ungrapple.

Intermediate travel was time spent moving between bunches. Travel empty, intermediate travel, and travel loaded distances were also measured.

When operating normally, there was no intermediate skidder travel because each bunch represented a full turn. In the test where bunches consisted of two

accumulations, they were doubled up by the skidder operator, requiring both intermediate travel and a second grappling task. For analysis purposes, grapple times in this case were combined.

Chipping productivity was based on observations of time required to fill a trailer. Product weights were obtained from load tickets. Recovery was estimated by weighing chipper rejects by chip van load.

In earlier tests of this harvest system in short rotation sycamore, the chipper produced a high percentage of long, thin material that caused handling problems at the mill. It was assumed that the unsuitable material resulted from the chipper grabbing and pulling through whole branches and tops. As a possible means of reducing the amount of material unsuitable for pulp, a Peterson chain flail was briefly tested in March 1993 with the harvest system. To estimate flail losses, 10 groups of approximately 8 trees each were weighed, then fed through the chain flail and the residues collected. Chips from flailed and unflailed trees were tested at the mill for percentages of accepts, fines, and overs.

RESULTS

Felling Productivity

Time study data were obtained from a total of 11 and 9 bunches for the 2 and 4 accumulations per bunch (apb) tests, respectively. Felling time per tree (tt , total cycle time divided by number of stems accumulated) was modeled using the following equation:

$$tt = am + b + gj, [1]$$

where m was move-to-first-tree distance (m), a was the average dbh of trees accumulated in a bunch, and gj was a fixed value for $j=2$ or 4 apb. Each parameter was significant at the $P < 0.005$ level, and overall model R^2 was 0.25. Parameter coefficient values (standard errors in parentheses) were $a=0.00084$ min/m (0.00031), $b=0.010$ min/cm (0.0032), and gj was 0.0116 (0.027) min for $j=2$ and 0.0278 (0.025) for $j=4$. Including other sampled elements in the equation (move-to-dump distance, dump time, and accumulation time) did not significantly improve the model.

Least square mean time per tree was 0.119 min for $apb=4$, and 0.103 min for $apb=2$. These values were significantly different ($P=0.01$). Using the estimated mean times, and assuming an average tree weight of 31.8 kg (7.6 cm dbh), felling productivity was 582 stems, or 18.5 green t, per PMH for $apb=2$, and 504 stems, or 16.0 green t, per PMH for $apb=4$.

Table 1. Parameter estimates for the coefficients of equation 1

Parameter	Estimate	Standard Error
p	0.139	0.032

at	0.00054	0.000038
ai	0.0010	0.000089
gj, 1 bunch per turn	0.22	0.06
gj, 2 bunches per turn	0.55	0.06
μ	0.05	0.02

Skidding Productivity

Skidding data was obtained for a total of 12 cycles, 6 each with either 1 bunch per turn (4 felling accumulations) or 2 bunches per turn (2 accumulations). Grapple times were summed when skidding two bunches. Travel times were linearly related to travel distances ($P < 0.002$, $R^2 \geq 0.9$), and regression coefficients for the travel empty and loaded functions were not significantly different. The regression coefficient for intermediate travel, however, was about twice that for travel empty or loaded and was significantly different from both ($P < 0.01$).

From these results, skidder cycle time was modeled as

$$t = p + atdt + ai di + gj + u, [1]$$

where, p was average position time in minutes, at was the regression coefficient relating travel empty/loaded round trip time with distance, dt in m, ai was the regression coefficient relating intermediate travel time with distance, di also in m, gj was grapple time in minutes for picking $j=1$ or 2 bunches, and u was average ungrapple time in minutes. Because of the relatively low number of observations, cycle elements were modeled individually and total cycle time was assumed to be their sum. The overall prediction error rate, therefore, is not known. This implies that the model is more descriptive in nature and should be used with caution in other applications. Table 1 shows estimated values for the parameters of equation 1. Measured average round trip skid distance was 399 m, and average intermediate travel distance was 20 m. Average number of stems skidded per turn was 42.8. Using these values, skidder productivity was 35.8 green t/PMH with bunches of 4 feller-buncher accumulations, and 24.6 green t/PMH for bunches of 2 accumulations. Stokes and Hartsough (1993) reported productivity of a smaller grapple skidder (60 kW) to be much lower in similar stands--9.4 green t/PMH.

Table 2. Assumptions used in calculating machine rate for all equipment tested

Cost	Basis	Value
Machine	Years	5
Salvage value	% Purchase Price	20
Interest rate	%	12

Fuel cost	\$ per Liter	0.26
Lube and oil cost	% Fuel Cost	37
Operator wage and benefit	\$ per SMH	10
Scheduled machine hours	year	2,000

Chipper Productivity

Four observations were made of time to chip a van load, reject weight (on two loads), and product weight. An average of 97.1 percent of total material was recovered as chips. Average chipping time per load was 18.8 min, not including move and position time for the van. Position times were not measured and a value of 7 min was assumed. Based on this assumption and an average load size of 25.3 t, chipping productivity was 57 green delivered t/PMH.

System Costs

Machine rates for the equipment used in the study were calculated from the methods presented in Brinker and others (1989). Assumptions used in calculating machine rate are shown in table 2. Machine-specific values needed for the calculations, as well as the machine rates themselves, are shown in table 3.

Table 3. Machine-specific costs and machine rate for studied equipment

Cost	Units	Machine		
		Timberjack 450B Grapple Skidder	HydroAx 411 Feller Buncher	Morbark Model 30 Chipper
Purchase Price 1993		\$121000	\$125500	\$289000
Utilization	% SMH	60	65	75
Repair & Maintenance	% Annual Depreciation	90	100	100
Fuel Use	$\frac{l}{kW - hr}$	0.14	0.13	0.12
Engine Power	kW	132	94	600
Insurance	% Purchase Price	5	4.5	2
Machine Rate	\$ per PMH	65.75	61.65	118.41

From the productivity results, a balanced system for the study conditions would consist of four feller-bunchers, two skidders, and the chipper--slightly different from the system tested that had only three feller-bunchers. When piling 2 apb, the feller-buncher had higher productivity, but this gain was more than offset in loss of productivity for skidding. Harvest costs per green t, based on 4 apb and excluding transport, totaled \$8.71 per green t and are shown in table 4. Adler (1985) reported \$0.06/t-km as an average haul cost in the New England area. Assuming a value of \$0.07 per t-km at current prices, and a haul distance of 80 km, transport costs would raise the total to \$14.3/green t. This cost excludes overhead, i.e. crew transport, service vehicles and equipment, and profit.

Chip Quality and Flail Recovery

Problems with clogs in the material handling system from long, thin chips were encountered at the mill with material received from the short rotation sycamore plantations. The probable source of the troublesome material was identified as small-diameter limbs and tops yanked by the chipper disc through the chipper feed rolls. This problem was largely overcome by modifying the chipper feeding methods, i.e. overlapping grapple loads as they were fed in, which left enough material between the feed rolls at any particular time to prevent the chipper disk from snatching smaller material through. Before this method was perfected, however, a flail was tested as an alternative for reducing the amount of small-diameter material entering the chipper.

Table 4. Productivity and costs for a balanced system operating in short-rotation sycamore

Machine	Number	Productivity <i>green delivered t per PMH</i>	Costs \$ per PMH
Feller-Buncher	4	62	246.6
Skidder	2	75	131.5
Chipper	1	579	118.4
System			\$8.71 per green t

Recovery was measured by weighing bundles of 6 to 8 stems before and after flailing. Results for 10 such bundles indicated that on average, 32 percent of the whole tree, by weight, was lost in flailing. Flailing also resulted in lower fines and bark contents after screening (table 5), but an increase in the percentage of overs. This was unexpected and could have indicated that the flail was not effective in reducing the potential for clogs in the material handling system at the mill.

Table 5. Results of after-screen chip quality analysis for flailed and unflailed short-rotation sycamore

Material	No Flail (%)	With Flail (%)
Overs (>10 cm)	3.5	4.4

Fines	1.4	0.6
Bark	4.9	3.9

Including the flail as a component in the system was evaluated using production data from a previously unpublished study conducted in 1989 with Scott Paper Company. The study was done to determine recovery of various hardwood species, including short-rotation sycamore. Productivity of flailing (Peterson Pacific, Model 4800) was also measured, although observations were limited and the operator was inexperienced. Results indicated that, for 5.3 cm dbh green sycamore trees, 2,039 stems/PMH could be processed. Assuming the same number of stems per hour, a 30 percent loss in product from flailing, and a 7.6 cm average dbh, flail productivity would be 45 green t/PMH. System costs for the flail are summarized in table 6. Hourly cost for the flail is based on the value reported in Hartsough and others (1992) of \$78/SMH and an assumed utilization of 60 percent. Final system cost, excluding transport, was \$13.9/green t. This cost, however, would likely change and is only approximate.

Table 6. Productivity and costs for a balanced system, including a chain flail, operating in short-rotation sycamore

Machine	Number	Productivity <i>green delivered t per PMH</i>	Costs \$ per PMH
Feller Buncher	4	62	246.6
Skidder	1	75	131.5
Flail	1	45	130
Chipper	1	57	118.4
System			\$13.9 per green delivered t

SUMMARY

Productivity of conventional harvesting equipment operating in 6-year-old, short-rotation sycamore plantations was determined. Results indicated that a four-wheel feller-buncher produced 16.5 green m t/PMH in 7.6 cm diameter trees planted on a 1.5 x 3.0 m spacing. No statistically significant felling production improvement was found when bunching 2 versus 4 accumulations per bunch (apb). Productivity of felling 4 apb was 15.5 green t/PMH. Skidding productivity, however, was affected significantly by the number of felling apb--35.8 versus 24.6 green t/PMH for 4 and 2 apb, respectively. Chipper productivity was estimated to be 59 green t/PMH. Based on the measured results, a balanced system consisted of 4 feller-bunchers, 2 skidders, and the chipper, with estimated harvest costs of \$8.42/green t. Including a flail in the system raised the cost per green t to \$13.9.

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MECHANIZATION IN SHORT ROTATION, INTENSIVE CULTURE (SRIC) FORESTRY



Short Rotation Forestry in Loblolly Pines

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*Paper presented at the Mechanization in Short Rotation,
Intensive Culture Forestry Conference, Mobile, AL, March 1-
3, 1994*

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ABSTRACT

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

INTRODUCTION

Short rotation intensive culture (SRIC) forestry is being conducted in a limited manner across the South. Traditionally, SRIC forestry has focused on hardwood species such as eastern cottonwood, American Sycamore, sweetgum and exotic species. Several factors have limited SRIC forestry in the South including: 1) the high cost of silviculture; 2) inconsistent results due to complex species-site relationships; and 3) the relative abundance of natural hardwood fiber.

Pine plantation forestry is a significant practice across the South. Approximately 12 million ha (16 percent) of southern forests are pine plantation type (Kelly 1994). The intensity of silviculture and the length of rotations in southern pine plantations varies widely. Conventional plantation silviculture, as generally practiced over much of the past 30 years, will not be characterized as SRIC in this

paper. The potential for SRIC pine has increased dramatically in the past few years with the development of cost effective herbicides and plows. These technologies could make 12 to 16 year, high yield pine rotations feasible.

SRIC PINE ON JAMES RIVER TIMBERLANDS

Background

James River currently owns about 40,000 ha of predominately pine timberlands. This timberland base is the primary softwood supply source for James River's Naheola pulp and paper mill, located in west-central Alabama. Almost all of this timberland is located within 60 km of the mill.

James River is managing multiple rotation lengths at varying intensities which are site specific. For the past five years, SRIC pine plantations have been established on James River's higher quality sites. These sites are suitable for SRIC due to gentle terrain and high growth potential.

SRIC treatments

A typical SRIC establishment site is a recently clear-cut, 25-year-old, pine plantation. The SRIC prescription begins with harvesting as all stumps are cut as low as possible. Following the harvest, a broadcast burn is conducted to reduce logging slash and enhance plowing operations.

A Savannah Forestry combination plow is then pulled across the site on three m intervals. The plow is pulled with a 150 kW crawler tractor equipped with a V-shear blade. The V-shear blade is used to push large debris to either side and clip residual sub-merchantable trees. It is not used for shearing stumps off at ground level. The blade is generally run in a slightly raised position and does clip the tops of taller stumps.

The Savannah Forestry combination plow cultivates, fractures, subsoils and beds. This plow has a coulter, blade plow, subsoiler tine, and stump-jump bedding discs. The coulter cuts debris and splits stumps associated with an uncleared site. The blade plow which follows behind the coulter cultivates 15 cm deep, undercutting hardwood root stocks and stumps.

The subsoiler follows the blade plow and fractures the soil 60 to 70 cm deep. Four independent stump jumping bedding discs follow the subsoiler. These discs cultivate a bed 2.4 m wide. These discs are hydraulically actuated at 42 to 56 kg cm⁻² psi. As a disc hits a stump the hydraulic cylinder on the jump arm allows the disc to give way and roll over the top of the stump. The remaining three discs remain in the ground cultivating.

Figure 1. Illustration of a Savannah Forestry Equipment, Inc., Combination Plow used by James River Corporation in Alabama

The **Savannah**
COMBINATION PLOW



Treatment	Ground Line Diameter (cm)	Height (cm)	Volume (cm ³)
No weed control	3.30	189	539
Weed control	4.83	259	1581

Three-in-one combination plowing appears to enhance growth on most James River sites, however, at varying degrees. Tree growth response to combination plowing appears to be soil texture related on James River sites. Compacted sandy loams to sandy loam clays seem to benefit the most from plowing. Table 2 shows the growth response to three-in-one combination plowing on a loam topsoil-clay subsoil site. This site was treated with hexazinone herbicide which provided herbaceous weed control to both the treated and untreated areas. Note that after three growing seasons the plowed area trees contain more than twice the volume of unplowed area trees.

Table 2. Growth response to three-in-one combination plowing on loam topsoil-clay subsoil site for loblolly pine on James River timberlands located in Sumter County, Alabama

Tree Measurements (cm)						
Diameter ¹	Height				Volume (cm ³)	
Growing Season	Control	Plowed	Control	Plowed	Control	Plowed
1991	1.39	2.09	64	85	32	95
1992	3.82	5.24	174	213	664	1530
1993	6.86	9.14	265	338	3263	7389

¹Diameter is measured at ground line.

Table 3 shows the results of combination plowing versus no plowing and conventional bedding. Plastic, silty clays respond significantly to combination plowing, but not significantly more than from conventional bedding. James River research indicates that the difference between the deep fracture of subsoiling versus conventional bedding on silty clays is not significant on seedling growth.

Table 3. Results from research plots on James River timberlands located in Sumter County, Alabama, comparing first year growth of loblolly pines to no plowing, conventional bedding and combination three-in-one plowing on a silty clay soil

Treatment ^a	Ground Line Diameter (cm)	Height (cm)	Volume (cm ³)
No plowing	0.59	45	4.1
Conventional bedding	1.02	52	14.2
Combination 3-in-1 plowing	1.11	61	19.7

^aAll three treatments included shear and rake site preparation and herbaceous

weed control applied shortly after planting in 1991. This search is located on Wilcox silty clay.

CONCLUSIONS

Reports from scientists (Busby 1992) familiar with early herbaceous weed control experiments indicate a potential of a three-year reduction in rotation length when this SRIC treatment is conducted. With the additional treatment of deep soil fracture through combination plowing, rotation length could be shorter. As such, James River believes 12 to 14 year, high yield, SRIC pine rotations are quite feasible.

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Utilization of Cottonwood Plantations

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Paper presented at the Mechanization in Short Rotation, Intensive Culture Forestry Conference, Mobile, AL, March 1-3, 1994

INTRODUCTION

Cottonwood plantation management is utilized by James River to secure a continuous supply of fiber to the St. Francisville Mill in Zee, Louisiana.

Fitler Managed forest (FMF) land base consists of 15,000 ha fee and leased lands along the Mississippi River, stretching from just north of Vicksburg at Fitler, Mississippi to Baton Rouge, Louisiana. Total cottonwood plantation acreage consists of 8,000 ha.

The majority of this land is located in the flood prone batture areas along the river. Soil types are all of the alluvial classification. They contain high levels of nutrients and are well supplied with moisture. They range from well drained to poorly drained.

Stand establishment

Site preparation begins once all slash, stumps, and other debris have been removed from site. Equipment such as the Caterpillar Challenger 65 tractor (210 kW) are used to pull an Amco disk with 81 cm "Scalloped Pans". This procedure is performed two times. A smaller (68 kW) tractor is used to lay off and mark rows 3.7 m apart, usually running the shortest distance of a field. After marking is complete, subsoiling begins running perpendicular to marking trenches, using a "Straight-Shank", 7.6 cm wide and 53.3 cm long. This trench will fill with siltation into which cuttings will be planted.

FMF currently has 18 operational clones that are all of improved genetic crosses of Deltoids. The cottonwood nursery is located at Fitler, MS and produces 1 million cuttings each year. The nursery is planted on 97 cm row spacings and 20 cm inter-row spacing. At harvest cottonwood shoots reach 3.0 to 4.6 m in height.

Delimbing begins in late November, then harvest, bundling, cutting into 46 cm cuttings for hand planting.

Hand planting begins in December. Hand planting is preferred over machine plantings due to wet soil conditions that exist during winter months. Production per man ranges from 3.2 to 4.0 ha per person per day, or 3,020 cuttings. Cuttings are planted 36 cm deep in the subsoiled trench.

VEGETATIVE CONTROL

A pre-bud break herbicide for residual control of early annual herbaceous vegetation is applied on a 1.8 m band during February. This chemical will give 3 months control before breaking-down. Bud break usually occurs in early March.

A post directed herbicide combination is used for contact kill of emerged weeds and residual for germinating weed seed. This application is made when trees reach 0.6 to 0.9 m in height, directed to the lower 15 cm of the tree.

Overhead sprays are used in control of weeds such as Johnson Grass.

MECHANICAL CULTIVATION

Intense mechanical cultivation begins in mid-May after herbicides have dissipated. This is done using 68 kW tractors equipped with front-mounted field cultivators and pulling a 3 m disk in middles. Cultivation aids in weed control, aeration, and building soil around the base of trees. Two to three cross cultivations are usually necessary.

Less intense cultivation is needed in year 2 of growth. One cross cultivation only is used, aiding in nutrient release, aeration and moving root systems deeper into the soil.

GROWTH

After the 2nd year cultivation is complete, no other means of weed control is necessary through harvest. Rotation age is generally 8 to 10 years depending on soil type. Yields range from 148 to 173 green tons per ha. Average DBH is 20 to 25 cm, height 24 to 27 m.

HARVEST

A John Deere 643 D shear is used to fell trees. The Cat 518 Grapple Skidder is used to transport trees to a logging dump, where they are backed through a delimbing gate. A Prentice 210 knuckleboom loads tree lengths onto a pole trailer, which is trucked to Kings Woodyard. Kings functions as a transfer facility. The trees are then slashed to 1.5 m lengths, loaded on railcars, and shipped to the St. Francisville Mill in Zee, Louisiana.

MILL

Each pulpwood stick is run through a drum debarking system and ground in

pressurized grinders. The mill end product is communication papers.

CONCLUSION

Much progress has been accomplished in cottonwood plantation management over the past 20 years, although there is much more to be learned about cottonwood culture. Our research needs are many and vital to the continued success in short rotation intense culture plantation management.



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Stand Establishment and Culture of Hybrid Poplar

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Abstract

Fueled by the energy crisis of the mid 1970's and a simultaneous increase in domestic demand for communication grade paper products for the computer age and world demand for tissue and towel grades, technicians turned to short rotation intensive culture research for biomass and pulp fiber supplies. In the United States pulp and paper industry, the increase in computer driven demand and the insistence of papermakers for higher percentages of hardwood fiber in the "furnish" to improve paper quality far outstripped the ability to supply hardwood fiber in the Pacific Northwest through traditional managed forest growth practices. By crossing native Black cottonwood of the Northwest and Eastern cottonwood, a short rotation hybrid with superior growth characteristics was developed. To achieve maximum growth, best management agricultural practices have been developed for site preparation and cultivation. Harvesting machinery properly selected and utilized proves to be an effective means to maximize yields from individual stands throughout scheduled harvested acres. An overview of all management practices developed to successfully establish, maintain and harvest short rotation hybrid cottonwood in the Pacific Northwest by James River Corporation is presented.

INTRODUCTION

The forest industry in the Pacific Northwest has gone through a series of significant changes over the past four decades. Forestry has progressed from the early management attempts of the 1950's to forest land and timber investment optimism in the 1960's. The economic boom of the 1970's gave way to an economic tightening in the 1980's. These changes in the Pacific Northwest run hand in hand with a continuing race for low-cost wood. Pulp fiber, traditionally a by product of the timber and wood products industries, historically has become

expensive. In the 1990's, wood supplies in the Pacific Northwest have become difficult to obtain due to environmental pressures placed on traditional sources (ie. state and federal timber lands).

FACTORS LEADING TO FIBER FARM CONCEPT

James River Corporation operates two pulp mills along the lower Columbia River, at Camas, Washington and Wauna, Oregon. The wood supply for these mills comes from southwest Washington, northwest Oregon and areas along the Columbia River in eastern Washington and Idaho. The relatively high cost of wood fiber in the area has significantly affected the relative competitive position of these mills. Wood supply costs have risen due to the reduced availability of sawmill and plywood residuals, a direct result of the Pacific Northwest's loss of market share to Canada and Southern States. Traditionally, native red alder and hemlock have provided additional sources of both short and long-fiber, respectively, but both species supplies are diminishing due to the successful efforts of forest managers to replace them with high valued Douglas fir. Greater fiber recovery from the limited sawmilling and planing operations add to the dismal fiber picture. James River's needs for alternative sources of both alder and hemlock is the driving force behind short-rotation intensive culture of hybrid poplar.

HISTORICAL BACKGROUND

In 1981, Crown Zellerbach's Forestry Research Division established a research station in the Lower Columbia River Floodplain near the town of Westport, Oregon. The focus of the research projects established were primarily on selection of plant materials and genetics, planting stock quality and propagation, and plantation culture. Specifically, projects addressed plantation spacing, poplar clonal testing, species/site comparison studies, European alder provenance tests, herbicide screening tests and competition effects studies. From the information gained in these study projects, an operational farm was established in 1982. This first attempt to establish cottonwood operationally was a dismal failure. Success was first achieved in 1983 and has flourished since that time. In 1986, James River Corporation purchased the pulp and paper division of Crown Zellerbach including the established cottonwood plantations.

SITE LOCATION

James River currently has 4,450 ha (3,560 ha are in actual production) located in diked, drained land along the lower Columbia River. The Fiber Farm currently lies in both the states of Oregon and Washington and stretches from the Pacific Coast on the northwest 160 km south and east towards Portland, Oregon.

The lands consist of cultivated fields and unimproved pasture lying within levees. These areas have alluvially deposited silt loam, peaty clay loam, or sandy loam soils which are at or below river level. Because these soils are moderately to poorly drained, drainage systems with pumps or tide gates are required. It is not uncommon to have standing water in portions of the fields throughout the winter

and late spring. Permeability is moderate to moderately slow. Percent of organic matter ranges from 1 percent to 35 percent. Fertility of the sites varies, but generally they are plentiful in both macro- and micro-nutrients.

The area has a maritime climate with mild, wet winters, cool, dry summers and a long growing season. Precipitation that normally occurs in western Oregon and Washington (up to 1,520 mm annually) occurs mainly in winter, largely from mid-October to mid-May. Prolonged cloudy periods are common as well as an occasional ice and snow storm.

SITE PREPARATION

Proper site preparation is critical for a successful plantation. Falling short of the standards stated has proved disastrous for the Lower Columbia River Fiber Farm in both survival and growth. In order to promote root development, adequate soil aeration, and allow for maximum herbicide effectiveness, we encourage proper site preparation.

In the final condition, the soil should be tilled 25 to 30 cm deep, have a maximum clod size less than 8 cm and contain a proportional range of soil particle sizes. The ground should be free of any weed vegetation after tillage. Since root development will move downward as well as laterally, any hardpan or deep heavily compacted soil should be broken. The finish disking should allow for uniform herbicide application. No clod shadows, oversized clumps or extremes in topography should exist.

Timing of site preparation should allow enough time to prepare the site before the rainy season, and yet have the last operation occur just before the rainy season, to control fall resprouting of weeds.

Spacing needed for proper tree growth and full utilization of land has not yet been fully defined. Current spacing varies between 3.0 x 1.5 m, 3.0 x 2.1 m, 2.7 x 2.7 m, depending upon clone, site and proposed cultural activities. Planting design can be square or rectangular. One must allow adequate room for potential operations in the fields after planting. Allowance for herbicide application, mechanical weed cultivation, and crop monitoring should be taken into consideration.

Marking the planting rows in the finished field can be done by equipment or manually. We have planted in 25 cm high hills in order to minimize exposure of the cutting to standing water.

Rows are marked for planting using a subsoil shank (38 to 51 cm depth) combined with a hilling implement attached to a 100 kW tractor. The implement has two hillers with hydraulically controlled 'wings' for marking the next tractor pass.

Costs for site preparation will vary depending upon type of equipment used. Standard costs published throughout the industry indicate a cost of \$70 per ha.

HERBICIDE Application

Currently, our experience regarding proper timing of soil active herbicides is January to mid- March for both pre-plant and vegetation control in one year old stands. Treatment is extended to those few select stands of older trees where vegetation control is required due to poor growth for one reason or another. Typically, a mixture of glyphosate (Roundup) and pre-emergent herbicides are applied to kill existing winter annuals and to give residual control into the growing season. Current rules and regulations concerning herbicide use have greatly reduced the number and type of products available for use in hybrid cottonwood plantations. A good working relationship with chemical suppliers is a must in order to stay ahead of fast-changing and often confusing rules and regulations.

PLANTING

Genetic Consideration - Cottonwood plantations are established with unrooted, dormant cuttings collected from either one-year-old whips grown in a stoolbed or a one-year-old whips grown in a stoolbed or one-year-old side branches from two-year-old trees. This is an example of vegetative reproduction; every tree grown from cuttings produced by the same stoolbed is genetically identical. A clone is a group of trees, not necessarily of the same age, which share the same genetic makeup.

Different clones frequently exhibit large differences in growth rate, form, survival, disease resistance, and adaptability to varying site conditions. Use of the proper clone can be the determining factor in the success of a planting program.

Based on the results of extensive field tests conducted first by Crown Zellerbach and then James River, the best clones for the lower Columbia River region are those which have been developed by hybridizing native black cottonwood with eastern cottonwood. Recent developments using material from Japan is providing additional diversity of traits suitable for this region. To date, our best hybrid clones have exhibited good adaptability to a limited range of site conditions.

Stock Quality - Considering economic and operational feasibility, use of unrooted cuttings approximately 25 to 30 cm long has provided adequate survival and growth. The cuttings should be of one-year old material, dormant, have a minimum and maximum diameter of 1.0 cm and 1.9 cm respectively and contain at least one prominent bud located on the upper $\frac{1}{4}$ of the cutting.

Stock Storage - If you cannot plant cuttings shortly after they have been collected, cold storage will provide adequate protection. Protect them from drying by placing in air tight plastic bags and refrigerating them at temperatures between -3.9 to -2.2 degrees C. These temperatures limit black stem disease and permit cuttings to be safely stored for several months.

Stock Planting - Preferred planting season is mid-February through mid-April depending upon moisture received during this time frame. Manual planting provides easy access to planting sites and requires minimal equipment investment as opposed to machine planting. Field conditions found during this time frame in the lower Columbia River region are not conducive to mechanical planting.

Cuttings are carried in tree planting bags and pushed into the ground by hand and are planted vertical and right side up. Place at least 25 cm of the cutting into the soil, leaving only the tip extending beyond the soil surface. Deep planting ensures deep rooting, and when most of the cutting is below ground, only one sprout is likely to emerge to form the tree. If necessary, loosen portions of the planting spot with a shovel, or use a planting bar (dibble) in hard ground or for larger cuttings.

MAINTENANCE IN PLANTATIONS

The need for minimal weed competition is critical for a successful crop in the lower Columbia River region. If weed and grass are not adequately controlled, hybrids will grow slowly and may not survive. Furthermore, unwanted vegetation provides cover to voles, which can girdle and kill trees as old as four years. Plantation weed control is usually performed by combining mechanical and manual cultivation and herbicides during the first and second growing seasons.

To minimize herbicide use, the area between tree rows are mechanically cultivated using a variety of small disks, rototillers, and dyna-drives. Down the tree row, cultivation is accomplished by adapting equipment developed for other agricultural crops. Cultivation is most effective when weeds are small. Limit cultivation to no more than 8 cm in depth to minimize damage to tree roots.

Chemical weed control during the growing season is very limited. Products such as Poast<2>, Fusilade and Diquat will give some grass and weed control without much damage to the trees. Care must be taken when applying chemicals with backpack spray operations being the most advantageous.

Manual weed control provides excellent weed control but is extremely expensive. However, this option must be considered should conditions risking growth and survival loss prevail in a plantation.

HARVESTING

Prior to long term harvesting in 1991, many different types of equipment were tried on the Fiber Farm. Several types and sizes of feller/bunchers, skidders, delimbers, yarders, and transportation methods were tested to try and determine the most economical method in delivering a final product to the pulp mill. Various studies and cost analyses were conducted to try and improve equipment efficiencies and production rates and thus lower costs.

In May 1991, the first sustained harvest of 400 ha commenced. The most economical system found to date includes a Bell feller-buncher, both rubber-tired and track skidders, a knuckle-boom loader that feeds a modified chain flail delimeter/debarker, chipper and chip vans. The mill advocates having material every day of the year which precludes seasonal harvesting. With this fact in mind, the present system includes both rubber-tired and track machines. Track machines consist of a high-track dozer and FMC skidders.

CONCLUSION

This paper presents one system for the production of short rotation intensive culture hybrid cottonwood plantations. Because the silvicultural activities of this crop resemble closely those commonly found in agriculture, both the states of Oregon and Washington have declared it so. Success in the production of trees depends upon having good soil, appropriate cultural practices, matched genetic material for location selected and, most importantly, machinery necessary to complete the required tasks, at the right time. The future of the production from cottonwood plantations will solely depend upon the advancement of technology in site preparation, cultivation, herbicide applications, and harvesting equipment.



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Development of a Flail Harvester for Small Diameter Brushand Coppiced Trees to Produce Energy/Chemical Feedstock

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Abstract

The design, fabrication and field testing is described for a harvester to produce shredded woody biomass from small diameter natural brush stands and coppiced energy plantations. In the southwestern United States, typical applications include harvesting of mesquite, juniper and sage brush, while in the southeastern United States, typical applications would include precommercial thinning of pine stands too small for pulpwood, and thinning of pioneer hardwood stands. These small diameter stems have not been economically harvested to-date because the brush is too small to be handled by conventional forestry equipment, yet too woody to be harvested by conventional agricultural equipment. A harvester was built on a John Deere 210 kw forage harvester. A flail shredder and auger conveyance system was used to sever the trees, shred them and blow them behind the harvester in a vehicle pulled behind the harvester. The harvester was examined for 3 weeks in the southeastern United States in 2 m tall coppiced sweetgum, sycamore and water oak, in 4 m tall seedling sycamore, in 2.4 m tall pines, in 6 m tall pines and in seedling hardwood site with 4 to 9 m tall sweetgum. When the trees were less than 3 m tall and less than 6 cm in diameter they were severed, captured and blown

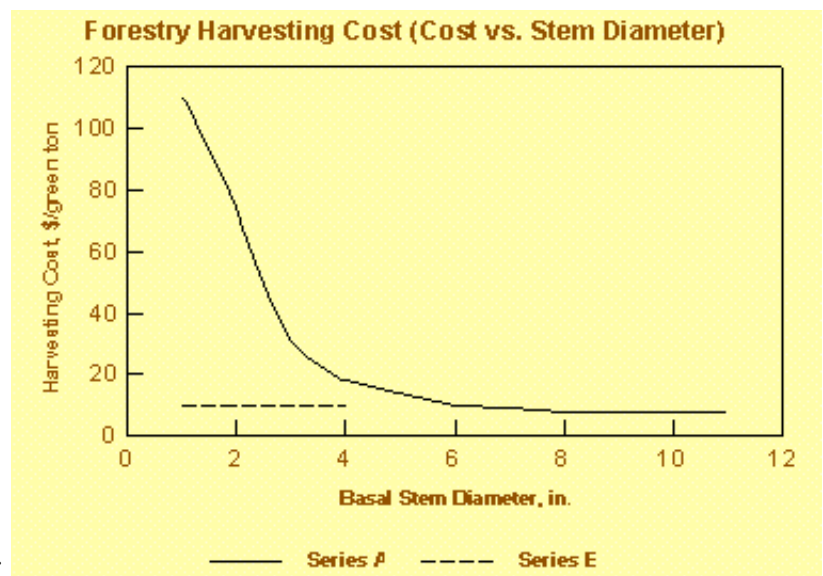
behind the harvester with little difficulty at 3.6 km/hr (0.9 ha/hr). Trees greater in diameter than 6 cm were not completely severed due to a non-overlapping knife pattern in the cutterhead. Nevertheless 12 cm diameter pines and sweetgum trees were mowed down and partially captured at a rate of 1.6 km/hr (0.4 ha/hr). The operating cost of the harvester was estimated to be about \$75/hr.

Economical operation of the harvester will require both a silviculture need for thinning and an energy market for the chips. The current version of the harvester is not suited to typical forestry terrain. It will be necessary to build the harvester on a 4 wheel drive, high clearance frame (such as with skidders) in which all components are located internally. A team of forestry companies, equipment manufacturers, universities and government would be best suited to develop this harvester.

Introduction

Our economic analysis indicated that for biomass farming operations in the southwest, over 50 percent of the final delivered cost of the biomass was attributable to the harvesting and transportation of the biomass (Felker 1984). Similarly we believe the major economic constraint to competitively priced biomass production from rangeland brush will lie in the harvesting and transportation. Our particular interest lies in harvesting of mesquite (*Prosopis*) since it exists on 30 million ha in the United States (Parker and Martin, 1952) with 22 million ha in Texas. Since the standing biomass in mesquite stands ranging from 6 to 18,000 stems/ha varied from about 3 to 40 dry metric tons/ha (Felker and others, 1988), the total biomass resource for mesquite in Texas would range from about 60 to 800 million tons. If expressed in the U.S. Department of Energy units of quads (1015 BTU), the energy resource from Texas brush would range from 1 to 15 quads (at 18 million BTU/metric ton). Total U.S. consumption of energy is about 80 quads and therefore the woody biomass in Texas could be very significant. In South Texas, dense regrowth containing 5 to 10 dry metric tons/ha can occur in 15 years. This renewable resource should be available indefinitely.

Present mechanized forestry harvesting equipment typically harvests 300 38-cm diameter trees per hour (Cullen and Barr, 1981). However, as the stem diameter class decreases, the harvesting cost per ton increases since it is necessary to harvest more stems per ha. As shown in Fig. 1, Kluender and Plummer (1980) found that when the average stem diameter size class decreased below 15



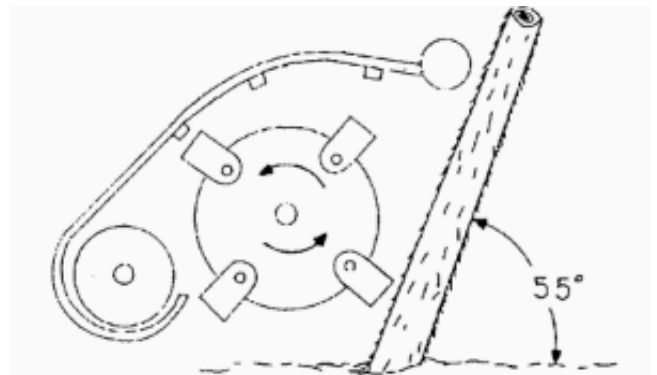
cm, the harvesting cost per ton rose exponentially reaching a cost of \$54/ton for 5.1 cm diameter stems. In contrast, Felker and others (1988) measured mesquite densities as high as 18,000 stems/ha with an average biomass of 0.8 kg/stem. These stems cannot be treated individually and require the development of a swath harvester.

Biomass Harvester Development

Significant work regarding the economical harvesting of rangeland brush for energy and chemical feedstocks has been pursued at Texas Tech and Texas A&M University - Kingsville in the 1980s. A "Texas Tech biomass combine" (Ulich,1983) was reported to harvest 4 tons/hr in a 1.52 m wide swath, at a cost of \$12.40 per ton of 12 percent moisture chips, with an energy cost of \$0.73/million BTUs. If wood chips could be obtained at the rate of 4 ton/hr, with an operating cost of about \$30/hr, this would be a cost of about \$7/ton.

The basic principle behind the flail harvester is shown in **Figure 2. Harvesting Method for a Horizontal Shaft Cutter**.

The trees are bent over at about a 55 degree angle using a push-bar. The tree stem is designed to come into contact with the center of the flail shredder which provides the double action of severing the stem and forcing it upwards between the cutterhead knives and the shroud. As the stem progresses farther



backwards, the knives continue to reduce the size of the stem as the clearance between the knives and the shroud becomes less. Ulich patented the geometry of this system in which he used 2.5 cm square bars that were welded beneath the shroud to create stages of diminished clearance and thus reduced stem size classes. After the stems have passed through the 4 stages of clearance they are captured in a trough with a flow through auger. This auger strips the head of chips and is the first stage of the materials handling system. The last bar only has about 6 mm of clearance.

The Texas Tech harvester was mounted on a farm tractor with a standard mechanical transmission. The severing and shredding head was mounted on the front of the tractor with front-end loader arms. The cutterhead consisted of a 64 cm diameter horizontal cutting cylinder with 26 10-cm wide stirrup-type knives having a 360 degree swing circle. The cutting blade speed was 2,600 to 3,000 m/min. A 2 ton cotton module basket capable of dumping the chips onto a truck bed was used. The elevator used to take the chips from the cutting head to the basket, consisted of a chain drive with 25 cm semi-circular paddles. The power for the cutting head and elevator assembly was obtained from an 80 kw tractor through a hydraulic pump mounted on the PTO shaft of the tractor.

In year long field trials at Texas A&M University - Kingsville the flail shredder principle used for simultaneously severing and shredding the brush proved

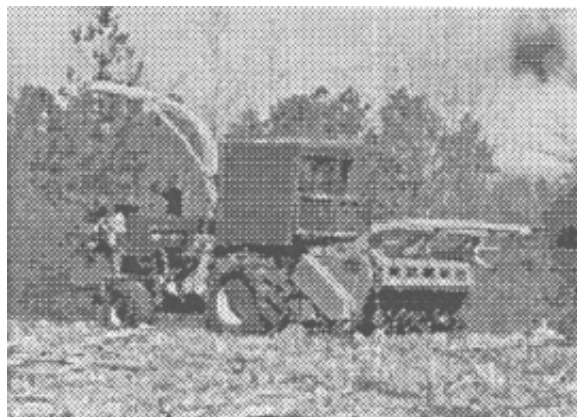
satisfactory. However, other aspects of this harvester were most inadequate.

Texas A&M University - Kingsville Biomass Harvester

We significantly modified the Texas Tech (TTU) biomass harvester design discussed above. The major features of the Texas A&M University - Kingsville (TAMUK) design include the following:

1. Use of a John Deere Model 5280 type silage harvester with (a) hydrostatic drive, (b) more powerful (213 kw) engine, and (c) radiator in the rear. The hydrostatic drive was necessary to avoid repeated clutch failure caused by the constant clutching that was necessary to maintain full engine rpm for the cutting head while keeping the forward movement slow enough to avoid clogging the cutterhead. Greater horsepower was required for the cutterhead and associated chip transfer system. The radiator in the rear was necessary to reduce frequent clogging of the radiator by dust from the cutter-head located in front of the tractor causing the engine to overheat.
2. Use of a straight through design of the materials handling/conveyance system from the back of the cutterhead to the trailer. This was necessary to eliminate the chip clogging problems encountered with the previous TTU design that included two right angle turns involving screw augers and chain driven paddles.
3. A redesign of the cutterhead support system to avoid cracking of the front end loader arms and failure of the front rims and lug bolts caused by the excessive weight of the cutterhead. Since the forage harvester operates "backwards" as compared to traditional tractors, the large axle and tires were available to support the weight of the cutterhead and frame.
4. Use of foam filled and forestry tires with reinforced rims to eliminate (a) flat tire problems in the field and (b) failure of the front rims and lug bolts.

Figure 3. Texas A&M-Kingsville Biomass Harvester during Spring 1994 Field Test shows the Texas A&M - Kingsville biomass (mesquite/rangeland brush) harvester in action during field trials in Spring 1994. It shows the tractor with the cutterhead in operation and moving forward to harvest brush. This is the opposite of conventional tractors. The remainder of this section discusses the steps involved in the development of the biomass harvester design.



In 1989 we purchased a used John Deere 5280 forage harvester and mounted the original 1.5 m Texas Tech cutterhead and associated hydraulics, but without the materials handling system. This system performed quite well in harvesting and chipping mesquite. (It is relevant to point out that mesquite has a specific gravity of 0.7 kg/l and is most similar to hickory in hardness and density).

To test suitability for an improved chip transfer system, shredded chips were gathered from the ground for use in a materials handling test bed. We found that the 2 23-cm diameter augers that came with the forage harvester quite adequately transferred the chips to the blower paddle assembly and out the spout. The materials handling system even successfully transferred some stem pieces as long as 40 cm. Thus, it appeared that the transfer of the chips from the cutterhead to the blower paddles would not create a problem.

Therefore, a materials handling system was designed that consisted of (1) a cross auger with main axis parallel to the cutterhead to strip the chips from the auger and bring it to the center of the cutterhead, (2) 2 23-cm flow-through augers to transfer the chips from the cross augers immediately behind the cutterhead under the tractor to the tractor blower assembly, and (3) the tractor blower assembly rotating at 1,000 rpm from the PTO shaft that blows the chips into a van behind the harvester.

Since we had more horsepower than the 80 kw engine used in Ulich's design, we would be able to drive a wider cutterhead. While Ulich fabricated his own flail cutterhead, we desired to obtain a commercially available flail cutterhead to facilitate rapid commercial adoption of this technology. After a review of commercially available flail cutterheads and discussions with cutterhead manufacturers, we chose to employ the 2.6 m wide Brown Bear Flail cutterhead. A joint development agreement between Brown Bear and Texas A&M Kingsville was signed to develop a new harvester using their cutterhead.

Brown-Bear used this cutterhead in a 200 kw brush clearing machine to shred the chips and leave them on the ground. In the Brown Bear design, the rotation of the cutterhead was such that the top of the cutterhead moved in the same forward direction as the harvester. In the Ulich and TAMUK design the cutterhead rotated in the opposite direction, cutting the stems and bringing the severed stems over the top of the cutterhead between the shroud and the cutting knives. Due to the differing objectives of chipping the severed stems on the ground by the Brown-Bear cutterhead, and of severing the stems and dragging them over the top of the cutterhead in our design, there were fundamental differences in the geometry requirements of the cutterhead knives.

Having established basic requirements for the cutterhead geometry and the materials handling system, we found it necessary to design a frame to house the cutterhead and augers and to design a hydraulic system for the cutterhead and cross augers as well as the flow through augers.

Cutterhead/auger housing frame:

A weight of 2,268 kg at a distance of 1.22 m from the center of the drive tires of the tractor was used to design the frame to support the cutterhead and auger housing. Sway bars were also installed to prevent side to side movement of the head. To enable the cutterhead to be raised and lowered, hydraulic cylinders were mounted at the front of the tractor. These cylinders were powered by tractors hydraulic system and used 2 way check valves to prevent them from creeping up or down. One end of this frame was attached with pins that allowed it to pivot up

and down, under the bottom of the tractor near the center.

Hydraulic system:

A closed loop hydraulic system capable of transferring the full 213 kw of the tractor engine to the cutterhead was designed with the assistance of Womack Hydraulics of San Antonio, Texas. The complete hydraulic system used the 76 l/min - 16 MPa system on the tractor as well as 3 hydraulic pumps, an auxiliary heat exchanger and 5 hydraulic motors.

The main hydraulic system that drove the cutterhead was driven with a fixed displacement pump coupled to the 1000 rpm tractor PTO shaft. This system was designed to transfer 360 l/min of 32 MPa fluid to two hydraulic motors on either side of the cutterhead. A high tension cog belt connected the tractor PTO shaft to two smaller pumps connected by the same shaft. One of these pumps was a charge pump used to keep the main pump primed. The other pump provided fluid for the two hydraulic motors for the cross augers and the flow through augers. Variable flow dividers were used to regulate the speed of these augers.

An auxiliary heat exchanger to cool the hydraulic fluid from the cutterhead was mounted on the back of the tractor. The fan for this heat exchanger was powered from the tractors hydraulics.

Preliminary Field Evaluation of Harvester on Pines and Sweetgum in the Southeastern United States

In the spring of 1994, the biomass harvester was transported to Alabama for a demonstration for a Short Rotation Intensive Culture (SRIC) mechanization workshop and then to South Carolina and Georgia for field trials harvesting dense pine stands and sweetgum regrowth sites.

At the Alabama site, the harvester was examined on 1 year old coppice regrowth from several year old sycamore, sweetgum, and water oak stools, and on 3 year old sycamore seedlings. When sycamore, sweetgum or water oak stems were less than 5 cm in diameter and the height less than 2.4 m tall, the harvester passed through the material at about 3.5 km/hr capturing nearly all of the stems and then passing it through the blower. Given the 2.6 m width of the cutterhead, a 3.5 km/hr forward speed corresponds to 0.91 ha/hr.

There was concern that the flail cutterhead did not cut the coppice cleanly enough to allow adequate resprouting. Clearly the severed stems were split several cm below the site of the cut. If shoots will emerge below the location where the stems are split, it should be possible to have a high percentage resprouting by cutting the shoots higher on the stump. It is important to base the decision on whether to pursue development of a harvester for hardwood coppice upon quantitative measurements of percentage stool resprout as a function of knife geometry rather than conjecture.

While the harvester was capable of mowing down the 4.5 m tall 10 to 12 cm diameter sycamore seedlings, the trees were not severed and captured by the

shredder. We found that a major contributing factor to the failure to capture the 4.5 m tall sycamore trees was the geometry of the cutterhead. The knives on the cutterhead extended only 5 cm beyond the disk that held them to the head. Since none of the knives overlapped, the maximum depth of cut was only 5 cm. As a result, trees with a greater diameter than 5 cm were merely pushed over and 2 parallel 5 cm deep gouges extending the length of the tree were found on the trees.

When operating in the southeast, it was necessary to operate the engine at 1,700 rpm rather than the desired 2,100 rpm due to excessive pressure on some hydraulic components. This also slowed the blower paddle speed giving the chips less trajectory and provided less horsepower to the cutterhead. This problem is currently being corrected in Texas.

The harvester was examined on 2 pine sites near Greenwood, South Carolina. Both sites were hand planted, but large numbers of additional pine seedlings became established from natural seedlings. At the first site, the originally planted trees were about 13 cm in diameter and 6 m tall. The naturally established pine seedlings were less than 6 m tall but so thick that it was often not possible to discern where the original rows were. At the second site of pine, the trees were typically 1.8 to 2.4 m tall. As discussed later, some portions of this field had pine seedling densities as high as 13 trees per square m (130,000 trees/ha). On this site 1.8 m square plots were clipped to measure the standing biomass.

The goal at both of the South Carolina pine sites was to clear 2.6 m wide paths, leaving a width of 0.5 m between the 2.6 m wide lanes. The trees in the 0.5 m width could then grow faster with reduced competition. Six lanes about 230 m long were made in the 6 m tall trees at 1.6 km/hr, before it was decided these trees were just too large and the terrain too difficult for the harvester.

In contrast to the flat agricultural type field sites in Alabama, the South Carolina sites had old windrows, 30 cm diameter rocks and ditches that required that the cutterhead be maintained about 10 to 20 cm above ground. This in turn, created 10 to 20 cm diameter stumps that precluded pulling an agricultural type trailer behind the harvester.

On two occasions the harvester became stuck despite no indications of moisture from the surface. This was no doubt compounded by the fact that the 2,270 kg head was mounted in front of the front tires. It is clear that future harvesters will have to be mounted on a 4 wheel drive "skidder type" frame to provide greater maneuverability, clearance and traction in moist conditions.

At the second South Carolina site the trees were 1.6 to 2.4 m tall with pine tree densities as great as 130,000/ha. At this site the harvester was capable of mowing and harvesting the trees at 3.6 km/hr thus clearing 0.93 ha/hr. If one included the 0.5 m width in which the trees remained, then the area treated for thinning was about 1.08 ha/hr. The harvesting speed at this site was more dependent on the terrain than the amount of biomass to be processed.

Following testing at the South Carolina pine sites, the harvester was tested on a sweetgum regrowth site near Athens, Georgia. The sweetgum was typically 5 to 10 cm in basal diameter and 6 m tall but there were some 15 to 20 cm basal diameter

9 m tall trees. This site was scheduled for bulldozing, stacking into windrows in preparation for planting back to pines. To measure the biomass at this site, trees were harvested and weighed for regression equation development in three plots of 40 square m.

The following regression equation was developed based on 13 trees ranging in circumference and weight of 1.04 cm and 0.68 kg to 6.00 cm and 15.25 inches and 28.8 kg.

$$\log \text{ biomass (kg)} = 2.145908 \log \text{ circumference (cm)} - 1.90783$$

The detransformed r^2 was 0.928 and the root mean square error 2.13 kg.

The biomass estimates were derived from basal diameter measurements on 3 plots of 40.5 m². By applying the regression equation to the 3 plots we estimated the biomass/ha as follows:

- Plot 1 with 25 trees had a brush biomass of 89.72 kg (22,161 kg/ha) (each of the plots were 40.5 m²).
- Plot 2 with 19 trees had fresh biomass of 117.26 kg (28,963 kg/ha).
- Plot 3 with 23 trees had a fresh biomass of 129.87 (32,078 kg/ha).

Thus, the mean biomass/ha was 27,733 kg/ha with a standard deviation of 5,078 kg/ha. The mean and standard deviation for the number of trees per ha was 5,515 +/- 755 trees/ha.

When harvesting the sweetgum trees at 1.6 km/hr, we harvested about 0.4 ha/hr. Given the fact that the standing biomass of this site was 27,731 kg/ha, the theoretical maximum capture would be 11,092 kg/hr. Thus, there is enough biomass at this site to provide 11 ton/hr of biomass which at \$9/green ton would be a \$90/hr credit. If 85 percent capture could be achieved, the harvesting could generate \$76/hr of revenue.

While we had mechanical problems at this site, related to trees hitting exposed hydraulic lines, we cleared about 1 ha at a harvesting rate of about 1.6 km/hr (0.4 ha/hr). For the first time at this site, the power of the harvester became limited in harvesting isolated 17 cm basal diameter, 9 m tall sweetgum trees which fell in front of the harvester and entered the cutterhead to be chipped. This resulted in slower cutterhead and engine speed which resulted in some large wood pieces (15 cm by 4 cm) becoming lodged in the augur. Nevertheless, with improved cutterhead geometry, and the harvester operating at 2,100 rpm instead of 1,700 rpm (due to excessive hydraulic pressures at heat exchanger), it should be possible to routinely harvest 10 to 12 cm diameter sweetgum trees at 1.6 km/hr.

Conclusion

In summary, the basic concept of the harvester worked well but it will be essential to mount the cutterhead on a skidder type frame if it is to operate in the woods, as opposed to short-rotation coppiced fields on farm land. It appears as if harvesting rates of 0.4 to 1.0 ha/hr are possible. Based on the experience in operating a flail shredder, one of us (SB) estimates the operating cost of this harvester (with

operator) to be about \$70/hr. Harvesting in light stands of 1.6 to 2.4 m tall trees at 3.5 km/hr (0.9 ha/hr) would cost about \$76/ha. If in addition, 4 ton of green biomass at \$9/ton could be harvested, the thinning cost would be \$40/ha. This compares favorably to costs of \$384/ha for bulldozing, stacking and burning in windrows. Furthermore the absence of soil disturbance or windrows leaves the site in a better condition for planting.

It is clear that the successful economic operation of this harvester will require both a silvicultural need for thinning pines or hardwoods, and a market for chips used for energy. There are thousands of ha in the southeastern United States where thinning hardwood and volunteer pines is desirable, but not economically feasible, due to the high cost of manual labor and the unavailability of suitable equipment. By combining a silvicultural need with a market for energy, it should be possible to economically thin these stands, allowing them to reach their full economic potential.

Upon our return to Texas, we are making modifications to allow operation of the harvester at full engine rpm by correcting the hydraulic overload on the heat exchanger. This will allow greater power at the head and increase the discharge speed of the chips from the blower. In the summer of 1994, we will mount a revised cutterhead with overlapping tooth geometry in the harvester.

Neither the government, nor industry, nor the university community has the time or financial resources to solve this problem alone. At this point there exists (1) a prototype machine that serves as an excellent test bed for commercial development, (2) a university with staff and students committed to further development, (3) a commercial forestry equipment manufacturer (Brown Bear) interested in building the machines, (4) government agencies (SERBEP) and Western Area Power Authority providing modest funds, and (5) a need of pulp and paper companies to more economically thin stands.

It would appear prudent to create a working group among private forestry companies, universities, government and equipment manufacturers to provide their own unique capabilities to further the development of such harvesters. It will be necessary to examine the engineering aspects, the ecological aspects of site harvesting, silvicultural aspects, economics, and the matching of the biomass harvested with end-users. A pragmatic approach would be to make the modifications necessary based on the southeastern USA spring 1994 trip (including better cutterhead design) and then seek support from commercial forestry companies to reexamine the machine in the fall of 1994 in the southeast. Based on those results it would be best if several commercial forestry companies could jointly share the purchase of 1 or 2 harvesters (about \$230,000), incorporating the best designs, and built on forestry skidder frames. Following the field testing of the new skidder based machines the working group would re-evaluate costs, engineering aspects, silvicultural aspects, biomass fuel markets, and site ecological aspects for future development.

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Mechanization of Short-rotation, Intensive-Culture Wood Crops

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ABSTRACT

Three impediments to harvester development--cultural, operational, and economic--that have plagued the development of short-rotation harvesting equipment are discussed. Strategies for the future include concentrating on cropping strategies that (a) result in material that can be harvested by heavy-duty agricultural equipment (<3 mm in diameter, <10 cm tall), (b) result in material that can be handled by conventional forestry equipment (>10 mm DBH, >20 m tall), or defining a small subset of options between these limits and develop purpose-built equipment to suit. Demand/supply and cost/price relationships have to be more stringently defined before short- or long-line equipment manufacturers will enter this market.

INTRODUCTION

The need for harvesting equipment tailored to short-rotation, intensive-culture (SRIC) plantations of woody crops has been an issue and concern since the initiation of the program. The development has been slow, faltering, and expensive for a variety of reasons. Many of the historical impediments are still in place and frustrating current development efforts.

These impediments or barriers may be broken into three broad categories: cultural, operational, and economic. The associated controlling forces are the grower, the consumer, and the market place.

CULTURAL IMPEDIMENTS

An advantage of short-rotation, intensive culture is the plethora of permutations,

species planting density, cultural intensity, and rotation ages that are available. While this offers considerable opportunity for finding the best or "ultimate" fit for a particular location or scenario, harvesting is reduced to shooting at a moving target, or encounter the nightmare of having to develop a different harvesting methodology for each of several broad categories of permutations.

Species

The species to be harvested is among the most critical concerns, for this defines six critical severance and materials handling parameters.

Stem form, whether deliquescent or excurrent, has a strong impact on the design of capture and handling mechanisms. When rotations are very short, deliquescent forms tend toward a situation where each plant is unique. Severance components must deal with branching or forking in the zone of severance as well as single, relatively clean stems. Capture after severance and handling demand a method that both holds the stem or stems and forces it into a standard shape or volume for subsequent processing. The severance problem becomes less severe as rotation age lengthens and the plant takes on a single-stem form, self-prunes at the base, and the main stem can be used to pull or force the top onto processing equipment.

Excurrent forms generally have a more predictable growth habit, a greater tendency toward single-stem development and regular branching habits. The problem of fitting the plant into a standard form or volume persists for very short rotations.

These branches tend to fold upward along the stem with less breakage and are easier to compress for processing or storage. Branch angles of 45 to 90 degrees require more energy and effort to fold, are more likely to break, and are more likely to resist compaction. Downward sloping branches are the most difficult to work with. Folded downward, the path of least resistance, they tend to interfere with severance devices on small trees and resist handling by the butt in larger stems. These limbs are more likely to break in linear feed or skidding operations as well as require more energy and do more damage when dragged, as in skidding.

Branch angle adds a further complication. Species with branch angles of 45 degrees or less from the vertical require less hardware and energy in handling than those with branch angles more nearly perpendicular to the stem. Branch size, both length and diameter, varies with species and within species. Small-diameter, flexible limbs are the easiest to handle, providing they can be kept from tangling around shafts and other rotating machine components. Branching

habit and rotation age combinations which allow branches from stems in adjoining rows to become entangled are especially troublesome; the harvest becomes one continuous tug of war.

Self-pruning, especially, near the point of severance, is especially desirable. Living or dead branches in this portion of the stem interfere with severance devices; become entangled in feed rolls, belts, or chains of continuous travel machines; and tend to harbor large amounts of grasses, vines, and forbs that interfere with machine operation.

Specific gravity determines the "energy density" or "fiber density" of the harvested material leaving the tract. Specific gravity among candidate species ranges from 0.30 to 0.355 for hybrid poplars and willows to 0.65 for black locust. Packing densities (volume of material per unit volume of occupied space) is roughly the same for both species, whether in roundwood or chip form. Species of higher specific gravity deliver twice as much product for each activity carried out.

Differences in coppice or sprouting habit also impact on harvester design. If the species chosen only has stump sprouts or has stump sprouts that quickly crowd out root sprouts, the row characteristic of the plantation is maintained and machine design held constant between harvests. Root sprouting, however, transforms the planting from what is referred to as a "row crop" in agriculture to a "field crop" after a few harvests, and harvesters much be changed accordingly.

Cultural intensity

Cultivation and irrigation can affect harvesting machine and system design, cultivation by loosening the soil between rows to the point that machine trafficability is reduced or by mounding soil around or near the stem or stool such that it interferes with severance. Irrigation lines must be removed prior to harvest and special care exercised to assure that no pipe, posts, or stakes are left on site, adding costs that are too often identified as harvesting, rather than cultural, in accounting systems.

Demands for special harvest treatments increase with the level of cultural intensity. Restricting harvesting to the dormant season to maximize coppice production and minimize nutrient losses is a fairly common requirement, and one that can be accommodated, providing weather during the dormant season is not so wet that access to the sites is limited, nor so cold that stools shatter during severance, nor snow so deep as to interfere with operations. Sufficient volume must be available during the operable periods of each year to amortize the investment in harvesting equipment. Seasonal operations also demand equipment that requires moderate to low operating skills.

The development costs to prepare a tract for intensive culture requires that maximum area be kept in production: "idle" areas in roads, landings, and on-site storage areas are minimized, further restricting operational flexibility.

Reproduction process

The reproduction method to be used is one of the major determinants of harvesting machine and system design. Reproduction from seed cuttings or seedlings at the start of each rotation allows the greatest flexibility. Each harvest is a new start; site preparation can remediate soil compaction or disturbance during the harvest. Tree size is likely to be consistent from one harvest to the next. Damage to the stump or stool is not a concern. Stem spacing can be maintained or adjusted with each planting and there is less tendency to leave irrigation systems or other cultural appliances in place between rotations, and harvests do not need to be tied to the dormant season.

Coppice regeneration reduces harvesting flexibility. The extent of the reduction is a function of the species being used and rotation length. Damage to the stool from the severance method used or as a result of machine movement across the site should be kept to a minimum. Stool size and character changes between coppice rotations and stem size decrease with each rotation. Machine traffic is usually limited to movement along, not across, rows, and dropping material on the site and then picking it up with grapples or forks increases the risk of stool damage. Machine designs that capture the material and carry it to row end are favored. Soil compaction and soil disturbance that may damage roots is to be minimized. Harvesting is generally restricted to the dormant season to maximize coppice vigor. Stem spacing and organization are fixed until the stools are removed and the stand re-established.

Coppice regeneration of species that root sprout readily, such as some *Populus* species and *Robinia*, is most problematic, for the nature of the stand changes dramatically with coppice rotations. Root sprouts tend to spread between rows, masking any row organization of the stand. Root sprouting species are almost universally shallow-rooted, and many have a strong tendency for root grafting. Shallow rooting increases the probability of infection by disease fungi immediately after harvest; root grafts facilitate the movement of rot and disease organisms from one stool to the next.

Rotation length

The active question is, "how short is short?" Rotations which result in stems being harvested when they are between 2 and 3 cm at severance height and less than 4 to 5 m tall can usually be harvested by heavy-duty agricultural (corn and sugar cane) equipment. Material over 15 cm on the stump can usually be harvested with conventional forestry equipment--feller-bunchers, skidders, and processors.

Stems between these bounds (>3, <15) have historically been the domain of land-clearing and right-of-way maintenance contractors. The equipment available (bush hogs, stirrup flails, chain flails) has been designed to destroy or reduce the material and leave it on site as mulch, with no consideration of capturing it as a marketable product. Survivability of stools and minimization of coppicing damage have not been design considerations. In fact, having few stems survive the bush hog, flail, or other treatment has been considered the mark of a good job.

Stems in the 3 to 15 cm DBH range do not fit easily with either area or single-stem acquisition technology. Area-based acquisition and severance equipment such as combine headers work best with a uniform distribution of material and a relatively homogeneous plant size. Single-stem technologies, which can be generalized to single-stool technologies, require a plant spacing open enough to get the implement on the stem (roughly 6,000 stems or less per ha) and stem or stool form that facilitates multi-stem accumulation.

These concerns are compounded when coppice reproduction is expected for several harvest cycles. Repetitive coppicing results in stool enlargement and a tendency toward an increased number of proportionally smaller stems. There is a point at which the change in material after repetitive coppicing is great enough to

require a change in harvester or harvester design.

OPERATIONAL CONSTRAINTS

Transport and transport modes

Agricultural transportation modes parallel agricultural harvesting techniques for material less than 5 cm DBH. The three most common systems are: (1) reduce the material to chip or particle form in the field; (2) transport by off-road truck or wagon to site or bin storage; (3a) compact the material into a large bale or package during the harvest and transport these to a storage area along the edge of the field or concentration yard, or (3b) compact into smaller cubes which are transported to off-site covered storage. A fourth alternative, full-stem transport, is also available.

Chipping in conjunction with harvesting and small-bale strategies usually include transport in conjunction with processing. Harvesting must be restricted to those days that the material can be moved across and from the site with minimal damage to soils and growing stock, implying high-flotation tires or tracks with limited grouser depth. Vehicles which are unsuited to long distances over-the-road transport. Reloading at field edge for long-distance transport adds an additional cost center.

Large-bale technology offers greater economies for long-distance transport if bulk densities can be achieved that maximize legal loads. full-stem transport is to be used in some European operations, where full stems are transported by forwarders to field edge, piled, and covered. The processor (chipper) then moves along these piles, blowing the material directly to road transport equipment.

Material over 10 to 15 cm can be handled by conventional forestry equipment--feller-bunchers, grapple skidders and whole-tree chippers if the site and growing stock can withstand that level of disturbance.

Agricultural systems have evolved in a manner which minimizes grower or producer transport. Cropping strategies have developed that concentrate producers around markets and processors. Grain is moved to a local elevator; every small town in the Cotton Belt has a gin. Forage and cane crops are seldom transported long distances.

The normal trucking radius for conventional forest products is 160 km, with rail or barge transport used for long distances.

The market and supply have developed together in both instances, with production concentrated in those areas with a transportation advantage. In fact, both forestry and agriculture have seen an implosion of "procurement areas" over the last 20 years as rail transport has diminished. In the case of forestry, tract-to-plant transport has become fully integrated into the harvesting process.

ECONOMIC IMPEDIMENTS

Products

The intended market for the product is yet another delineation of harvesting systems and practices. The three major markets that have emerged are energy production by direct combustion, conversion to liquid or gaseous fuels, or pulp furnish. Each has its own set of requirements and a separate set of market prices.

Direct combustion purchasers prefer fuels of consistently low moisture content. Solid matter fuel losses during prolonged storage are of concern for those facilities requiring dormant season harvesting serving a facility with year-round demand. Storing the material in the round or field-drying the stems before processing can reduce the losses common to even the best-designed chip pile. Other product forms--chunks, billets, bundled, crushed, and baled, and other modes of storage--covered, enclosed, elevated, and packaged--have been tested experimentally, but the current level of demand has not justified major shifts in technology. Direct combustion facilities are usually fairly tolerant of a range of piece sizes and bark and minerals in the furnish.

Conversion to gaseous or liquid fuels through fermentation works best with feedstocks where the initial moisture content, free sugars, and starches have been maintained. Juvenile stems have a larger percentage of living cells per unit weight and a correspondingly higher loss to respiration after harvest. Ideally, the harvested material should be used fresh or kept very cold or dried after harvest to slow respiration.

Most pulping processes work best with fresh material as well. Demand is less seasonal than for energy, and most harvesting systems harvest with a week or two of conversion. Harvesting for pulp production tends to be hot (the wood arrives at the mill within a day or two of harvest), reducing the need for on-site storage. Direct combustion facilities are usually fairly tolerant of a range of piece sizes and bark and minerals in the furnish. Pulping processes are becoming increasingly restrictive concerning bark, fines, and dirt content of the furnish.

Markets are likely to become more demanding in their raw-material specifications as conversion technologies and environmental restrictions become more sophisticated. These demands will quite quickly translate into tightened harvesting requirements.

Cost/price

The value of these products cannot be established until the demand/supply situation is better understood, and this relationship is the function of issues well beyond the plantation or even the target industry. The market competition for SRIC material is from substitutes for biomass such as natural gas, petroleum, coal, and recycled materials, both petroleum- and biomass-based. The price of these alternatives will depend on international politics, national environmental and industrial policies, and the public's acceptance of individual products. Supply competition arises from natural timber stands, extensively managed plantations, agricultural crops, and residues and recyclables.

SRIC crops must carry high cultural costs. The key question is, "will the market price be sufficient to cover both these costs and the harvesting and transport costs of the material?" Traditionally, high "stumpage costs" as a result of cultural investment or market competition for the standing material have resulted in harvesting contract rates being suppressed to near the lowest level of economic activity for the harvesting firms, a level which cannot support the development of specialized machines or products.

Niche markets exist where these larger constraints do not obtain. Market prices may be levered upward in an attempt to save a plant or industry whose traditional raw material supply has been lost. Stumpage prices may be forced downward when the cultural costs are mitigated by, for example, farmers choosing to produce SRIC crops as a substitute for traditional agricultural crops which are no longer in demand, or for which their farm is a marginal producer. The up-front investment in land, mobile and cultural equipment is avoided, and the producer sees this cropping alternative as a means of salvaging his investment rather than an entrepreneurial effort.

These issues are far from resolved, and as a result, the contract rate per ton on million BTU's is still in conjecture. The era when a prospective equipment manufacturer could invest research and development funds in a project in the hope that the product would meet the desires of an undefined market is past. Supporting development with government funds allows mechanical, but not economic, development to go forward.

SUMMARY

Mechanization of short-rotation crops is a systems problem and involves the entire system from seed to feedstock. Both forestry and agriculture are rife with examples of the growing stock and cultural practices being modified to match harvesting requirements and harvesting being adapted to cultural requirements. The trade-offs have to be deliberated and the solutions defined.

The market for short-rotation harvesters is both limited and largely undefined. The nearly 25-year history of the SRIC concept has been one of shifting cultural and conversion scenarios and the search for the species/cultural combination that yielded the ultimate yield per unit area.

The current approach is restricting the development of short-rotation crops to those that can be harvested with agricultural equipment at one pole and those that can be captured with conventional forestry equipment at the other. It is unlikely that any major investment in engineering design or fabrication will occur until both ends of the system--cultural and conversion--have stabilized. Bringing a harvester or harvesting system to market is a long and expensive process. Local job shops may be enlisted to construct a single-purpose-built harvester for a specific application, but this level of development lacks the financial, sales and parts support and warranty backing provided by a short- or long-line manufacturer.



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Growing *Eucalyptus* for Pulp and Energy

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To produce pulpwood for a pulpmill that Simpson Paper Company owns near Anderson, California, Simpson Timber Company began, in 1987, to establish 4,047 ha of short-rotation, intensive- culture *Eucalyptus* plantations. The plantations are located in the northern Sacramento Valley on agricultural land of marginal quality that, prior to planting, had been used for only six to eight weeks per year each spring for grazing sheep. In this area of very hot and dry summers, it is necessary to irrigate the plantations to assure first year survival and in subsequent years to maximize growth. Because winter time temperatures sometimes drop to as low as 10 degrees to 15 degrees F. (-12 degrees to -9 degrees C), it is also very important to plant species that tolerate, at least to some extent, very cold weather.

Initially, two species, i.e. *Eucalyptus camaldulensis* and *E. viminalis*, were selected as being sufficiently cold tolerant while also capable of withstanding, under irrigation, the very hot summer temperatures. The species were, of course, also selected because they are suitable for the manufacturing of quality paper.

For the first five years of this plantation establishment project, the planting stock was grown from seeds obtained in Australia and, in some cases, from seeds collected from other plantations elsewhere in California. As the result of research carried out during these five years, Simpson, by 1992, had successfully developed a tissue culture process of micropropagation for *E. camaldulensis*. With this process, clones of the most rapidly growing and best formed individual trees are mass produced. Since 1992, therefore, all of the planting stock used for the establishment of these plantations has been of clonal origin with total plantation yields expected to increase dramatically over that which will be realized from plantations established with planting stock grown from seed.

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

As was mentioned above, the Tehama Fiber Farm project involves the establishment of a net 4,047 ha of *Eucalyptus* plantations. The plan is to grow the plantations on an eight-year rotation which means, then, that approximately one-eighth of that total area, i.e. 506 ha, must be established each year for eight years.

To provide the required summertime water, the plantations are drip irrigated. The topography is too irregular for furrow or flood irrigation. Drip irrigation systems require elaborate engineering that takes into account planned well locations, elevational changes, roads, streams, property boundaries, and various other topographical features. For this project, a system of approximately 506 ha is designed each year. The actual acreage is based on the best compromise of the above-mentioned factors rather than a strict adherence to the 506 ha figure. To minimize the number of wells that must be developed, each irrigation system is comprised of a number of irrigation blocks that can be operated independently of one another. The systems are also designed to allow for the future development of additional wells as water requirements increase with the increasing canopy cover of the developing plantation.

Upon completion of the irrigation system design, the first element of site preparation, i.e. soil ripping, begins. This activity is accomplished during midsummer, when the compacted clay soils, often with hardpans, are very hard and dry. Ripping involves the use of two D-9 Caterpillars pulling, in tandem, three steel shanks with hardened teeth that extend into the soil to a depth of 71 to 81 cm. With the soils so hard and dry, very thorough fracturing of the soil profile, including hardpans, occurs.

Immediately after soil ripping, the area of $506 \pm$ ha is surveyed to accurately locate and mark, on the ground, the exact location of all underground pipes, including main lines, sub mains, valves, and other elements associated with the under-ground portion of the irrigation system. Construction of the system involves trenching, gluing together miles of PVC pipe of various sizes, installing the necessary valves, water filtration equipment, and, of course, the installation of pumps and pump engines.

It is late autumn or early winter when the above described activities are complete. No further activities are scheduled until the following April when the area is disced to eliminate weeds and grasses that germinated during the late winter and spring. With this discing, the area will remain essentially weed and grass free for the remainder of the year because the soil surface is dry without significant chance of additional rain, at least through the remainder of the spring, summer and early autumn.

The discing leaves a very well-prepared surface over which emitter lines are stretched and attached to "risers" that come up from the underground network of pipes that were installed during the previous late summer and early autumn. These emitter lines (and risers), spaced 3 m apart, are oriented as per the irrigation system design. Emitters are spaced at intervals of five feet along the emitter lines. When the emitter lines of each irrigation block (approximately 40.5 ha) are all attached to their respective risers and the ends crimped to prevent water from flowing out of the tubes, the appropriate pumps are started. After five to six hours of pumping, there is an obvious wet spot of soil at each emitter. A *Eucalyptus*

seedling or plantlet is planted at every other wet spot along each emitter line. When completely planted, the spacing between planted spots is approximately 3 x 3 m which results in a plantation density of approximately 1,111 trees per ha.

Under these conditions, survival is surprisingly good with most irrigation blocks in excess of 95 percent and many blocks near 100 percent, even though temperatures at the time of planting may be as high as 32 degrees to 38 degrees C (90 degrees to 100 degrees F). Growth is also excellent with trees reaching 2.4 to 3.7 m by the end of the first growing season. Trees at harvest age are expected to be 24 m tall and 25 to 30 cm in diameter at breast height.

Irrigation during the first year totals approximately 15 ha-cm of applied water. The total is increased to about 31 ha-cm during the second summer and to about 61 ha-cm during the third and all subsequent years. During any given year, the amount will vary as the intent is to provide approximately 50 percent of measured evapotranspiration.

The irrigation system, in addition to delivering water, is used to provide accurately-measured amounts of nitrogen to the plantations. During the first year, approximately 2.7 kg of actual nitrogen is applied. The amount is increased each year until year five when total applied nitrogen is 56 kg per ha. Thereafter, the plantations continue to receive 50 kg of nitrogen per ha per year.

So far, pest problems have been minimal although grasshoppers will sometimes cause serious damage shortly after planting if not controlled. Voles will also damage trees during the second and sometimes third year following planting, but only where conditions of grass and weed cover provide them with a favorable habitat under or near the plantation edge. Vole populations and, therefore, vole damage can be easily controlled by reducing the area of favorable habitat.

This plantation establishment operation is managed by an organization consisting of five people in management and supervisory positions with three additional full-time employees who assist in monitoring plantation growth and who maintain all equipment including the irrigation systems. During the summer months, 10 additional people are employed as irrigators to operate the irrigation systems which must run essentially 24 hours per day to provide the required amounts of water where and when needed.

The irrigation system design is accomplished by contract as is most of the site preparation, irrigation system installation, planting, road construction, road maintenance, and certain other activities such as well drilling and pest control. At times, with contractors on site, the work force will increase to as many as 20 to 30 people or more.

Planting stock is produced in a nursery that is also owned and operated by Simpson Timber Company. Production of the planting stock involves the year-round operation of a tissue culture laboratory employing eight people as well as a four to six month nursery growing period that employs eight to ten people for periods of time when the planting stock is transferred from the tissue culture laboratory to the green houses and when the planting stock is packed for transport

to the plantations for planting.

The subject at this conference, i.e. mechanization in short rotation, intensive culture forestry, is of vital interest to Simpson Timber Company as the day rapidly approaches when harvesting and processing of the wood from the Tehama Fiber Farm will begin. Cost-effective mechanization of all processes including tree-felling, accumulating and forwarding will be very important.

Since the primary purpose of these plantations is to produce wood for paper pulp, an improved system of debarking small *Eucalyptus* logs is needed. Only clean, bark-free wood chips can be used in Simpson's paper pulp making process. Also needed are improved systems for field chipping of the debarked logs.

It is expected that about 30 percent of the above-ground biomass produced, including the bark, will be unsuited for use in the paper pulp making process but will be quite suitable for use as fuel. Efficient systems for separating, processing and transporting the fuel biomass components would also be very helpful. At 30 percent, fuel biomass could amount to as much as 100 to 110 green tons per ha.



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Management of Irrigated Hybrid Poplar Plantations in the Pacific Northwest

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ABSTRACT

Increasingly reduced timber availability in the Pacific Northwest has necessitated the search for alternative sources of wood fiber. Short rotation, intensively cultured plantations of hybrid poplar have the potential to mitigate some of this wood supply shortage.

Boise Cascade Corporation has embarked on a project to establish about 8,000 ha of irrigated hybrid poplar plantations in the Columbia River Basin of eastern Oregon and Washington. These tree farms will provide approximately 15 to 20 percent of the raw material supply for the company's pulp and paper mill at Wallula, Washington. The fiber will be used in the production of uncoated free sheet white papers. In addition to increasing the fiber available to the mill, the hybrid poplar provide other benefits including: reduced bleaching and improved paper qualities of brightness, opacity and print ability.

Fiber farms are developed on existing agricultural land. Traditional irrigation systems are converted to drip irrigation. Planting sites are prepared with mechanical cultivation and pre-emergent herbicides. Planting stock is unrooted dormant cuttings produced in stool beds. Planting is done by hand during the month of April. Crop tending consists of irrigation, weed control, fertilization and pest control. A six year rotation is planned at which time the trees are expected to be approximately 18-20 m in height and 15-20 cm in diameter at breast height.

INTRODUCTION

The supply of wood fiber in the Pacific Northwest from both public and private land has been severely curtailed by preservationist activities. This artificial supply shortage, coupled with continued societal demand for wood products, has caused the price of wood to increase dramatically. Therefore, the cost of producing fiber

from intensively managed hybrid poplar plantations has become economically justifiable.

The concept of fiber farming is based on the assumption that the trees are an agricultural crop. And, indeed, they have been deemed so by the legislative and regulatory authorities. This crop is established, grown, and harvested using the same intensive, mechanized philosophy applied in more traditional crops. The short rotations and high yields achieved are dependent on this aggressive management approach, and can not be attained through less intensive practices.

The goal of Boise Cascade Corporation's fiber farming project is to supply 15 to 20 percent of the raw material for the company's pulp and paper facility at Wallula, Washington. This volume of wood will require approximately 8,000 ha of plantations. The project began in 1990, with the first planting done in 1991. The first harvest of trees is scheduled for 1997. Harvesting will be done on a six year cycle, with the expectation that the rotation can be shorted over time with improved genetics and agricultural practices. Year round harvesting is planned to minimize storage time for the chips. A sustainable, even flow of wood is required, which will entail harvesting and planting about 1,500 ha annually. Hybrid poplar was chosen as the species to grow based on its adaptability to the local environment, fast growth, and wood characteristics.

LOCATION

Boise Cascade's fiber farms are located in the arid regions of eastern Oregon and Washington. Annual rainfall is approximately 15 to 20 cm, of which half falls as snow. Temperatures are extreme, regularly reaching 40 degrees C in the summer, and falling to below -20 degrees C in the winter. Soils are alkaline, with a pH of 7 to 8. Soil texture is extremely sandy, with very little organic matter or water holding capacity. Natural vegetation is a steppe-sage habitat dominated by sagebrush and grasses, with occasional cactus. The growing season is quite long, usually having up to 200 frost free days. The northern latitude provides additional hours of sunlight. Agricultural crops grown in the area all require irrigation, and include: corn, wheat, potatoes, alfalfa, asparagus, onions, carrots, grapes, apples, cherries, peaches, and a variety of minor crops.

IRRIGATION

Irrigation was brought to the Columbia Basin beginning with Bureau of Reclamation projects in the 1950's. These projects were open canal systems which transported water, diverted from rivers or impoundments, through prime agricultural land. Individual farms then tapped in to this vast supply. More recently, wells have been developed in some areas which supply ample water from deep aquifers. Pumping stations have also been established on rivers and lakes which supply water to independent farms or irrigation districts.

Traditional irrigation systems include: flood, rill, hand lines, solid set, wheel lines, and center pivots. Drip irrigation is relatively new to the area, and used mostly in vineyards and orchards. However, drip irrigation is the most practical method of

irrigating fiber farms due to the height growth and dense canopy of the trees. It is also a very efficient method of irrigation in that less power is required due to low operating pressures and there are almost no evaporative losses.

Irrigation systems are designed specifically for the tree crop. The drip tube rows are about three meters apart. Emitters are spaced at one meter intervals along the tube. Trees are planted at every other emitter which gives an approximate planting density of 1,500 trees per ha. Irrigation blocks are designed for hydraulic efficiency based on the existing equipment and land topography. The irrigation blocks range from 100-600 ha. They are then subdivided into 15 to 20 ha planting blocks which are generally rectangular. The underground lateral pipes are 500 to 800 m long, and the above ground individual drip tube rows average 300 m.

A variety of drip irrigation system designs and equipment has been tested. Each situation may be somewhat unique, but standardization of the systems is operationally desirable. In general, Boise Cascade's preferred drip irrigation design includes: sand filtration which is essential to keep emitters from plugging, buried (1 m), telescoping PVC laterals with end flush outs, a shutoff valve, screen filter and pressure regulator on each line, pressure compensating emitters, and a pressure sensor at the end of each line. These materials may be provided by a number of manufacturers. Experience in a particular application will determine the best suppliers.

Maintenance of the drip tube is a continuous process. Each tube must be flushed periodically to remove sediment. Animal damage occurs routinely and must be monitored and repaired. Plans are to remove the above ground portions of the system before harvest, and then to reuse it for subsequent rotations.

The irrigation season lasts from April to October. Water is applied on a daily basis to keep the soil moisture slightly below field capacity. Weekly soil moisture measurements are taken

using neutron probes. Irrigation schedules are then determined based on changes in soil moisture and tree demand based on predicted weather patterns. The systems are capable of delivering up to ten mm of water per day which is the estimated maximum evapotranspiration demand of the trees. Annual water application varies between 50 and 90 mm depending on the site and age of the trees.

SITE PREPARATION

Hybrid poplar establishment usually follows other crops. Protection of the site is important due to high wind erosion hazard in the area, so, unless sufficient organic residual is left after harvest of the prior crop, a cover crop of winter wheat is established. The site is surveyed for the construction of the drip irrigation system, and the reference stakes are used to determine the tree row locations. Each row is mechanically marked by cutting a twenty cm slit in the soil. A two m band centered over the tree row is treated with Treflan pre-emergent herbicide, and rotovated during the winter or spring prior to planting. Immediately before planting, a broadcast herbicide treatment of glyphosate or 2,4-D may be applied to the site depending on the weed community that is present.

PLANTING

Hybrid poplars which perform best in the Columbia Basin are crosses between *Populus Trichocarpa* and *Populus Deltoides* or *Populus Deltoides* and *Populus Nigra*. Cloning individual hybrid genotypes is very easy due to their ability to form roots and shoots from both dormant wood and actively growing plants. Clones selected for operational planting are field tested for growth rate, cold hardiness, insect and disease resistance, and wood characteristics. Five clones have been used operationally to date in 4,500 ha of plantations. Deployment strategy is to match the clones to site conditions, and then use the fastest growing clone available for that site.

The planting stock used is unrooted, dormant cuttings produced in stool beds. Stools are established at a density of 11 per square mm. Production after the year of establishment is about 375,000 cuttings per ha. Stool beds are usually replaced after 4 or 5 years. Cutting production begins in January and is finished by the first of March. The annual sprouts from the stools are cut with hydraulic shears in the field, and transported to a facility where they are cut into 20 cm lengths by a set of parallel circular saws. The sticks are then graded by diameter, 10 to 15 mm being acceptable. A viable bud within 2.5 cm of the top is also required. The sticks are then oriented in the same direction, and placed in plastic bags of 50 cuttings. The bundles of 50 are then placed in a larger plastic bag, and boxed in batches of 500 trees. The cuttings go from the stool to the freezer the same day to prevent desiccation.

Planting begins when the soil temperature reaches 13 degrees C, usually in early April. Cuttings are kept frozen at -2 degrees C until 3 or 4 days prior to planting. At that time they are placed at the planting site to defrost and initiate root development. No treatments, such as soaking or growth hormones, are applied to cuttings.

Mechanical planting has been attempted, but as of yet has not been successful. The difficulty is placing the cutting directly at an emitter, which is necessary to assure survival. Hand planting quality has proved satisfactory, since the planting spot is marked by the wet spot from the irrigation. Production rates are very high at about 5,000 cuttings per person day. The sticks are planted to a depth where the top bud is left above the soil line. Irrigation is applied prior to planting and continuously thereafter to enhance root development.

Initial survival in the plantations is 90 to 95 percent. This stocking level is supplemented about one month after planting by an interplanting done during an irrigation maintenance operation. Stocking levels at the end of the first year average about 98 percent.

CROP TENDING

Intensive crop management is essential to producing the expected yields at harvest. The hybrid poplars are sensitive to many factors which influence growth such as competition, nutrition, and pests. Control of these environmental

conditions to the greatest extent possible is necessary to obtain the maximum benefit from the clonal genetics.

Weed control is the biggest agronomic challenge facing the fiber farm. A variety of sources contribute to the difficulty in weed control including: lack of rainfall to incorporate herbicides, the sensitivity of the hybrid poplar to damage by herbicides, and difficulty with mechanical treatments because of the drip tube. Many site preparation herbicides require water, either from overhead irrigation or rainfall, to incorporate the herbicide into the soil or to activate it. Drip irrigation and the local climate do not provide the necessary water. Therefore, a tilled in herbicide is the most effective treatment, but to date a compound with a wide efficacy range on the local weed community has not been found. Once the trees are planted, any herbicide applied to the leaves can cause severe damage. Growing season weed control is limited to treating the row centers with a shielded spray or a wick application. Grass control herbicides can be used in a broadcast application. During the dormant season, a broadcast treatment is applied to remove annuals that germinate before the trees leaf out. Cultivation of any sort has generally not been successful due to damage done to the drip tube.

Maintaining the optimum nutrition for the trees is important in obtaining maximum growth. Fertilizer is applied annually throughout the growing season. Chemigation, i.e., application of treatments through the irrigation water, is the standard practice, although some treatments require application by ground equipment or by air. A mixed fertilizer containing zinc, phosphorous, sulfur and nitrogen is applied in April. This is followed by continuous light applications of nitrogen from May through the end of July. Desirable levels of foliar nutrients have been determined. Regular foliage samples are taken to determine if these targets are being achieved. If not, supplemental treatments are applied either on a broadcast or spot basis. Due to the alkalinity of the soil, micro nutrient deficiencies are the most common. These include: zinc, calcium, and manganese.

There are a number of pests that attack hybrid poplar in eastern Oregon and Washington. Insects are by far the most important, but are limited mainly to leaf beetles and stem borers. These insects can be easily controlled with systemic insecticides applied directly through the irrigation water. Results of a treatment can be seen in a few days, and the effect lasts several months. The hot dry climate is unfavorable to fungal diseases, but melampsora medusa leaf rust has occurred late in the fall after the growing season. Animal damage occurs sporadically, and can be important in localized areas. Deer browse when the trees are young can cause multiple stems and significant height reductions. Beaver damage occurs along most water ways, so an active trapping program is necessary. Mice cause the most severe animal damage by girdling young trees in the winter. This happens in weedy areas when there is a snow cover. Weed control is the best preventive measure, but baiting will reduce the incidence of damage if applied before snowfall.

RESULTS

During the first three years of operation the fiber farm has exceeded initial expectations. An annual inventory is taken on the entire farm to precisely

determine growth rates and standing wood volume. This information is kept in a detailed Management Information System (MIS), which is linked to a Geographic Information System (GIS) containing layers on planting blocks, irrigation blocks, soils, elevation, etc.

The stocking rates described above are more than adequate to obtain full site occupancy. Height growth rates vary slightly from year to year depending on weather conditions. Average first year height has been about 2.5 m. Second year height has averaged 6.4 meters. Third year height has averaged 10.7 m. While there is some variation around these average values, the range is remarkably small. This uniformity can be attributed to the use of clonal material, uniform site conditions, irrigation and intensive management. Diameter (DBH) is not measured in the first year. Second year DBH averages 5.3 cm and third year DBH averages 10.4 cm.

SUMMARY

Fiber farming of hybrid poplar in the Columbia Basin is proving to be a successful venture for Boise Cascade Corporation. Tree growth is exceeding expectations. Costs to grow the crop are predictable and controllable. The operating environment is favorable from a legislative and regulatory point of view. The additional wood supply at a reasonable cost is attractive to the mill. The short white fibers of poplar wood provide benefits to the mill in addition to fiber supply which include: improved brightness, opacity and print ability in the uncoated free sheet paper grades as well as reduced bleaching.



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Mechanization Potential for Industrial-Scale Fiber and Energy Plantations

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ABSTRACT

Current costs for all activities (annual maintenance, harvesting and reestablishment) on an irrigated, short rotation, pulpwood and energy plantation in California were compared with estimated minimum costs for the same activities if high levels of effort were put into mechanization. The plantation, with a total of 4,000 ha, is operating on an eight-year rotation, with 500 ha in each age class. At this scale, move-in costs are insignificant and can be ignored; most of the specialized equipment can be utilized throughout the dry operating season of approximately eight months. Given that the plantation has equal areas in each age class, costs for activities on each age class are incurred each year. The differential cost between current and minimum was derived for each activity, and yearly benefits were calculated. For the California plantation, further mechanization efforts were estimated to provide benefits of up to half a million dollars per year. The majority of this would come from an improved method of delimbing and debarking. Other large gains were projected for a continuous-travel felling machine, lighter chip vans and a better method of handling drip irrigation lines. Minor benefits would accrue from further mechanization of some cultural operations: planting, stump removal and thinning of coppice sprouts.

INTRODUCTION

Several commercial short rotation plantations are now operational in the United States. Many were established within the past six years and have not yet reached the first harvest rotation. Most activities in these plantations - establishment, cultural operations and harvesting - have been or are planned to be carried out with conventional agricultural or forestry equipment. This makes sense for a neophyte industry which is utilizing few pieces of equipment. As the scale of short rotation planting increases, it may be attractive to develop specialized equipment

for some of these activities. In this paper, we attempt a first cut at determining where further mechanization efforts have the most potential to improve short rotation activities.

APPROACH

We took the point of view of the owner of a plantation that is operating in a steady-state condition: all the initial establishment has been completed and each age class is represented equally in terms of plantation area. Using "base case" or current costs for each activity, total dollars currently spent on each activity were estimated. Sources of information published over more than a decade were used to derive the cost estimates, but all figures were adjusted to 1993 U.S. dollars. Then we estimated the potential reductions in costs for each activity. Equivalent present worths of infinite series of the yearly reductions can then be used as upper limits on what might be invested in further mechanization or other improvements.

For purposes of illustration, we used Simpson Timber Company's Tehama Fiber Farm, located near Corning, California. The plantation will provide a large part of the hardwood furnish for Simpson Paper Company's pulp mill, and residues will be utilized as fuel by Wheelabrator Shasta Energy Company's freestanding electric power plant. After the last blocks are planted in the next couple of years, the plantation will cover 4,000 ha. Rotation age is expected to be eight years, and yields are assumed to average 20 dry Mg/ha/year. Although planting densities have varied somewhat, 1,500 trees/ha is assumed for this example. The site is dry during the eight warmest months of the year, so drip irrigation is required. We assumed that equipment could travel in the plantation during the eight-month dry period, making it feasible to dedicate equipment for the one plantation. The large scale of the plantation also allowed us to ignore move-in costs. One-way haul distances are 70 km to the pulp mill and energy plant.

CURRENT COSTS

Plantation establishment activities

Before the first planting, Simpson's land was unirrigated pasture. Establishment operations included ripping, installing wells and the underground portion of an irrigation system, disking, installation of above-ground drip lines, and hand-planting of seedlings and/or clones. These activities are more fully described in Jim Rydellius' paper elsewhere in these proceedings. They will be ignored here because these one-time operations are "sunk" and have no bearing on future outcomes for a plantation which is already established.

Annual activities

Information on annual activities was taken from Simpson's experience, some of which was previously reported by Hartsough and Jenkins (1990). Costs of pumping irrigation water constitute the major part of the average annual activity cost (Table 1). Evapotranspiration potential (ET) is 1.07 m/year. Irrigation water is applied at 20 percent of ET during the first year, 30 percent during the second,

and 50 percent during the remaining years of the rotation. Nitrogen fertilizer is injected into the drip system and makes up the rest of the cost. Annual application rates average 37 kg N/ha. On Simpson's relatively dry sites, little vegetation control is required after planting. A small amount of pest control is required on the plantation perimeter, but the large plantation area makes this edge application a negligible cost when converted to a per unit area basis.

Table 1. Costs of annual activities, averaged over the rotation

Activity	Annual Cost, \$/ha
Irrigate	249.
Fertilize	24.
Control pests/vegetation	1.
Total	274.

Harvesting activities

Before harvest, the drip lines will be removed; for convenience in the analysis, drip line removal was lumped with the reestablishment activities.

While one short harvesting trial has been conducted by Simpson, the first operational harvesting is scheduled for 1996, so data from other locations were reviewed to help estimate costs. Sources included Arthur and others (1982), Baughman and others (1990), Desrochers (1993), Favreau (1992a), Hartsough (1992), Hartsough and others (1992) and Stokes and Watson (1989). A tricycle feller/buncher and rubber-tired skidder will supply trees to a flail delimber/debarker/chipper at roadside. Delimber/debarker residues will be comminuted with a tub grinder and the processed materials -pulp chips and residue fuel -will be delivered to their respective destinations in chip vans. We assumed that each stump-to-truck activity would handle or process the material from 225 trees in each productive machine hour (PMH), machine utilization was 67 percent for all equipment, and that harvesting labor costs were \$15 per scheduled hour including 50 percent loading. Machine cost estimates were based on Brinker and others (1989) and other purchase price estimates. Costs for chipping were calculated separately from those for delimbing/debarking for illustration purposes, even though both activities are to be conducted by one machine.

The resulting costs are shown in Table 2. When adjusted to costs per unit of pulp chips, the estimated stump-to-truck portions are two-thirds of those experienced by James River Corporation at their Lower Columbia River Fiber Farm (Hartsough and others 1992). These estimates appear reasonable as the average tree weight at Simpson is expected to be 107 kg dry versus the 54 kg observed during the James River study.

Table 2. Costs of harvesting activities

Activity	Cost, \$/total dry Mg
Fell	2.4
Skid	2.7
Delimb/debark	5.6
Chip boles	5.5
Grind residues	1.4
Haul pulp chips and fuel	5.4
Total stump-to-mill	23.0

Reestablishment activities

Simpson is debating whether to remove stumps and replant at the end of each rotation or to rely on coppice regeneration. We assumed a fifty-fifty mix of both methods. Prior to replanting (by hand), stumps will be removed by plowing, the area will be disked, and drip lines will be reinstalled. With coppice regeneration, drip lines will be reinstalled after harvesting. In order to reduce bark percentage in the second rotation, sprouts will be thinned in two stages: with loppers at six months, and by chainsaw when the largest sprouts reach three to four cm in diameter.

Disking, drip line reinstallation and replanting costs were based on extensive experience with initial establishment at Simpson's plantation. Planting costs include \$150/ha for seedlings and \$82/ha for labor. Costs for removing drip lines and thinning sprouts were estimated from limited trials conducted by Simpson. Costs to remove and reinstall drip lines are estimated at \$5 per 100 m, with approximately 3,300 m of lines per ha. Thinning costs include \$270/ha for the lopper entry and \$300/ha for the chainsaw operation. The cost for stump removal is an educated guess.

Table 3. Costs of reestablishment activities

Activity	Cost, %/ha
A. Replant	
Remove/reinstall drip lines	164.
Remove stumps	129.
Disk	53.
Plant	232.
Total	578.

B. Coppice	
Remove/reinstall drip lines	164.
Thin Sprouts	570.
Total	734.

Total yearly costs

For a steady-state plantation, the annual activities are carried out on each ha in each year. One-eighth of the area is harvested each year, removing 160 dry Mg per ha; replanting and coppicing are each conducted on one-half of the harvested area. Total yearly costs for each activity for the 4,000-ha plantation are displayed in Figure 1. Although irrigation is the single most expensive activity, combining the activities into the three major groups shows that harvesting is the most costly category (Figure 2). The sum of all costs is approximately 3.3 million dollars per year.

Figure 1. Current yearly costs for a 4,000 ha plantation, by activity.

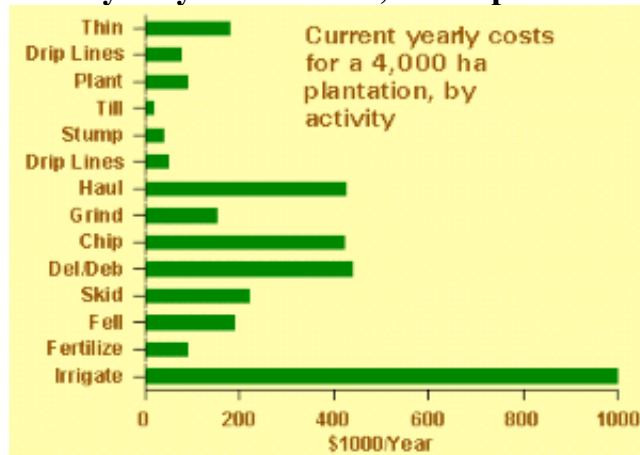
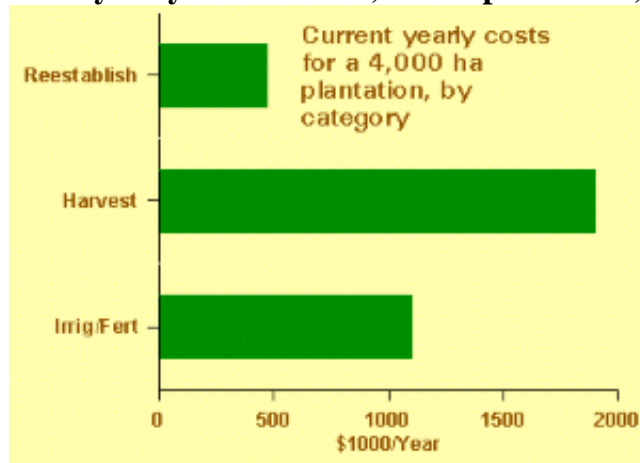


Figure 2. Current yearly costs for a 4,000 ha plantation, by category.



POTENTIAL FOR IMPROVEMENT

We suspect that there is little further mechanization potential for the annual activities: irrigation, fertilization, pest control and vegetation control. These have evolved over several decades in agricultural operations, and the short rotation forestry conditions do not differ markedly from those on conventional agricultural lands.

In contrast, harvesting equipment has been developed for forest conditions: rough and broken terrain with obstacles such as rocks, large stumps and down logs, and generally for coniferous trees that are larger and less-uniform in size than those produced in short rotation plantations. This indicates possibilities for improvements in harvesting equipment.

It may appear that an improvement in one stump-to-truck activity might have no benefit, because of an imbalance between equipment production rates. However, three or more sets of equipment will be required to harvest 500 ha per year over an eight-month period, and all will be working in close proximity. Therefore the integer balancing problem is less of a concern here than in most conventional forestry operations.

In felling, reduction in cost is possible by developing a continuous-travel feller/buncher, similar to those proposed by Golob (1986), prototyped by Hyd-Mech for the Bioenergy Program of the National Research Council of Canada (Curtin and Barnett 1986), and tested by Stokes and others (1986). Effective derivatives of the Hyd-Mech FB-7 or FB-12 would eliminate the stop-and-go, forward-and-back travel pattern inherent to conventional feller/bunchers. Although limited studies show that feller/bunchers can be highly productive in short rotation plantations (Stokes and McDonald 1993), it is difficult to imagine a conventional machine competing with a continuous-travel machine over the long term. Impressive results with continuous-travel machines for harvesting willow in Sweden support this concept (Culshaw 1993) harvesting productivity is higher than for traditional forestry operations even though both the willow volume per ha and average stem size are much less than in traditional plantation clearcuts. Based on results for the FB-7 reported by Stokes and others (1986) and Stoke's unpublished data on the FB-12, we estimated that current felling and bunching costs might be reduced by 40 percent. This assumes a purchase price of \$300,000 for the machine, and an average travel speed of 2 km per hour.

Skidders were designed for rugged terrain, but potential reductions in skidding costs via modifications of skidders seem minimal. Existing skidders can be fully utilized by carrying relatively large turns of small trees on the flat agricultural sites.

Flail delimbing and debarking is widely considered the bottleneck in operations where clean chips are being produced (e.g. Thompson and Jackson 1991). Many studies indicate that either chipping production rates must be reduced to obtain low bark contents, or high bark levels are accepted in order to maintain higher production rates. Bark contents between one and six percent have been reported (Favreau 1992b, Franklin 1992, Sauder 1989, Stokes and Watson 1989, Thompson and Jackson 1991); lower production rates will have to be accepted to meet tolerances of one percent, as specified by some pulp mills.

Chain costs represent the largest single component of flail delimbing/debarking costs. Stokes and Watson (1989) estimated chain costs to be \$0.9 to \$1.8 per dry Mg of conifer chips, or 20 to 28 percent of total flailing costs, assuming 25 PMH per set of chains. Empirical studies have shown these early estimates to be too optimistic. For conifer chips, Carte (1991) and Sauder (1989) pegged costs at \$2.0 to \$2.6 per dry Mg. Reported chain costs for hardwood have been higher: \$3.8 (Sauder 1989), \$4.6 (Hartsough and others 1992) and \$6 per dry Mg of chips (Kaiser 1994). This may be due to inherent differences between bark of conifer and hardwoods, differences that might be exploited to design a more efficient debarking method for hardwoods.

Compared with processes such as chipping, flail delimbing/debarking is inefficient from an energy standpoint. Chipping requires on the order of 10 to 20 MJ per dry Mg of wood (Rodgers 1948). Based on fuel consumption figures reported by Stokes and Watson (1989), flails use 40 to 70 MJ per dry Mg of residues. An additional 40 MJ per dry Mg is necessary to comminute the residues with a tub grinder (Arthur and others 1982).

Moving incrementally from the chain flail, delimbing/debarking for short rotation hardwoods can be improved by 1) increasing production rate so the delimeter/debarker does not limit chipper and tub grinder production and 2) reducing the chain cost and 3) using a more-efficient concept. The first is easy: build a bigger, more powerful unit, possibly with longer drums or a third drum. Examination of the costs of forestry equipment within a single class, such as skidders, shows that the purchase cost per horsepower declines as machine power increases. Assuming flail throughput rate would be proportional to power, the delimbing/debarking cost per unit material would decline if power was increased. Finding a concept that is more efficient and has lower cost than a chain flail is more problematic. While a potentially-successful concept is not immediately apparent, we assumed that chain costs could be halved, and improved efficiency would reduce other costs by one-sixth. The combined maximum potential reduction from current levels would then be approximately 45 percent.

Chipping is a mature science; we assumed no improvement in chipping capability. Chipping costs and residue grinding costs, however, may be reduced by an increase in delimbing/debarking rate, since the bark content limit constrains the production of existing equipment. We have assumed a potential reduction in chipping and grinding costs of one-sixth.

Hauling is also mature, and yet recent reductions in log trailer weights (Stuart 1993) may indicate a potential for similar reductions in chip van weights. We assume a potential increase in net load weights, to 13 dry Mg from the current 12 Mg. Loading times would also be reduced by the increase in delimbing/debarking, chipping and grinding rates, and unloading times might also be reduced, possibly by up to five minutes per load. In sum, these two factors might reduce hauling costs by up to 14 percent, but hauling reductions are considered less-likely than others.

We have been fairly conservative in our choices of harvesting systems to evaluate. Some methods not considered here that may have benefit include:

- a feller/chipper, with separation of pulp and fuel components carried out at the pulp mill,
- chipping whole trees at roadside, with separation at the mill,
- a feller/loader for whole trees; trees would then be processed at the mill in a drum debarker.

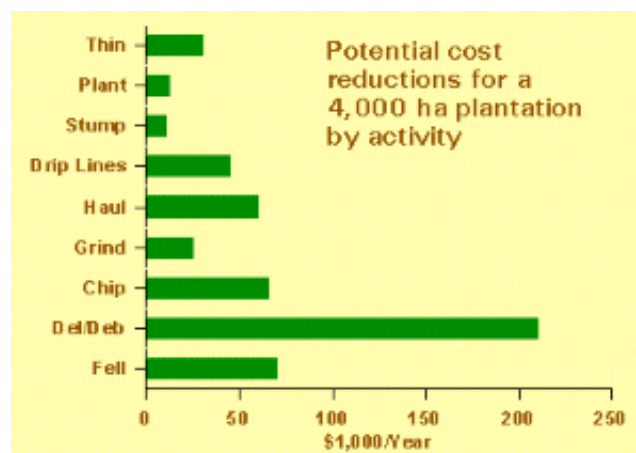
Data on use of a large reel system to install and retrieve drip lines on agricultural lands (Coates 1985) was used to estimate costs for an improved system for handling drip lines. We assumed a crew of four, working with a tractor, could reel in lines at a rate of two ha/PMH; the same crew could reinstall lines on 3.5 ha/PMH. Utilization was assumed to be 80 percent and labor costs were assumed to be \$10 per SMH, including loading. This system would reduce current costs by about half.

We assumed that stump removal costs, uncertain at present, might be reduced by about 25 percent via further development of equipment.

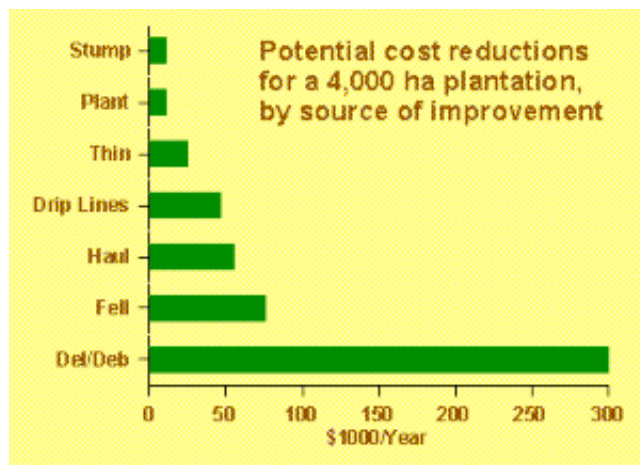
Based on data from other areas (Christopherson 1989, Culshaw 1993), we estimate that existing continuous-furrow mechanical tree planters could cover up to one ha an hour, resulting in costs in the range of \$50 to \$80/ha. Intermittent-furrow planters are more expensive, on the order of \$90/ha (Miles and others 1985). Hand planting is used by Simpson to insure seedlings are placed in the zones wetted by the drip emitters. It is feasible to design equipment to sense wet spots; assuming this feature could be added to a continuous planter at negligible extra cost, the maximum potential reduction from the current cost is about \$30 per ha, or 40 percent, excluding seedling costs which are assumed to remain constant.

An improved motor-manual scheme might reduce the costs of thinning coppice sprouts; we have assumed a potential reduction of one-eighth. The major challenge here is preventing damage to the crop sprouts while thinning.

The potential yearly cost reductions by activity for the 4,000 ha plantation are displayed in **Figure 3. Potential cost reductions for a 4,000 ha plantation, by activity.**



Because all of the gains in chipping and grinding are due to improvements in delimbing/debarking, the three have been combined in **Figure 4, Potential cost reductions for a 4,000 ha plantation, by source of improvement**



which shows reductions by source of improvement. Of a total potential reduction of half a million dollars per year, over half is due to improvements in delimbing/debarking. Felling and hauling developments each account for over ten percent of the reductions, and improved drip line handling for almost ten percent. Relatively small gains can be made in the three cultural operations: thinning, planting and stump removal. This indicates that development work should primarily be focused on the two harvesting activities: delimbing/debarking and felling.

How much should be spent on developing improved equipment and methods? No more than the expected present worth of the benefits, which is the yearly benefit times the probability of success of the development work, divided by the risk-free, inflation-free discount rate:

CONCLUSIONS

For the example 4,000 ha pulp/fiber plantation, potential mechanization benefits total approximately half a million dollars per year. The majority is due to delimbing/debarking improvements. Other substantial amounts are available in felling, hauling and drip line handling. Minor amounts can be gained in cultural operations.

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Establishing and Tending Poplar Plantations in the North-Central U.S.

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Intensive Culture Forestry Conference, Mobile, AL, March 1-
3, 1994*

ABSTRACT

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

INTRODUCTION

Establishing successful plantations of hybrid poplars requires thorough site preparation, effective weed control until tree canopy shade prevents weeds from growing, and other specific care. When properly established, plantations are ready for harvest in 6 to 10 years with yields ranging from 6.7 to 13.5 metric tons of wood plus bark per ha per year (Hansen and others 1993).

In this paper, we describe the cultural methods and equipment used in establishing and caring for hybrid poplar plantations. Our recommendations on site preparation, planting material, planting, weed control, fertilization, and insecticide application stem from a program of short rotation intensive culture (SRIC) multidisciplinary research that began at the North Central Station's Forestry Sciences Laboratory in Rhinelander, Wisconsin, in 1971. In 1976, the program expanded to incorporate both developmental and basic research at the Harshaw Forestry

Research Farm near Rhinelander. Supplemental funding in 1977 from the U.S. Department of Energy further expanded this research. In 1986 a regional network of plantations was established in Wisconsin, Minnesota, North Dakota, and South

Dakota in cooperation with the Northern States Power Company and the Department of Energy. These plantations continue to provide information on biomass yields, clonal performance, and cultural treatments across a wide range of soils, climate, and weed conditions.

SITE PREPARATION



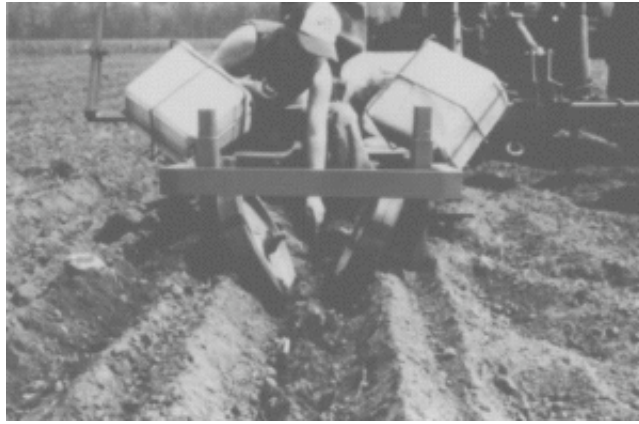
(Figure 1. Moldboard plow to a depth of 25 cm or greater for good site preparation)

Poplar plantations in the north-central U.S. are typically planted on tilled agricultural land. Large agricultural farm tractors and implements are used for site preparation. Implements include large moldboard plows or field cultivators, discs, and harrows. On fields in sod, pasture or hay, apply glyphosate (Roundup) and plow the site by midsummer, and leave it fallow during the remainder of the season. On fields subject to erosion, seed a fall cover crop, leave vegetated strips, or use other conservation tillage practices. On fall-harvested fields, apply glyphosate if perennials are present after harvest and plow a minimum of 25 cm deep (Hansen and others 1984). Field cultivate or otherwise till 25 cm deep a day or two before planting in the spring. Do not use no-till unless required for erosion control (Hansen and others 1986).

PLANTING MATERIAL

Most planting material is 25-cm-long hardwood cuttings with diameters of 1 to 2 cm. The cuttings must have well-developed buds, no disease, and no bark damage. Store them in plastic bags slightly below freezing. Warm and soak the cuttings for 5 to 10 days before planting. Make small slits in the bags, leave cuttings in bags, and immerse three quarters of their length in water (Dickmann and others 1980). Keep the cuttings shaded at a temperature of 10 to 21 degrees C. Cuttings are ready to plant when the buds start elongating, showing some bright green around the bud scales, and just before roots begin to grow. If weather prevents planting, cuttings can be held for weeks by placing them in cold storage at 1 degree C or by covering them with crushed ice (Phipps and others 1983).

PLANTING



(Figure 2. Unrooted hardwood cuttings are machine planted with one bud above the ground surface)

Poplar plantations are normally planted between mid-April and early June. The best time is when soil temperatures reach 10 degrees C, or when corn is being planted locally (Hansen 1986). Tree spacing ranges from 2.5 x 2.5 m to 3 x 3 m (1730 and 988 trees per ha, respectively). The width of available tending equipment for access between tree rows often determines row spacing. Narrow row spacing has the advantage of allowing tree crowns to shade out competing weeds as early as year three or four. Wider spacings may require continued tending operations through year five or six, or even through the entire rotation. Soils should be moist; otherwise delay planting until after rain (Hansen and Phipps 1983). Keep cuttings wet while planting. Hand plant using a marked wire-core rope for a spacing guide, or machine plant with a tractor driver and two 1-row planters. Hand planting rates are 4 ha/day/person; machine rates are 16 ha/day/3-person-crew. Plant cuttings with one bud above the soil surface (usually about 2.5 cm of the cutting exposed) (Hansen and others 1991). When hand planting, push cutting into soil by hand if the soil is loose. If soil is firm, use a dibble to make a hole and insert the cutting. Eliminate air pockets by pushing the soil against the cutting. Do not pack the soil. If machine planting, be sure that soil tilth is adequate for firm, but not excessive soil packing around the cutting. Many planting machine designs have been used with variable success over the years to plant unrooted cuttings. Problems with machine planting most commonly occur in rocky soils, wet soils, or soils that have not been well prepared. Hand planting must be used if cross-cultivation is planned.

WEED CONTROL



(Figure 3. Preemergent herbicides are oversprayed immediately following planting)

Use a combination of selected herbicides and tillage equipment to control weeds. Immediately after planting, overspray the field with the preemergent herbicide linuron using boom application equipment covering multiple rows. These booms are also used to apply selective grass herbicides (when needed) like sethoxydim directly over the tree tops until midseason of the first year. High clearance spray equipment will allow you to spray multiple rows until the end of the first growing season, and sometimes early into the second growing season.



(Figure 4. Rotary hoes are used to control germinating weeds in light (sandy) soils)

Rotary hoes can be used to till newly established plantations on light (sandy) soils to control emerging weeds until the trees are 30 cm tall . Taller trees become entangled and damaged by the rotary hoe blades. Rotary hoeing can be very effective if weather renders a preemergent herbicide ineffective. It is most effective if done every 7 to 10 days as weeds germinate; larger weeds are not removed with this equipment. Also, if cuttings are planted flush with the ground, the tender growing shoots can be buried by soil.



(Figure 5. Narrow four-wheel drive tractors are used for between-row operations)

Once the trees are too tall to straddle, smaller equipment must be used. Small old

tractors, or newer compact tractors can be operated in plantations with row spacing as close as 2.5 m. The newer compact tractors of about 30 horsepower have maximum widths of less than 1.5 m and four-wheel drive options. The compact tractor with implement is efficiently transported with a one-ton pickup truck and trailer .

Narrow light discs (1.8 m wide and less), 1.5-meter-wide mowers, fertilizer spreaders, and small sprayers are easily pulled with these tractors. The shallow rooting habit of poplars requires shallow tillage (2.5 to 5 cm) during weed control to avoid damaging root systems. Discs are very effective for between-row cultivation because they can be towed at a higher speed (6 km per hour) and they remove large weeds. But discs compact the soil more than from other types of cultivation equipment. Rototillers, set very shallow, provide the most complete control of small weeds, but their slow travel speed makes them prohibitively expensive for large areas. Shovel cultivators with a variety of configurations and shovel types can be effective if they are set shallow and the frame does not scrape the trees. Combinations of tillage equipment with sprayers can be used to both band herbicides within tree rows and cultivate between rows in a single operation.

FERTILIZATION



(Figure 6. Four-wheel ATV's are used to apply granular fertilizer between rows of plantations)

Most planting sites in the Midwest have adequate nutrients for poplars for at least the first one or two years (Hansen, in press). However, nitrogen may be needed on some sites by year three or later. Granular nitrogen fertilizer can be applied by either ground or aerial equipment. Ground application of granular nitrogen is done with cyclone-type applicators pulled by either a small tractor or a four-wheel ATV (four-wheeler) . Alternate rows are traveled because it is difficult to apply fertilizer uniformly to more than two rows per pass. Helicopters with cyclone-type spreaders apply fertilizers much more quickly and uniformly than ground application systems. However, cost can be a limiting factor of aerial application.

INSECTICIDE APPLICATION

Severe damage to poplar plantations can occur from outbreaks of cottonwood leaf beetle (*Chrysomela scripta*). Defoliation, as well as damage to the growing tips of young poplars, can significantly reduce growth and in some cases cause tree

mortality. During the first growing season and occasionally early in the second growing season, pesticides can be applied with standard farm sprayer boom systems. As the trees get taller, fog systems pulled by small tractors can be used. However, at tree heights greater than 5 m, ground application systems become ineffective. In those situations, and even in younger plantations, insecticide application by either small airplane or helicopter can be effective and economically competitive.

SUMMARY

Many types of standard agricultural equipment are being used to establish and tend hybrid poplar plantations in the north-central U.S. Successful plantation establishment requires good site preparation followed by rigorous weed control during the first several growing seasons. Small compact tractors allow the tending of plantations with rows spaced as close as 2.5 m. At this spacing, the plantation canopy may shade out weeds in 3 or 4 years much sooner than at wider spacings where tree crowns may never completely shade out weeds through an entire 10-year rotation. No matter what equipment is used be sure to select good clones, plow deep for adequate site preparation, till shallow for good weed control, and **KEEP THE WEEDS OUT!**

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Silvicultural Techniques for Short Rotation *Eucalyptus* Plantations in Brazil

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ABSTRACT

Brazil has established several millions of ha of *Eucalyptus* plantations primarily on abandoned agricultural lands. Intensive management of these sites has resulted in average annual growth rates of 20 to 30 m³/ha/yr. Genetics programs over the past 15 years have produced superior genotypes routinely used for plantation establishment. Selected and tested individuals are clonally propagated on a large scale in specially designed nursery facilities. Rooted clonal cuttings are hand planted to a site prepared using machinery or a chemical/machine combination. Nitrogen and phosphorus fertilizers are applied according to soil diagnostic recommendations at the time of planting or as top dressing during the first year. Herbaceous weeds are controlled during the first year after planting by a combination of a preemergent herbicide, manual weeding, and mechanical weeding. Weed control is not necessary after about 12 months due to crown closure. Although insect and disease problems have occurred, their influence on plantation productivity has been limited through a combination of clonal selection and silvicultural treatments. The most serious insect pest is the leaf cutting ant. The vast majority of *Eucalyptus* plantations are managed to maximize raw material production for fiber or energy industries and are therefore not thinned. Clearcut harvesting usually occurs at age 6 to 8 years.

INTRODUCTION

Brazil is a large country with abundant natural and human resources. Covering 48 percent of the total land mass of South America, Brazil is the 5th largest country in the world geographically. Ranging from about 33° South latitude to 5° North latitude, the climate varies from subtemperate grasslands in the south, semiarid scrub forests in the northeast, and the humid tropical rainforests of the Amazon Basin. Images of Brazil are frequently linked to the Amazon region with its exotic

animal and plant life, indigenous populations, and problems associated with tropical deforestation. Most of the economic activity, however, is concentrated in the bottom third of the country and Brazil is highly industrialized in several sectors such as automobile manufacturing, iron production, and agriculture. A country of 150 million people, Brazil may be generally considered an intermediate income developing nation with the 9th largest economy in the world (Swann 1993).

Although deforestation may often be associated with Brazil, the country has been very active in establishing tree plantations. By some estimates, the country has at least 5 million ha of plantations (Mather 1990) which is approximately 65 percent of the plantation area in all of Latin America (Sedjo and Lyon 1990). *Eucalyptus* is a significant part of the Brazilian planting effort. For example, *Eucalyptus* accounts for 76 percent of the total .95 million ha reforested in the state of São Paulo (Florestar 1993).

Eucalyptus plantations contribute 25 percent of the total amount of wood consumed in Brazil (Sociedade Brasileira de Silvicultura 1990) where the primary uses are as an energy source and industrial roundwood for pulp and paper production. Energy production in the form of charcoal and firewood account for the majority of Brazil's total wood consumption, 26 percent and 53 percent, respectively (Lima 1993). The largest consumer of charcoal is the iron industry which used close to 80 percent of the total 1991 Brazilian charcoal production of (Magalhães 1993). The exact contribution of *Eucalyptus* plantations to the overall wood energy consumption in Brazil is difficult to ascertain, but there is little doubt that *Eucalyptus* because of its availability and excellent wood properties, is widely used as an energy source. Swann (1993) estimated that *Eucalyptus* covered .8 million ha of a total 1.4 million ha (57 percent) of the industrial plantations used for pulp and paper production in Brazil.

SPECIES AND PRODUCTIVITY

Eucalyptus plantations in Brazil are found mostly in the southern third of the country with concentrations in the states of São Paulo, Minas Gerais, and Espírito Santo. The region is humid subtropic with an evenly distributed annual rainfall varying from 1000 to 1500 mm (Golfari and Neto 1970). The more commonly planted *Eucalyptus* species for this region are *grandis* and *urophylla*. Other species commonly planted in the past include *saligna*, *alba*, *tereticornis*, and *citriodora*. *Eucalyptus* species easily hybridize and one of the more commonly utilized hybrids is *grandis x urophylla* (*urograndis*). Because a key component of maximizing plantation productivity is matching genotype to site characteristics, many of the industrial plantations in Brazil are currently using a mixture of species and hybrids.

Growth rates for *Eucalyptus* will range from 20 to 40 m³/ha/yr (based on site visits and interviews with company personnel) and phenomenal growth rates of up to 75 m³/ha/yr (Kageyama 1980) have been reported for specific sites. Rotation lengths for industrially grown *Eucalyptus* is normally from 6 to 8 years. Such high productivity is due to not only to the inherently aggressive growth characteristic of *Eucalyptus*, but also because Brazil has developed modern silvicultural systems

that accelerate this growth. *Eucalyptus* plantations in Brazil are tree farms, where there is considerable investment made into intensive site preparation, genetic improvement, and weed control Table 1.

Table 1. A Typical sequence for *Eucalyptus* plantation establishment in Brazil

site preparation

intensive mechanical, or mechanical/herbicide combinations

leaf-cutting ant control

fertilization

hand plant container grown stock

water

pre-emergent herbicide

replant, if necessary

machete, rotary mower, and/or chemical weed control (1st year only)

NURSERY PRODUCTION AND GENETICS

Eucalyptus plantations are established with seedlings and rooted cuttings produced in container nurseries based on systems using small "bullet type" plastic containers placed in racks above the ground. These containers are normally round with 2 to 3 cm diameter and 18 to 22 cm in length and filled with a potting medium before receiving seed or a cutting. This filling process is usually mechanized and the soil medium a mixture of vermiculite and locally produced organic wastes such as burned rice hulls or composted bark. When growing seedlings, most growers sow directly into the container and cover the racks with shade cloth until germination is complete. Seedlings are fertilized and protected from pathogens until reaching 4 to 6 months in age and approximately 30 cm in height. Planting is usually seasonal, with the best results in the cooler part of the year (May through October), although some companies will plant throughout the year and therefore have continuous nursery production throughout the year.

One of the key factors in Brazilian *Eucalyptus* productivity is related to the clonal planting program pioneered in Brazil during the 1970's (Brandão 1984). Individual *Eucalyptus* trees are selected in the field based on growth, form, health, and wood characteristics. These individuals are felled and the coppice sprouts vegetatively propagated to be tested for both rootability in the nursery and field performance. Individual clones are tested to specific site (soil) conditions. If a clone is selected because of its superior performance, then it is placed into a "clone bank" near the nursery which is managed to produce cuttings used for propagation. Coppice shoots are cut into approximately 15 cm segments used for rooting into the "bullet" containers. The cuttings go through an initial 45 day rooting phase under mist in a shade house then are moved to the sun for an additional 45 days. Rooted cuttings are therefore ready for planting in 90 to 100 days.

Most Brazilian companies involved in clonal propagation also have tissue culture programs. Small amounts of stem tissue from an individual tree can be grown

under highly controlled laboratory conditions to a propagule that can be transplanted to the nursery for growth to plantable size. Such techniques allow for an even more rapid expansion of a specific genotype. The process is very expensive and the economic justification for using tissue culture over the traditional stem propagation techniques has not been entirely established (Zobel 1993). Nevertheless, Brazilian companies are steadily accumulating valuable experience in the practical implementation of *Eucalyptus* plantation establishment based on tissue culture propagation. Whether future advances in genetic manipulation (an introduction of herbicide resistance, for example) can be integrated into a tissue culture program is only speculative at this point, but undoubtedly being considered.

The use of asexual propagation (cuttings) provides several important advantages over sexual propagation (seedlings). Clonal propagation allows for the genetic superiority of an individual to be amplified over large areas in a relatively short period of time. With a rotation length of 6 to 8 years, a genotype evaluated at 3 years of age is already halfway through the rotation. This is especially pertinent to selection for disease resistance. *E. grandis*, for example, was known to be susceptible to a stem canker. Through hybridization with *E. urophylla* and the selection of resistant clones, this problem has been mostly controlled. Asexual propagation also allows for the matching of individual genotypes to specific sites, which can maximize site productivity.

SITE PREPARATION PRIOR TO PLANTING

The sizable investment made in planting stock quality is supplemented by intensive planting site preparation. The Brazilian philosophy regarding preparation for planting has been influenced by an agronomic history. First, the vast majority of sites now used for tree plantations are abandoned agricultural lands. With the notable exception of the Jari Project in the Amazon (Mc Nabb and others 1994), Brazilian forest plantations are on lands previously used for crops such as coffee, sugar cane, and cattle. These sites therefore may be some of the better soils and topography for the region they are located in. Such sites are more amenable to intensive management as they can be worked well with machinery and respond to cultural inputs. Second, because the first foresters in Brazil were trained in agronomy, they tended to view cultivation, weed control and fertilization as an entirely normal part of any crop system, including forestry. This philosophy continues today, although many companies are now experimenting with "minimum cultivation" to reduce the amount of times machinery pass over any given site.

Most industrial operations will use dozer mounted root rakes to clear any stumps, branches, or other debris from the site. In the past it was common to grade the area prior to planting leaving the appearance of an agronomic site. The site may be ripped (subsoiled) depending upon soil conditions, usually at a spacing identical to the recommended between-row planting spacing. It is a common practice that fertilization be done simultaneous to ripping. Granular fertilizer is placed either in the slit or at the surface. It is more common for phosphorus fertilizers to be placed right below the depth of planting, while nitrogen fertilizers may be laid at the surface during ripping. Fertilizers are also manually placed at

the surface beside each seedling within the first 3 to 6 months after planting. Fertilization recommendations are made after soil analysis with most forest plantation operations having their own soils analysis laboratory.

With the current emphasis on "minimum cultivation", herbicides are becoming more common in site preparation. Glyphosate is applied prior to planting to kill existing vegetation including stump sprouts from a previous *Eucalyptus* rotation. Branches or other woody material may be manually stacked in rows between planting lines before or after herbicide treatment. Some companies allow local people to enter recently harvested plantations to remove woody debris for their use in charcoal manufacturing. Fire as a site preparation tool is rarely used in Brazilian silviculture. Brazilian foresters generally regard fire as environmentally destructive, due to what they feel is excessive soil organic matter consumption, nutrient volatilization, and soil erosion.

An integral part of site preparation in Brazil is the ant patrol. Leaf cutting ants (*Atta* spp.) are the most serious insect pest throughout Brazilian agriculture and forestry is no exception. After site preparation and prior to planting, company crews will pass through an area scheduled for planting to locate and destroy leaf cutting ant nests. Fumigation with methyl bromide or placement of baits are used to control this pest. A single pass is usually not sufficient to find all the nests, however, and it is not uncommon for companies to search each site for ants three or four times during a six to eight year rotation. Obviously, ant control is more critical during the establishment phase when there is little forage for the ants and small recently planted trees are most susceptible to damage.

PLANTING

Eucalyptus container grown stock is planted by hand at a spacing of 3 by 3 m (1,111 stems/ha) or 3 by 2 m (1,667 stems/ha). Planting stock is forwarded from the nursery to the planting site in specially designed trucks where boxed seedlings can be carried on shelves. The most common planting tool is a small hoe 6 to 10 cm in width with a 40 to 60 cm handle. An appropriately sized hole is dug using this hoe then the seedling is removed from the "bullet" sleeve and planted. Workers carry seedlings with them in small trays, bags, or boxes. Because planting is so labor intensive, Brazilian foresters are trying to find ways to improve planting efficiency. Although machine planting has not yet proven satisfactory, Scandinavian style planting tubes are being tried by some companies. In this case, the worker does not have to bend over to plant the seedling. The planter has a cone at the bottom of a 1 m long tube. As the worker drops a seedling in the top of the tube, he then opens the cone at the bottom of the tube to deposit the seedling in the ground. The planter then closes the slit with his foot. Replanting is done on a few occasions. Survival rates of above 90 percent are routinely obtained, although weather, poor planting, and poor seedling handling can reduce this. Usually replanting is done only when a general area failure occurs.

An integral part of planting in many Brazilian *Eucalyptus* operations is the watering of planting stock immediately after planting. This operation is obviously weather dependent but forestry personnel do not hesitate to invest in a post

planting watering operation when deemed necessary. For some parts of the year in some parts of the county, this means all planting stock is watered. The procedure usually calls for a tanker truck or tractor to pass through the recently planted area. Hoses feeding directly from the water tank are used to apply between 1 to 2 L of water to each plant. This is done only once as soon after planting as possible. This operation "seats" the seedling or cutting in the soil and reduces moisture stress related to the disturbance of planting.

POST PLANTING CARE

Eucalyptus is sensitive to weed competition and considerable efforts are made to ensure virtually total weed control. Not only do the plantations begin with a very clean site, but through a combination of chemical, mechanical, and manual means, the site is kept weed free until the point of crown closure which usually occurs at about 1 year. Although confronted with a broad spectrum of weeds, grasses tend to be the most numerous and troublesome. Weed control begins immediately after planting with an over-the-top application of oxyfluorfen preemergent and early postemergent herbicide. *Eucalyptus* shows considerable resistance to oxyfluorfen and rates of 1 to 3 L/ha are commonly used. Application technique varies between companies but most will apply to a band of about 1 m in width with a typical farm tractor mounted boom sprayer, while some companies apply broadcast with a tractor or from the air. Oxyfluorfen provides weed protection for approximately 6 to 12 weeks. At this point manual cleaning using machetes or hoes is used and rotary mowers cut weeds between the planting lines when possible. *Eucalyptus* is between 1 to 2 meters tall at an age of 6 to 8 months and a directed spray of glyphosate can be used alone or in conjunction with rotary mowing. Shading is sufficient to suppress herbaceous weed growth after crown closure. Some companies will make a directed spray of glyphosate to weeds during the last year of *Eucalyptus* rotation. This is not to help the current plantation growth but rather to get a head start on site preparation. Any weeds that can be taken out before harvest, improves the effectiveness of site preparation for the next rotation. Unfortunately, Brazil depends heavily on the continued availability of glyphosate and oxyfluorfen. The number of chemicals labeled for forestry use are very limited and at present virtually all companies engaged in *Eucalyptus* production uses these two chemistries.

PESTS

As a general rule, *Eucalyptus* plantations in Brazil have not had serious insect or disease pests, at least not to the extent to make plantations unfeasible. Stem canker has been a problem in the past but seems to be under control now due to improved genetic selection and hybridization. Lepidoptera outbreaks routinely occur but to this point have been easily combated with aerial applications of *Bacillus* or insecticides. There have been reports of a "tip dieback" condition which appears to be a physiological problem and not a disease problem. Correct matching of genotype to site is expected to solve this.

SUMMARY

In the last twenty years, Brazil has developed a highly productive silvicultural system based on *Eucalyptus*. High levels of productivity are based on intensive management with considerable investment in site preparation, planting stock quality, genetic improvement, fertilization, and weed control. This investment appears to be cost effective. As evidence, Brazil has one of the lowest raw materials costs in the world for the manufacture of pulp and paper (Mather 1990). Moreover, there is every reason to believe that further improvements in *Eucalyptus* productivity will occur. Clonal testing and propagation is still gradually improving average company productivity. Not only is there opportunity for the selection of faster growing clones with optimum wood properties, there will be more precise matching of individual clones to fertilization regimes. Further refinements in the "minimum cultivation" should result in improved soil stability and long term sustainability and in all likelihood a reduction in plantation establishment costs.

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The Effect of Whole Tree Harvesting on Fuel Quality and Coppicing Ability of SRIC Willow Crops

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ABSTRACT

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

INTRODUCTION

The purpose of this study was two-fold. First, to determine how storage will affect SRIC fuelwood characteristics when it is stored as whole-trees over an extended period of time. Secondly, to find out how the second generation biomass production is affected by the stool damage caused by harvesting machinery. The opportunity to carry out this study arose when a seven-year-old, second generation willow crop was made available for research.

The common problems of wood storage include dry matter losses and uneven moisture content. Numerous studies on wood storage from conventional forestry operations have shown that if comminution of wood by chipping, shredding or hammermilling is followed by storage in piles the possibilities of self-ignition and health risks by fungi spores will eventually emerge. Although much emphasis has been put on the breeding, growth and yield of SRIC willow crops, the storage problem has been totally neglected. With this in mind a storage study was set up at the Finnish Forest Research Institute. The aim was to monitor moisture content, wood density, heating value and bark content over a period of 18 months. It is a well accepted fact that the comminution of the SRIC crops should be integrated into the harvesting operation. However, if it is necessary to store the feedstock for any length of time this should be done as whole trees. This is because chip

storage has been shown to cause extensive dry matter losses in numerous studies (Thornquist 1987; Thornquist 1988; Nurmi 1990).

A factor critical to the success of willow plantations is the sustainability of the coppice system over successive harvests. Several factors, both internal and external, influence regeneration from stumps described by Sennerby-Forsse and others (1992). Many external factors and practical management measures such as cutting season, stump diameter, stump height, cutting method, fertilization, site quality, rotation length, spacing have been shown to influence coppicing vigor.

Knowledge of the influence of factors affecting the coppicing ability and biomass production of short rotation plantations is necessary for the determination of cutting schedules and the development of harvesting techniques. The aim was to investigate the effect of harvest damage on willow coppicing.

MATERIAL AND METHODS

The experimental area was established in spring 1982 on a sandy mull field situated in southern Finland (60°32' N, 24°37' E). The willows (*Salix* 'Aquatika', clone V769) were planted at a density of 36,000 plants ha⁻¹ (80 x 35 cm) in early summer 1982. One-year-old rooted cuttings, the shoots of which had been cut back to the stem, were used for stocking. Weeds were controlled mechanically using a tractor-pulled harrow during the first summer. Willows were first harvested after three growing seasons (1985) and again after a seven year long rotation in 1992. This time harvesting was done with a chainsaw and a brushsaw to provide material for this study. This second crop also formed the material for the storage study.

The storage study was composed of 13 dry tons of non-comminuted willows. They were forwarded and piled after felling in a single, uncovered stack. Moisture content was determined on green weight bases by drying the samples at 102 degrees C to a constant weight. Calorimetric heating value was determined with a Leco AC-300 calorimeter. Basic density was calculated on the basis of oven dry weight and water saturated volume. Bark content was calculated from the dry weight of the sample. Sampling was done first during the piling of the fresh material and from there on once every three months over the 18 month storage period. It was done in such a manner, that each time two stems were extracted from the bottom, center and top of the pile. These six stems were further sampled at 10, 30 and 80 percent lengths, i.e. pile depth. Furthermore, every time the pile was sampled, two live trees were also sampled for the same characteristics.

To study the effects of forwarding damage and the choice of cutting method on the coppicing ability a willow stand was cut with a chainsaw (Experiment 1) and with a brushsaw (Experiment 2). The treatments consisted of four-meters-long tracks laid out along the rows of planted willow. The treatments included a control (A), light weight Farmi Trac mini-forwarder driving on the row of stumps (B) and manual damage of the stumps using a sledge-hammer (C). In both experiments, the treatments were replicated three times in a randomized block design. Height and the number of sprouts per stool were measured on the experimental plots after one growing season in autumn 1992. The leafless above-ground biomass was determined using allometric dry-mass equations based on sample trees (Hytönen 1988, Hytönen and others 1987).

THE EFFECTS OF STORAGE ON FUEL QUALITY

The moisture content of the fresh material at the beginning of the trial was 54.0 percent on green weight basis. As Hytönen and Ferm (1984) reported moisture content for a one year old stand to be 63.7 percent and 55.9 percent for a five year old stand, this might be an indication that the moisture content of fresh material decreases with stand age. The standing trees showed some variation with the season. This, however, was not significant and is in accordance with previous knowledge (Hakkila 1962). Wood and bark in the storage dried over the first summer to an average moisture content of 34.6 percent gaining some moisture over winter. During the second summer further drying took place proving the time factor to be statistically significant. The final moisture content was 20.0 percent. When the significance of the location in the pile (top, center, bottom) was tested for moisture content no significance was found. But, when the height of the stem, i.e., pile depth, was tested the 80 percent height was found to be significantly higher in moisture content than the other parts of the pile.

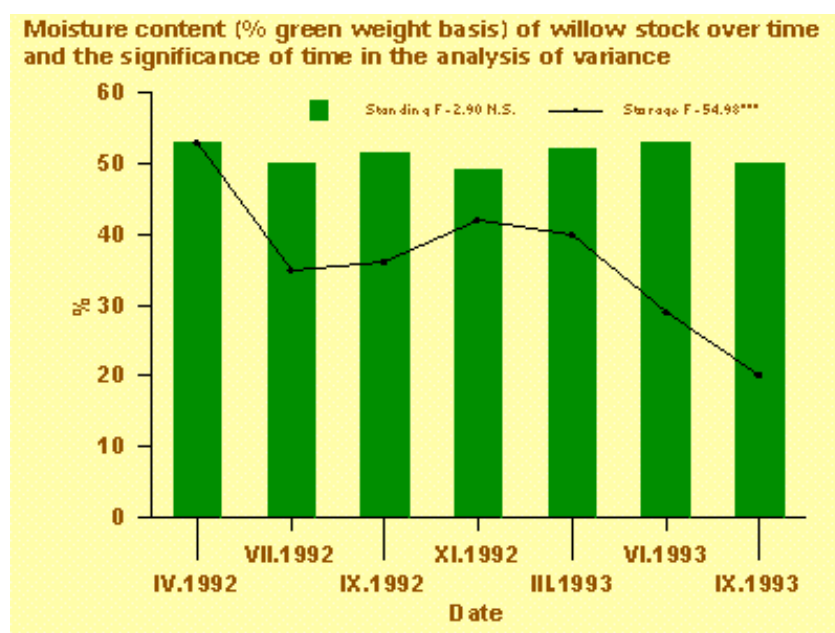


Figure 1. Moisture content (% , green weight basis) of willow stock over time and the significance of time in the analysis of variance

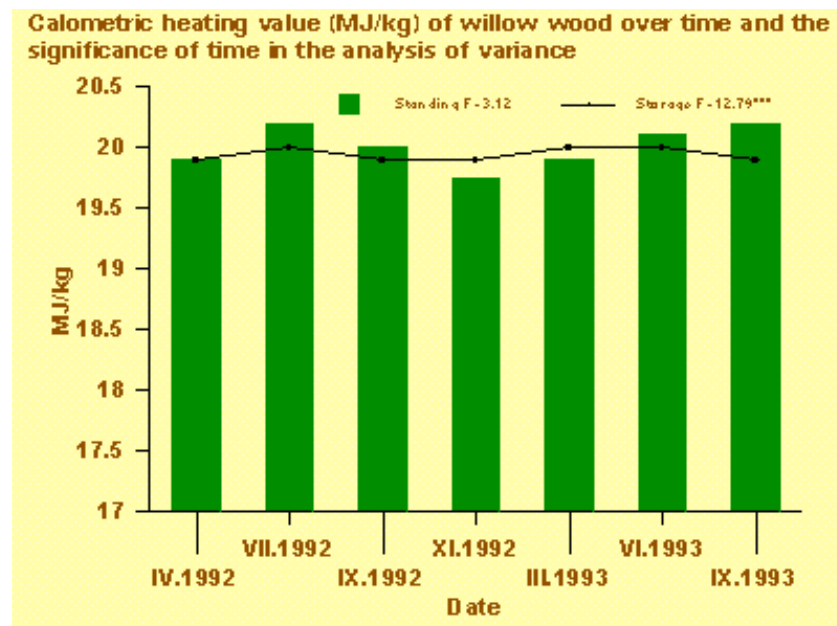


Figure 2. Calorimetric heating value (MJ/kg) of willow wood over time and the significance of time in the analysis of variance

The calorimetric heating value of wood and bark were determined separately. Heating value of both standing trees and those in the pile had very little fluctuation with time. However, this fluctuation in the pile was statistically significant. This was strictly caused by the fluctuation in the samples taken at 80 percent height. The cause of this behavior is not known.

The heating value of willow bark was higher than that of wood. The calorimetric heating value of bark ranged between 20.1 to 20.3 MJ/kg and of wood 19.8 to 20.2 MJ/kg. Season was a significant factor both among standing trees and those from the pile

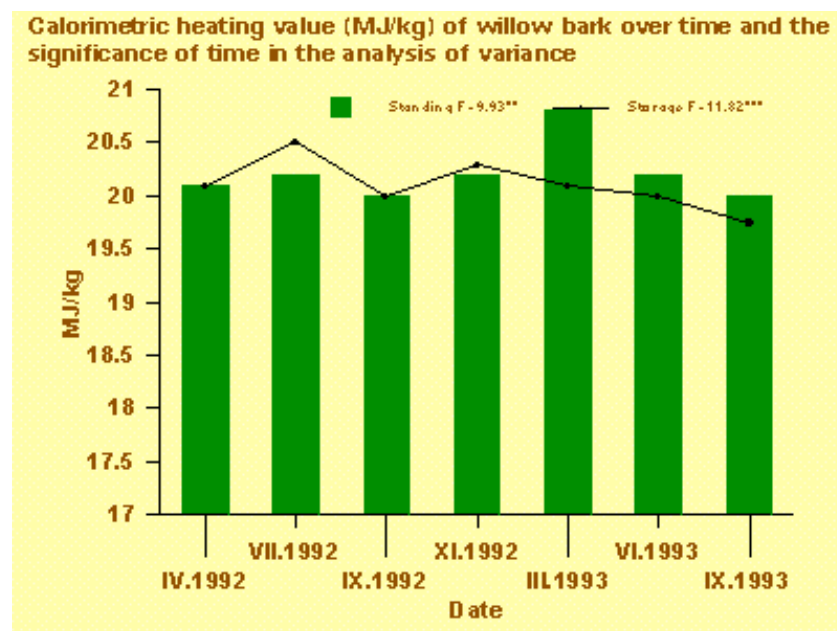


Figure 3. Calorimetric heating value (MJ/kg) of willow bark over time and the significance of time in the analysis of variance

Height of the pile did not turn out to be a significant factor. The pile depth was significant, however, as the heating value of willow bark increases from the base of the

stem to the top. Similar or opposite transitions along the stem have been recorded previously on other tree species by Nurmi (1993).

The wood density of the fresh material in the beginning of the study was 411 kg/m³. This is somewhat higher than what was reported for a 5-year-old stand (382 kg/m³) by Hytönen and Ferm (1984). This might be an indication of increased density with time. The density dropped during the storage to 399 kg/m³. This reduction proved to be significant. Similarly location, both in height and depth, proved to be significant factors. Wood density was significantly lower in the bottom of the pile and at the 80 percent depth than in other parts of the pile.

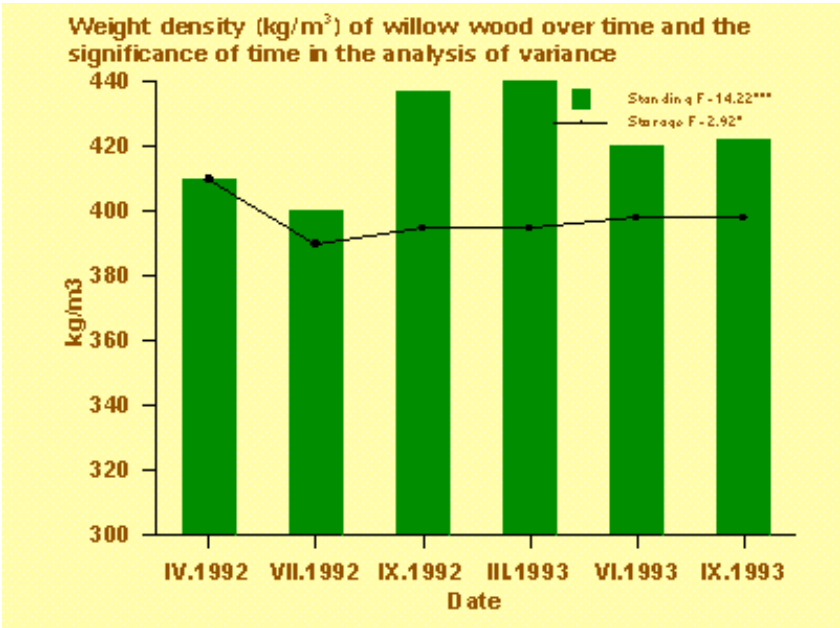


Figure 4. Weight density (kg/m³) of willow wood over time and the significance of time in the analysis of variance

The low density of the tops also proved to be evident at the end of the study when they suffered from much breakage during handling and comminution. Although this loss was not measured dry matter losses looked substantial.

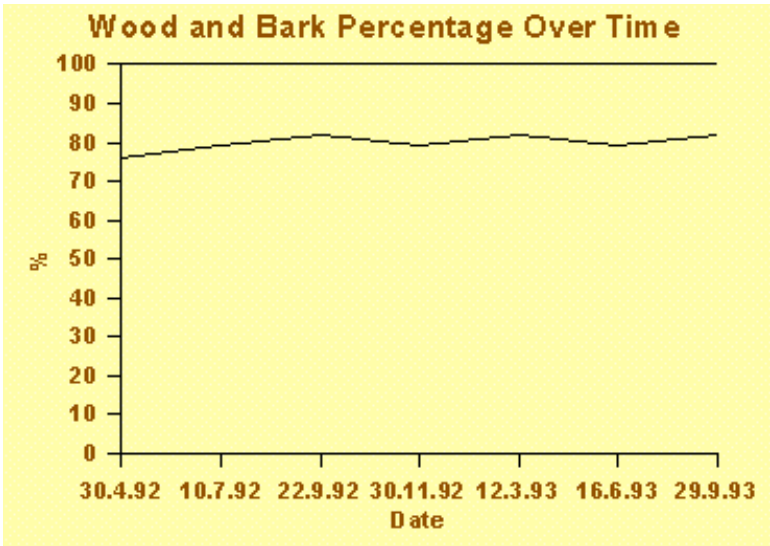


Figure 5. Bark content (%) over time

As tops contain more bark than the rest of the stem the average bark content fell from 25 percent to 15 percent . Consequently, the average heating value of the remaining material was lowered.

As a result of the storage study we can conclude that willow stems dried well in uncovered piles. Although the lowest moisture content was reached during the second summer it is recommended that the material should be comminuted and burned after the first summer. This is to reduce material loss through breakage of the tops and dry matter losses by fungi and bacteria.

HARVESTING DAMAGE

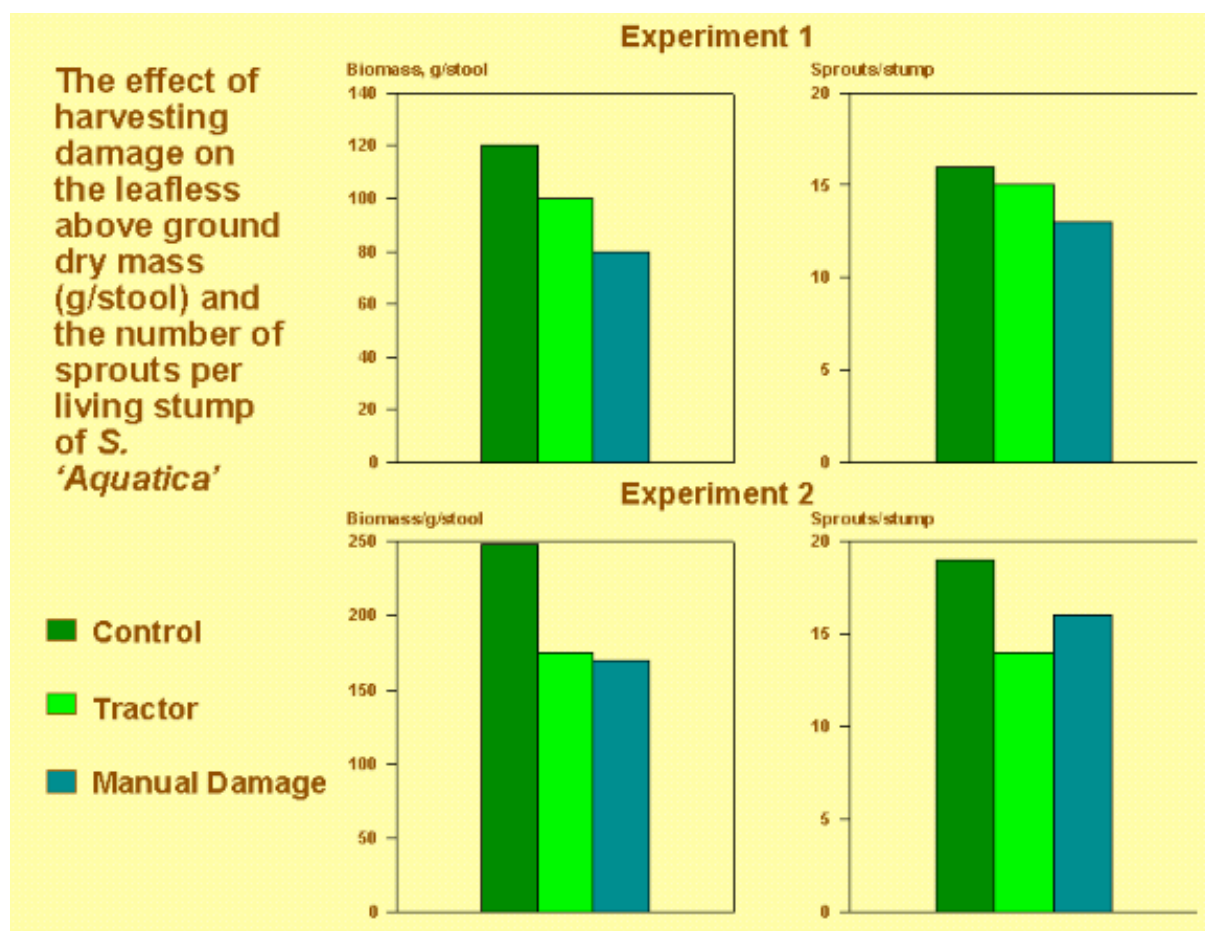


Figure 6. The effect of harvesting damage on the leafless above ground dry mass(g/stool) and the number of sprouts per living stump of *S. 'Aquatika'*

The effects of harvesting damage on the biomass, mean height and number of sprouts per stool were measured one growing season after treatment. In both experiments (1 and 2) the biomass per stool and the number of sprouts per stool was lower following harvest damage caused by the mini-forwarder . Mean shoot height was not affected by the treatment. Manual damage, thought to be more severe, caused similar effects. However, the differences between the treatments were not statistically significant.

Similar to birch (Mikola 1942, Ferm and Issakainen 1981) harvest damage did not have a significant effect on older, well established plantation. However, in young plantations, harvest damage has had a negative effect on survival, height growth and biomass production of *S. 'Aquatika'* (Hytönen 1994).

Differences between species in relation to effects of harvest damage may be due to the location of the sprout producing buds. About 90 percent of birch's basal buds are located below ground (Kauppi and others 1987, 1988) while most of the buds of *Salix 'Aquatica'* are above ground level (Paukkonen and others 1992). In coppiced *S. viminalis* most (85 to 90 percent) of the sprouts originate from the axillary bud groups located on the remaining basal parts of the previously harvested stems (Sennerby-Forsse and others 1992). Thus, harvesting damage may have more serious effects on willow than on birch regeneration. In the design of willow harvesters, their effects on the sustainability of the coppice system should be taken into account.

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Utilization of Short Rotation Forestry for Fuelwood from an Effluent Disposal Scheme

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ABSTRACT

At their Oringi abattoir, Richmond Ltd., Meat Packers and Exporters, have established a 100 ha plantation of short rotation *Eucalyptus* trees grown in combination with a land treatment scheme for the plant's effluent disposal. It is intended that a cyclic renewable system will be created where the biomass grown to treat the irrigated waste water will be used for boiler fuel, thereby substituting for some of the current coal demand.

This abattoir produces approximately 4,000 m³ of meat processing effluent daily, with high nutrient content. In 1986, problems with an irrigation system on to pasture warranted the need to investigate an alternative means of disposal. Based on a pilot study, the chosen option was a furrow irrigation network irrigating *Eucalyptus* trees grown on a three year coppice short rotation system at a density of 4,000 stems/ha.

A utilization system to harvest, handle, store, dry, comminute and combust the tree crop is now under development. Options for each component are being evaluated and incorporated into a computer model to identify the optimum cost effective system.

Major limitations in harvesting and drying have been identified. Tree specifications and site conditions currently limit the use of harvesting equipment

to manual chainsaw operation which is labor intensive. Mechanized systems are therefore being evaluated.

Field trials to determine drying rates of whole-trees cut throughout the year showed rates were influenced by seasonal variations in temperature, rainfall and sunshine hours. These rates will be used, in conjunction with a knowledge of the seasonal fuel demand of the plant, to determine harvest dates and quantities in order to provide a continuous stream of biomass feed-stock for the boiler.

INTRODUCTION

Richmond Ltd, Meat Packers and Exporters, believe that they have invested in the security of their future operations by establishing a sustainable renewable system of land waste treatment of the plant's effluent combined with the production of fuelwood. The concept of combining land treatment with fuelwood production grown under a short rotation intensive culture forestry regime (SRIC) is novel.

Mechanized forestry techniques for harvesting and processing SRIC are not well established. Consequently many private groups and companies are watching the Richmond project with interest to see how the fuelwood utilization phase of the system can be developed successfully.

Why Richmond established a SRIC plantation

Richmond Ltd. have a sheep abattoir (slaughter house) in central New Zealand with the capacity to process up to 10,500 sheep per day. This results in the production of over 5,000 m³ of nitrogen rich liquid wastes daily which require disposal (Sims and Handford, 1993).

In 1986 problems with a pastoral based border dike effluent disposal scheme resulted in contamination of a nearby river. After this incident the company considered alternative disposal methods. These included increasing the land area irrigated, harvesting the pasture instead of using grazing stock, or planting an alternative crop with a higher rate of nutrient and water removal than grass/clover.

A 6 ha trial plantation of fast growing short rotation coppice trees was established in 1987. It was assumed that this would produce large yields of biomass which if removed on a regular basis would remove a significantly large portion of the nutrients applied in the waste water.

The trial plantation included a range of effluent application rates, tree spacings and irrigation methods. Species planted were *Eucalyptus botryoides*, *E. ovata*, *E. camaldulensis*, *Acacia dealbata* and *A. melanoxylon*.

Over the four year period of the trial it was established that the effluent could be successfully treated when irrigated on to SRIC. In 1992, a major irrigation scheme was installed and the first 30 ha of a 90 ha plantation was established using various *Eucalyptus* species. A rotation length of three years, stocking rate of 4,000 stems/ha and a modified form of furrow irrigation were selected for the full scale system.

UTILIZATION OF BIOMASS

The primary objective of the plantation was to create an efficient sustainable effluent treatment system. This requires maximum nutrient removal on a regular basis (Sims and others, 1992). The other important objective was to maximize the boiler fuel potential of the biomass in order to offset the cost of effluent disposal (Sims and Collins, 1993).

Methods and techniques for efficient harvesting, extraction and conversion of the biomass material from a standing tree to a form suitable for combustion need to be clearly defined for this system. During biomass removal there should be minimal damage to the stools and soil structure (Kerruish, 1978; Hytonen, 1985). This will help to maximize plant regrowth, minimize soil compaction, and consequently help to maintain infiltration rates to provide acceptable effluent treatment. A further issue is how to best air dry the biomass from above 60 percent moisture content (wet basis) at harvest to a more acceptable 20 percent for efficient combustion.

Harvesting and drying have been recognized as having a large influence in determining the success or viability of this system. They are areas that are least developed in current utilization systems.

Harvesting

Immediate and long term effects of stump damage, soil and root compaction, and damage to unharvested trees during harvesting operations should be considered. Heavy machinery with high ground contact pressures should be avoided to minimize soil compaction on the wet soils resulting from frequent irrigation (Aust and others 1993). The condition of the site following harvesting can influence the vigor and productivity of coppice regrowth. Damaged stumps can increase the chances of disease build up. All slash should be removed from the site to avoid creating an environment which could encourage disease and physically impede regrowth. Since the site is being used for effluent treatment, all the harvested biomass should be removed to maximize nutrient removal.

For Salix crops in Europe the Claas harvester, Austoft sugar-cane harvester and others have been used for harvesting this SRIC (IEA, 1993). Other prototype specialist machines such as the Canadian FB7 have been developed for harvesting woody biomass crops. However, none of these machines have been tested under New Zealand conditions. Different crop factors such as tree growth forms and stocking rates, and different terrain characteristics make it difficult to estimate the productivity of these machines for the *Eucalyptus* crops being grown.

Motor manual felling which is commonly used in New Zealand for felling large forestry trees, is relatively inexpensive, simple and versatile (Vaughan and Shula, 1993). Chainsaws, despite often having a lower productivity rate than more mechanized methods, can be cost competitive depending on the size of the trees, area of the plantation, and labor costs. In the absence of other proven equipment for use with SRIC crops, motor manual felling is the only current option.

A potential problem facing the use of some mechanical harvesting machinery is that they operate over a relatively narrow range of stem diameters. The wide variations in stem diameters, together with the large numbers of small stems particularly from coppice regrowth, create design difficulties, reduce efficiencies and increase operating costs of harvesting machines.

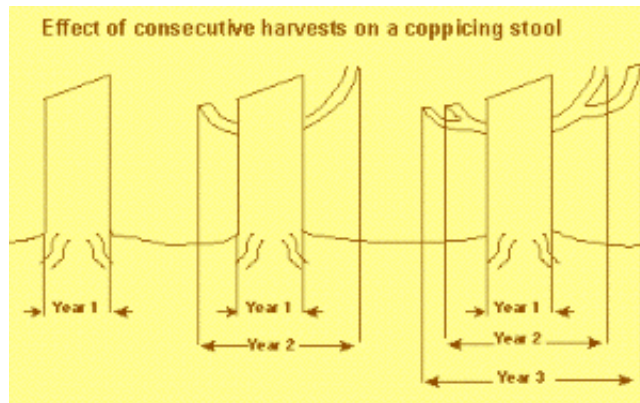


Figure 1. Effect of consecutive harvests on a coppicing stool

The first harvest of a typical New Zealand SRIC system occurs at the end of three years when each single stem has a diameter of 75-200 mm. During successive rotations after the tree has been coppiced, multiple stems are produced which must be cut from the original stump. Over this period the stump width increases from a single narrow stool to a wide and often multi-branched stool. Machinery designed for single stem harvesting is not usually able to handle such forms.

It is possible that pruning young regrowth may reduce the widening of the stump, produce a greater piece size, and allow machinery designers to retain a narrower cutting width. Pruning also increases the ratio of wood to leaf material, but since it incurs an added cost, it is not a practical option.

Extraction

The method of extracting the trees from the plantation will be influenced by the harvesting method. The form of the end product, determined by the use of the harvested material, also affects the extraction and transporting method.

It is desirable to avoid fuelwood material becoming contaminated with soil because of difficulties that are encountered during and after combustion so this must be taken into consideration. Continuous one-pass harvest/chip operations which directly chip the material as it is harvested, eliminate soil contamination. However, these machines are often heavy and may create soil compaction problems which is an important concern for irrigated sites. In addition the opportunity for transpirational drying of whole trees is forsaken.

Drying

Allowing felled trees to transpirationally dry on site for several weeks before being extracted and comminuted is considered to be advantageous, the benefits of

reducing the moisture content of the biomass offsetting the double handling required.

Trials at both the Richmond site and Massey University have been undertaken to ascertain whether cut trees with foliage left intact dry relatively faster than would comminuted biomass under New Zealand conditions . Initial tree moisture contents of 60 percent wet basis were reduced to at least 35 percent wet basis in four weeks by leaving the cut trees whole.

Storage

Approximately 1,500 oven dry tonnes of biomass can be harvested annually on a sustainable basis from the Richmond site. The establishment of artificial drying facilities (possibly using waste heat from the boiler stack) to further reduce the moisture content of air dried trees for this volume of material could be expensive and needs further investigation.

The young age of these harvested trees means that the ratio of foliage to woody material is high. The large proportion of leaves provides chipped material with a higher nutrient source than chipped stem wood alone. This, together with a smaller particle size from the chipped leaves could provide ideal conditions for the growth of micro-organisms and rapid temperature build up in storage piles resulting in increased dry matter losses (Jirjis, 1988).

It is believed that transpirational drying is a low cost and relatively fast means of obtaining a significant reduction in moisture content at minimal cost, especially at the scale of utilization envisaged.

SEASONAL HARVESTING

The opportunity to harvest trees throughout the year to match the seasonal boiler fuel requirements is being evaluated. With *Eucalyptus* it appears possible to harvest throughout the year without seriously jeopardizing coppice regrowth or increasing tree mortality rate. Trials comparing the rate of drying at different times of the year have been carried out.

Provisional results show that moisture losses were very rapid in the first 2 to 4 weeks irrespective of weather conditions. The rate of moisture loss then tapers off to a level which was influenced by weather conditions and time of year.

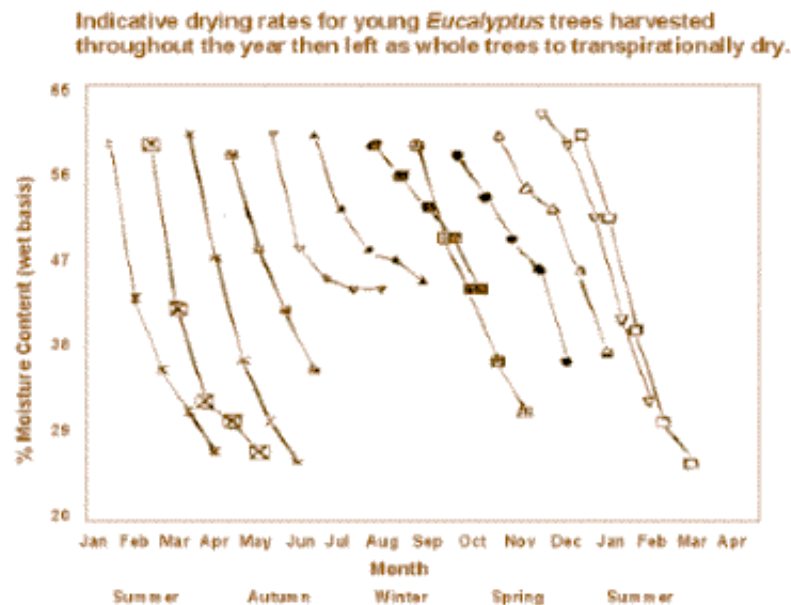


Figure 2. Indicative drying rates for young *Eucalyptus* trees harvested throughout the year then left as whole trees to transpirationally dry.

A dynamic computer model is being constructed that will enable the tree moisture content to be predicted at any given time after harvest depending on harvest date. If the moisture content required for combustion, and drying rate of unprocessed whole trees is known, it will be possible to predict the optimum times of harvest and the volumes required to meet boiler fuel demand.

SYSTEM SELECTION

To date an optimal solution to suit the utilization process of coppice *Eucalyptus* production has not been fully defined. The use of direct harvest/chipping/transport machines has been discounted as transpirational drying would be prevented.

For the scale of operation envisaged at the Richmond plant where approximately 120,000 trees will need to be harvested annually a likely mechanization scenario would be;

- chainsaw felling
- extraction by tractor with a grapple mounted on a trailer
- low cost drying of whole trees on a storage pad
- and - chipping prior to feeding into the boiler.

Due to the unavailability of detailed cost and productivity data, this may not be the optimal long term solution to the problem. If the initial cost, life and productivities were available for particular machines, more accurate assessments could be made. Meanwhile sensitivity analyses will need to be conducted to help identify from the limited data available a system that will be practically acceptable to Richmonds.

CONCLUSION

The Richmond company is satisfied with the original objective of efficiently disposing of the plant's effluent on to short rotation Eucalyptus. The environmental impacts of the outputs from their production system (effluent and CO₂) will therefore be lessened.

The successful establishment of an efficient tree harvesting and processing operation will enable the development of a clean renewable energy resource grown as part of an effluent disposal scheme to be developed.

ACKNOWLEDGEMENTS

Richmond Ltd. and Massey University are thanked for financial support towards the attendance of Mr. Lowe at the IEA Conference.

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Developing Sustainable Integrated Biomass Systems

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Paper presented at the Mechanization in Short Rotation, Intensive Culture Forestry Conference, Mobile, AL, March 1-3, 1994

INTRODUCTION

More than a year ago the Electric Power Research Institute (EPRI) published a white paper, "Strategies for Achieving a Sustainable, Clean and Cost-Effective Biomass Resource," which stated that it is realistic to consider that at least 20 million ha of cropland in the United States will be available for the production of biomass feedstocks between now and the year 2010. If those croplands were planted in energy crops that yielded better than 12.5 dry tons per ha annually, that would result in potentially 5 exajoules of heat energy, which could fuel approximately 50,000 megawatts of electric capacity. Inasmuch as the current electric capacity in the U.S. is nearly 700,000 MW, we are making the projection that this new renewable energy resource would be providing 8 percent of the U.S. power requirement.

The economics of competing feedstocks

For biomass to become a major energy feedstock, energy crops will need to compete economically with coal and natural gas, both presently priced at nearly record low prices. Coal costs presently are between \$1.00 and \$1.75 (U.S.) per kilojoule, and natural gas spot market prices are in the range of \$2.00 to \$2.35 per kilojoule. Based on productivity of 12.5 tons per ha and using the best currently available harvesting equipment, biomass energy crops are estimated to cost at least \$2.50 per kilojoule. However, included in the federal Energy Policy Act of 1992 is a production incentive of 1.5 cents per kilowatt hour for feedstock produced in a "closed loop" manner. For power produced by a facility with a heat rate of 10,000 kilojoules per kilowatt hour, that incentive could mean \$1.50 per kilojoule. With improvements in harvesting equipment and yields of 25 tons per ha, staff at Oak Ridge National Lab estimate feedstock costs of \$1.60 per kilojoule within the next ten to fifteen years.

Environmental and economic drivers

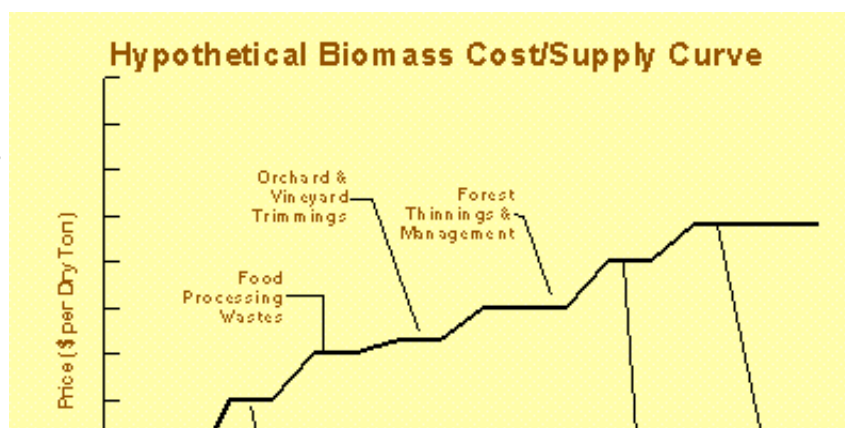
The United States presently has nearly 7,000 MW of biomass-fueled electric capacity on line; however, less than 300 MW is owned by electric utilities. The major portion of this power is being generated by the paper and pulp and other forest products industries, using residual harvesting and processing wastes as feedstocks. Only within the past 12 months, with the increasing recognition of a series of environmental and economic drivers, have U.S. utilities begun to take the biomass power option seriously.

The environmental drivers are: 1) the need for increased controls on emissions of sulfur and nitrogen oxides as a result of the Clean Air Act Amendment of 1990, and 2) mitigation of greenhouse gas emissions on the part of electric utilities. Furthermore, there is growing recognition of the potential for using woody and perennial herbaceous energy crops to improve soils, to protect surface and groundwaters from the intrusion of chemicals moving through the soil, and to benefit wildlife habitats.

The major economic driver for the utilities is that by using biomass feedstocks, the utilities put their fuel purchase dollars directly into their own service territories, creating jobs and improving economic well-being. With continued improvements in agricultural crop productivities resulting from the use of biotechnology, and a decrease in export markets for conventional agricultural crops, rural communities (and farmers) are seeking new crops, with new markets. Because these energy crops are deeply rooted species, agronomists suggest that they would better withstand the impacts of flooding, and in fact, U.S. Soil Conservation Service staff are assessing the opportunities to reduce federal subsidy payments by permitting these crops to be planted on lands currently in government set-aside programs.

While we at EPRI are enthusiastic about the benefits which may be achieved with energy crop production, we also are urging utilities to look first at the availability of other lower cost biomass resources within a defined area around the conversion facility that will use the feedstock. Historically, pulpmill and sawmill wastes have been tepee-burned or simply piled up on a "back 40." Air and water regulations now preclude this type of disposal in many parts of the country. Forest thinning and agricultural wastes also have been disposed of by slash or open-field burning - practices which are more and more limited.

Figure 1,
Hypothetical
Biomass
Cost/Supply Curve,
illustrates a generic cost-supply curve which would provide a project developer with a sense of the size and cost of the



sustainable resource for one specific project. Cost-supply curves should be developed using some sort of



geographic-information system to tie supplies to a specific land base. Projections regarding the costs and supplies of energy crops will depend on the availability and quality of croplands; thus they should also be tied directly to the area land base.

Developing sustainable systems

A shift of millions of ha of cropland into a new crop with notably different crop regimens would have significant environmental and economic implications, either positive or negative. Recognizing this, in the summer of 1992 EPRI and the National Audubon Society formed the National Biofuels Roundtable. The U.S. Department of Energy and the Tennessee Valley Authority also offered direct support by helping to cover the costs of a conflict resolution facilitator, travel expenses when travel budget cuts curtailed a member's participation, and publication of a consensus, or synthesis, document.

The Roundtable has 30 members, and they reflect the views of 24 different groups - state and federal government agencies, academia, both the paper and pulp and the electric utility industries, and environmental organizations. The Roundtable has met as a whole six times over the past 18 months and has reached consensus on all but three issues. These three concerns, which will be discussed in an agenda for future resolution, are:

- harvesting of forests for energy;
- using exotic plant species for energy production; and
- changing the requirements of eligibility for the biomass production tax credit.

The emphasis of the Roundtable has been to develop criteria or guidance for sustainable production of biomass resources - balancing environmentally preferred practices with their economic and social acceptability. Environmental principles on which there is agreement include:

- emphasize environmental opportunities, such as habitat protection, surface and groundwater protection, and soils protection;
- monitor and control wastes and emissions at conversion facilities;
- match crops to native vegetation when appropriate;
- value both species and genetic diversity;
- use spatial and temporal considerations in landscape planning;
- ensure protection of highly vulnerable areas.

Socioeconomic factors to be considered include:

- siting and sizing facilities appropriately;

- identifying niche opportunities, such as cofiring, repowering, and coproduction systems;
- optimizing the use of local resources;
- fostering ways of decreasing rural sector dependence on federal subsidies.

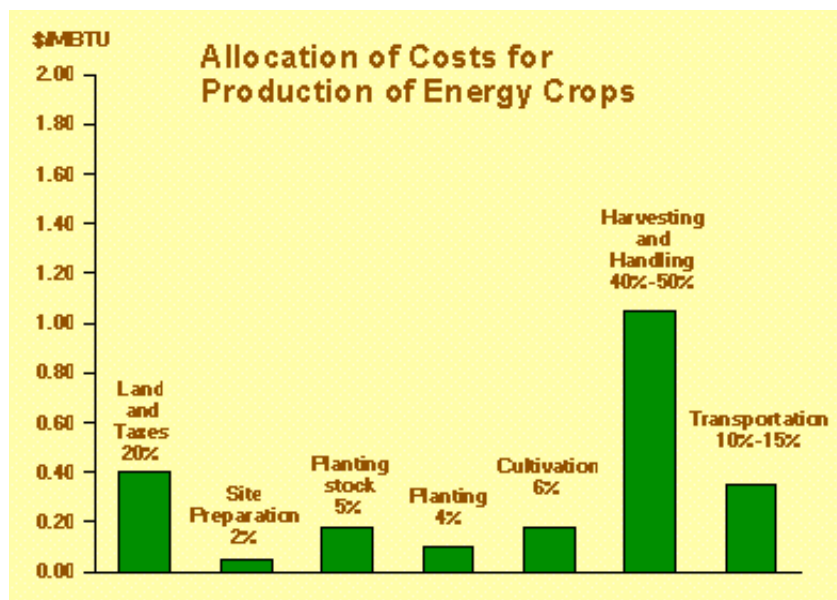
While the "Synthesis Document" of the Roundtable will present initial guidance for feedstock production, it will also identify ten barriers to the large-scale development of biomass energy systems, with options to be considered as strategies for addressing these barriers. The document is expected to be available by the first of May. from EPRI, Oak Ridge National Laboratory or the National Renewable Energy Laboratory.

Steps toward large-scale energy crop production

As noted earlier, large-scale deployment of integrated biomass production systems will depend on the extent to which dedicated crops can compete with coal and natural gas.

Figure 2, Allocation of Costs for Production of Energy Crops, is a somewhat simplified breakdown of the costs associated with the different aspects of crop production.

While it is clear that land and taxes are a significant part of the total costs, it is also evident that harvesting and handling costs are the dominant ones. Thus, improvements in harvesting and handling technologies are likely to be as important to the future competitiveness of these systems as the relative productivities of the crops themselves.



While many utilities are expressing increased interest in the possibility of using biomass as a renewable energy resource, their fuels management staffs have very legitimate questions about the reliability of the feedstock. The link between production of the resource and its delivery to the utility gate is generally thought of as the "infrastructure" - those functions and people who will provide the planning, management, funding, service, education, public relations, harvesting, handling, and transportation operations. While the ability to carry out such functions has been demonstrated for other agricultural products, there is not yet the assurance of the reliability of these operations in the case of energy crops. For this reason, EPRI is interested in supporting a number of regional pilot demonstrations.

Rather than 4 to 20 ha trials which are the typical size of existing research plots, we would like to see 6 to 8 pilot projects, each started with an initial 400 ha planted and scaling up to around 10,000 ha. These would be planted in 5 to 8 year rotations and intended to provide a sustainable 25 to 30 MW of power. We are working with Oak Ridge National Laboratory, the U.S. Forest Service, the Minnesota Department of Natural Resources, and Northern States Power Company, planning for the first pilot project using poplar cuttings on nearly 400 ha on 25 individual farms in and around Alexandria, Minnesota this spring. Hopefully, another two or three pilots will be under way before the end of this year.

Determining the feasibility of integrated systems

Along with pilot planting systems, EPRI is working with the U.S. Department of Energy's National Renewable Energy Laboratory, cost-sharing seven (out of a total of twelve selected for funding support) case studies of the economic and environmental feasibility of integrated biomass systems in individual utility service territories. These seven cover a broad spectrum of systems and approaches. Yet because more than six other utilities have told EPRI that they had not been aware of the first round of case studies or the range of benefits which might be realized through development of integrated systems, EPRI has issued a request for a second round of proposals. The next group will be evaluated during the summer of 1994, with decisions expected in the fall. One condition for selection will be the committed involvement of a broad-based team representing farmers, regional political interests, natural resource specialists, equipment vendors, power plant engineers, etc.

Conscious of the more than 14 million ha of highly erodible cropland in the federal Conservation Reserve Program, staff within the U.S. Department of Agriculture asked EPRI staff to carry out a limited- scale survey to learn if utilities with coal-fired power plants in rural areas might consider cofiring with biomass in their plants. Our survey was certainly not exhaustive; yet in the space of just a couple days we had a list of 94 plants in 20 different states. USDA staff evaluated the amount of set-aside land in the counties in which those 94 plants are located and concluded that for 16 of them, more than 10 percent (by heat content) of the fuel needed to power them could be grown on the set-aside lands in those counties. These particular lands currently cost the federal government more than \$16 million in annual subsidies. This was a small sample of a large set of potentially suitable coal plants. EPRI staff estimate that at least ten times the number of plants could fit this scenario. At this time no policy changes are actually under consideration; however, researchers at Iowa State University are evaluating the changes in soils which are the result of planting both woody and herbaceous energy crops on erodible soils.

It's time for commercialization

During 1994, the EPRI biomass program staff expect that several of the case studies of the economic feasibility of integrated systems will be completed and be ready for implementation. Efforts are under way to develop formal memoranda of

understanding between EPRI and the U.S. Department of Energy and the U.S. Department of Agriculture to promote collaboration in both research and development and commercialization of biomass energy systems.

Continuing research and development is needed in terms of improved breeding stock, in matching plantings to specific soils, in improving the handling and harvesting technologies, and in understanding better the ecosystem impacts of energy crop plantings. But it is also time to move beyond research trials toward commercialization. It is time that those parties in both the private and public sectors come to the same table to explore opportunities to share the remaining risks and to make a reality of the promise of biomass energy.



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Current Status and Future Directions for the U.S. Department of Energy's Short-Rotation Woody Crop Research

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ABSTRACT

The U.S. Department of Energy (DOE) initiated the Biofuels Feedstock Development Program (BFDP) at Oak Ridge National Laboratory (ORNL) in 1978. The program's goal is to provide leadership in the development, demonstration and implementation of environmentally acceptable and commercially viable biomass supply systems. Three model short-rotation woody crop (SRWC) species, i.e. *Populus* spp., *Acer saccharinum* and *Salix* spp., have been selected for further development based on their productivity, adaptability, and suitability as biomass feedstocks. Of these three, *Populus* is the primary candidate for SRWC in the United States. For *Populus* the prescribed management system involves the use of intensive site preparation of agricultural quality lands, improved clonal plant materials at ca. 2,470 trees/ha, mechanical and chemical weed control for the first 2 years, and rotation length of 6 to 8 years, followed by replanting. Currently, due to the wider spacings and larger tree sizes, traditional, start-stop, one- piece harvesting techniques are being applied to SRWC; this includes the use of feller-bunchers, skidding to a common landing, and on-site chipping. Under the above silvicultural system, harvesting and transportation expenditures account for 50 to 60 percent of the total production costs. The productivity goals for SRWC are 20 to 30 t/ha/yr, with the current average across all sites and clones at ca. 10 t/ha/yr. Productivity rates on large-scale plantings have been documented at 27 t/ha/yr. To increase the average productivity rates, silvicultural enrichments [e.g., spacing variances, fertilization once per rotation (ca. 78.5 kg/ha N), and irrigation], genetic improvement, and molecular genetics techniques are being applied to all model species. This research is being managed under the concept of regional, integrated "Crop Development Centers." There are

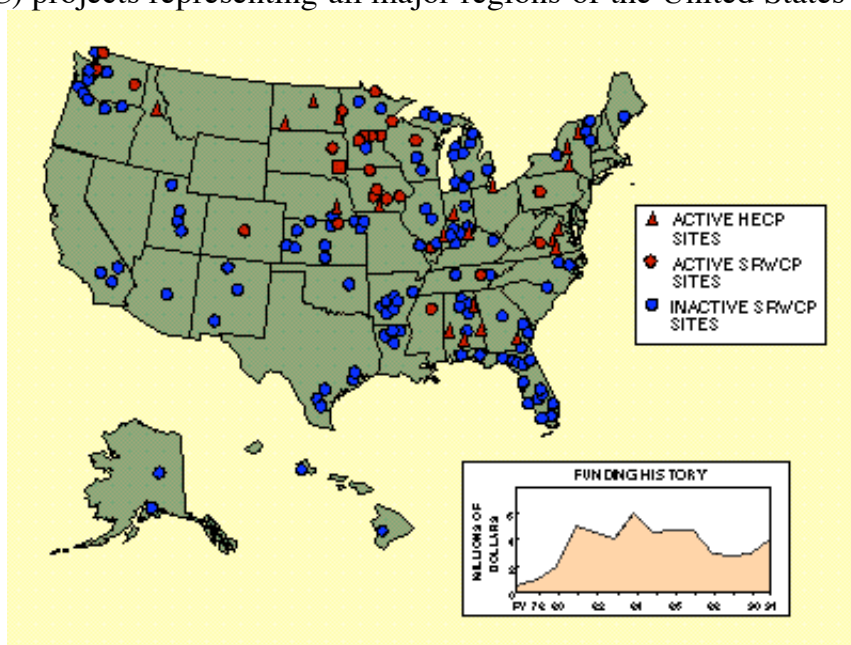
presently 3 *Populus* crop development centers.

Historical Background

The Environmental Sciences Division (ESD) at Oak Ridge National Laboratory (ORNL) has provided technical leadership for DOE's Biofuels Feedstock Development Program (BFDP) since DOE began energy crop research in 1978. The BFDP, a mission-oriented program involving research, analysis, and market assessment activities, provides leadership in the development, demonstration, and implementation of environmentally acceptable and commercially viable biomass supply systems capable of meeting a substantial portion of U.S. energy needs.

During the first 15 years of the program's existence, the primary emphasis was on plant breeding and selection, plant physiology, and biotechnology directed toward the development of fast-growing, pest-resistant woody crops. More than 150 woody plant species have been evaluated in 55 previous or current short-rotation woody crops (SRWC) projects representing all major regions of the United States (Figure 1.

Geographic depiction of previous and current locations of subcontracted research associated with the U.S. Department of Energy's Biofuels Feedstock Development Program since 1978). Silvicultural and agronomic studies have been used to identify the



best methods for achieving the optimum yields from these new crops. Much of the research has been and continues to be performed by cooperators at universities and U.S. Department of Agriculture research facilities. Directed, widely-distributed, competitive solicitations have been used to initiate most new research projects. Regular external technical reviews and BFDP subcontractor's workshops are used to ensure the quality of ongoing projects and to establish linkages among cooperating institutions.

ORNL uses its unique national perspective and technically experienced staff in its Environmental Sciences and Energy Divisions to provide integrated analysis, including resource assessments, and environmental and economic analyses. ORNL technical staff not only provide technical oversight to subcontracted research and development projects, but also serve as facilitators in the creation of consortia or cooperatives between academic and industrial partners. Table 1 lists some of the accomplishments of the BFDP over the past ten years.

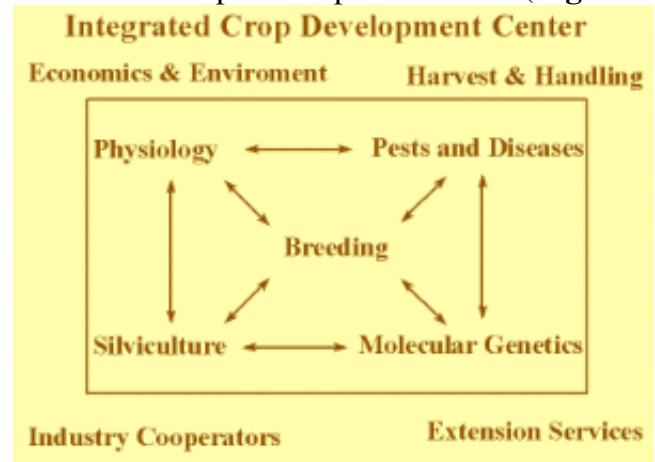
Table 1. Summary of some of the accomplishments of the Biofuels Feedstock Development Program over the past ten years

Reference	Accomplishment
Ranney and others 1986	Experimental yields of genetically selected hardwood clones demonstrated the potential for woody crops to produce yields that were 5 to 10 times that of natural forest yields and lead to the selection of 6 model species for further development
Ranney and others 1986	Hybrid poplar breeding programs demonstrated the potential for improving clonal yields by 100 percent over best wild-type clones available
Perlack and Ranney 1987	With technology improvements, the estimated costs of feedstock production were reduced from over \$4/GJ to about \$2.50/GJ
Ranney and others 1987	Over 150 candidate hardwood species were screened for fast growth potential
Wright and others 1988	Cooperators in the BFDP lead the way in applying biotechnology to hardwood tree species
Hansen 1991	Survival in early trials was quickly improved from 50 percent to 90+ percent by developing appropriate propagation methods, planting protocols, and weed control methods
Abelson 1991	The success of the hybrid poplar breeding program in the attracted the attention of the pulp and paper industry leading to the establishment of over 24,000 ha of hybrid poplars
Graham and others 1992	The capability of trees to reduce net CO ₂ emissions when used as a biomass energy feedstock has been evaluated
Summer 1994	Several utilities are conducting feasibility studies on the economics of using dedicated energy crops for biomass energy production Training in biomass energy concepts has occurred at 55 different institutions Approximately 1,700 publications have been published

Current Status

The BFDP currently manages nine short rotation woody crops (SRWC) subcontracts and three scale-up projects involving SRWC. SRWC systems development is currently limited to hybrid poplars, although a small amount of genetic screening is ongoing with silver maples and hybrid willow. Hybrid poplar crop development centers are located in the Pacific Northwest centered at the University of Washington/Washington State University and in the midwest with

the breeding work centered at Iowa State University. A new center in the southeast is scheduled to initiate work in July 1994. Each crop development center (**Figure 3. Schematic representation of interrelationship among the various disciplines associated with each crop development center**) combines a principle breeding program (to insure the continuous development of new clones) with associated levels of basic and applied research on plant physiology, silviculture, insect and disease evaluations, and molecular genetics. The BFDP intends to create fully integrated crop development centers consisting of experts in the fields of crop development, economics, environment assessment, mechanization, and agricultural extension. Production systems developed at each center will be transferred to individual producers and industrial cooperators in the various regions of the U.S.



Currently, the prescribed silvicultural production system for *Populus* involves diligent site preparation of agricultural quality lands, use of improved clonal plant materials planted at ca. 2,470 trees/ha, mechanical and chemical weed control for the first 2 years, and a rotation length of 6 to 8 years, followed by replanting (Hansen and others 1984, Hansen 1986). Because of the wider spacings and larger tree sizes, traditional, start-stop, one-piece-harvesting techniques are recommended for SRWC. This includes the use of feller-bunchers, skidding to a common landing, and on-site chipping. Under this scenario, harvesting and transportation expenditures account for 50 to 60 percent of the total estimated production costs. The productivity goals for SRWC are 20 to 30 t/ha/yr, with the current average across all sites and clones at ca. 10 t/ha/yr. Productivity rates on large-scale plantings have been documented at 27 t/ha/yr. To increase the average productivity rates, silvicultural enrichments [e.g., spacing variance, fertilization once per rotation (ca. 78.5 kg/ha N), and possibly irrigation]; genetic improvement; and molecular genetics techniques are being tested and applied to all model species.

Future Directions

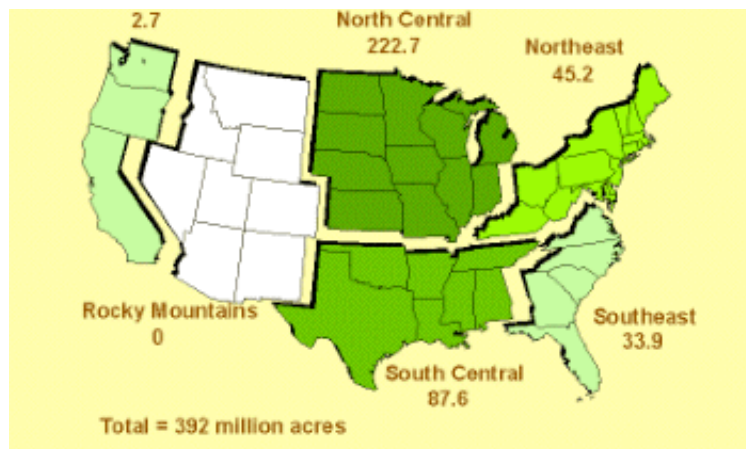
One of the challenges for the BFDP is to provide the new plant materials, technologies, and information needed to support the initiation of commercial biomass energy ventures, plus expand the basic R&D needed to meet the challenges posed by large-scale commercialization in the future. Major initiatives are being proposed by DOE's Biomass Power Program, the Biofuels Program and by a program to produce chemicals from biomass. The five-year plan of the Biomass Power Program suggests a production of 100,000 MW of biomass energy by 2030, the use of 14.6 million ha of land (**Figure 3. Estimates of the total and regional land potentially available to biomass energy crops**).

Estimates of the total and regional land potentially available to biomass energy crops within the continental United States (Million of Acres)

Pacific Coast

within the continental United States), and the generation of \$3.4 billion in private investments (U.S. DOE 1993). The Biofuels Program goal is to supply 10 percent of the nations liquid transportation fuels from cellulosic biomass by 2020 and half in the long term (U.S. DOE 1994).

While the first biofuels will be produced from wastes and residues, as much as 8.1 million ha of land in energy crop production will be needed to meet short term goals and more than 81 million ha will be need for the long term goals. It is reasonable to assume that short rotation woody crops would be the energy crop of choice on at least 30 million ha of that land.



The scale of these goals and the large percentage of the total cost that mechanization contributes to the per ton cost of the feedstock suggests that additional efforts should be made to improve the efficiency of all aspects of mechanization associated with SRWC production. Mechanization of SRWC cuts across all aspects of the production system, including site preparation, plantation establishment, routine maintenance, harvesting, processing, and shipping. If 30 million ha of land is managed for short rotation woody crop production, then 3.8 million ha will be harvested annually, 3.9 million ha will require site preparation, and 7.6 million ha will require mechanical and chemical weed control and maintenance. Harvesting and processing alone requires 6,000 operating units annually, each containing a feller/buncher, two skidders, and a chipper, functioning simultaneously at a value of \$560,000 per unit. This appears to represent a large business opportunity for agricultural and forestry equipment manufacturers.

The rate at which demand develops for short-rotation woody crops as an energy feedstock will occur slowly; however, the success of the early trials will determine the rate at which demand will increase. By the year 2000, it is likely that only a few demonstration biomass power facilities will be in place. The Biopower initiative suggests that about 243,000 ha of land may be required by the year 2000 of which less than 1/3 is likely to be woody crops. In addition, the pulp and paper industry may add 40,000 to 81,000 ha of short rotation woody crops during the next 6 years. While the immediate market demand for highly efficient SRWC mechanization is small, the importance of demonstrating that such equipment can contribute to reducing feedstock production cost is extremely important. To be economically competitive with petroleum-based transportation fuels, biomass feedstocks will have to be produced at a cost of \$33 to \$44 per dry t. This is a tremendous challenge that the U.S. can not meet unless considerably more resources are put into research, development, demonstration, and technology transfer on energy crop supply systems. If the 2015 and 2030 Biopower and Biofuels goals are to be met, an investment in technology development and demonstration will need to be made by both government and private sources

within the next 10 years.

Optimizing mechanization, harvesting, and handling may best be achieved through the formation of a cooperative consisting of equipment manufactures, potential equipment users and crop researchers who can describe the qualities of the systems needed. It would be desirable, however, for the harvest and handling cooperatives to be vertically and horizontally integrated within and across each energy crop centers which emphasizes the development of SRWC silvicultural systems. Each reduction in the proportional cost of producing SRWC achieved through the development of improved systems for SRWC mechanization will result in a proportional increase in SRWC profitability.

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Update of Short Rotation Intensive Culture in Canada

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Paper presented at the Mechanization in Short Rotation, Intensive Culture Forestry Conference, Mobile, AL, March 1-3, 1994

ABSTRACT

Canada is a large country with abundant quantities of biomass in many diverse forms. Forest industries and related operations alone annually produce 39 million oven dry tonnes. But in the past fifteen years, bioenergy has contributed only 7 percent of Canada total energy supply. Many provinces of Canada are fortunate in having affordable natural gas and hydro-electric power. As a result, the demand for wood fuel energy sources has risen very slowly.

In this context, what is the status of Short Rotation Intensive Culture (SRIC) for energy purposes? Is there any possibility for this type of cultivation to be commercially competitive as a source of energy?

INTRODUCTION

Canada is a large country where diversified forms of biomass are found in abundant quantities. However, bioenergy contributes only 7 percent of the total energy supply and the demand for wood fuel energy sources has risen very slowly because many parts of Canada have access to affordable natural gas and hydro-electric power.

This paper will review the status of Short Rotation Intensive Culture (SRIC). Emphasis will be on new developments which have occurred in some regions of the country and discussion of the feasibility for this type of cultivation to compete economically as an energy feedstock.

Canadian Land And Canadian Resources

Canada has varied and abundant biomass resources. There are over 453 million ha of Canadian forest of which practically half (46 percent) is classified as

commercial forest.

There are vast quantities of wood residues stacked in the forests and mill yards of this country. Bush logging residues, composed of tree tops, branches and foliage, are estimated at 30.6 million oven dry tonnes per year (M o.d.t./yr) (Simons, 1994) and across Canada, discarded wood mill residues are evaluated at 8.4 M o.d.t./yr. This total of 39 M o.d.t./yr of wood residues does not include urban wood waste which is estimated to be a further 14.2 M o.d.t./yr. This total of wood residues represents a potential of 750 PJoule/yr, which is equal to 12 percent of all of Canada's annual energy requirements.

Other important sources, including agricultural residues, municipal and industrial process wastes and peat resources, are a potential source for large quantities of feedstock for bioenergy.

However, even though great quantities of biomass exist in Canada, bioenergy contributes only 7 percent of the total energy supply. (EMR Canada) This is equivalent to the energy supplied by nuclear sources, and approximately half of that obtained from coal. In the last fifteen years, the demand for fossil fuel energy sources has risen slowly. Consumption has only increased an average of one-third of one percent annually.

Canada is also fortunate in having competitively priced hydro-electric power and affordable natural gas.

Therefore short rotation intensive culture (SRIC) for energy purposes has not been commercially developed. If only the economic aspect of these cultures is considered, and without a drastic change in the world's energy situation, it is unlikely SRIC will achieve competitive pricing. However, public concern with environmental issues is driving the search for more products and methods, which are environmentally friendly, including those used to produce energy.

What Is The Status Of The Fast Growing Trees?

Canada has 67.8 M ha of agricultural lands of which more than 21 M ha (Simons, 1994) of marginal land are considered usable for energy crop production.

Close to 80 percent of the total area of these lands is located in British Columbia and Alberta, the western provinces.

After examining the constraints of short intensive culture energy competitiveness, the potential and the ecological benefits accompanying the use of these cultures as clean feedstocks must be considered.

Because the exploitation of short rotation tree plantations for pulp, veneer, oriented strand board and energy is relatively new, there are few commercial plantations in Canada.

Provinces Affected

The diversity of the Canadian landscape is such that it is impossible to make general conclusions for the country as a whole. The situation varies from province to province and even from site to site. There is presently no fully operational energy plantation in Canada.

In British Columbia

In the province of British Columbia (B.C.) a pulp and paper fibre gap is predicted in about twenty years. Because poplar is an abundant native species, pulp and paper companies such as MacMillan Bloedel and Scott Paper Limited have been involved in testing of hybrid poplar and tree planting for pulpwood purposes, since 1984.

One thousand (1,000) ha of land in B.C. are under short rotation intensive culture. Scott Paper is currently harvesting 30 year old plantations in the Fraser Valley and replacing the trees by *Populus Interamericana*, a poplar hybrid to be grown on a fifteen year crop cycle. Scott Paper's oldest short rotation poplar plantation is now eleven years old and produces a yield of 30 m³/ha/yr mean annual increment.

A less intensive management occurs on the B.C. coast. Natural regeneration of *Populus trichocarpa* is augmented with planting of hybrid poplar or native cottonwood whips (*P. balsamifera* L. spp. *trichocarpa*) and grown on a 25 to 35 year rotation. Over 10,000 ha of land are committed to the extensive culture of poplars in B.C. (growth rates range from 10 to 20 m³/ha/yr; Scott Paper Ltd, Skeena Cellulose, B.C. Ministry of Forests and the Department of Indian Affairs are involved.) These numbers reveal that most of the fast growing tree plantations and the highest yield in Canada are in B.C.

Recent outbreaks of disease on hybrid poplars, in the States of Washington and Oregon, underscore the need to test disease resistant clones and avoid the establishment of large monoclonal block plantations. B.C. native *Populus trichocarpa* will be used in future breeding efforts.

In Alberta

In the province of Alberta, Alberta Pacific, a pulp and paper company, is in the process of starting an entire program of Poplar culture, including genetic breeding. These trees will be used primarily for Oriented Strand Board and Pulp and Paper.

In Ontario

In the spring of 1993, in the province of Ontario, the faculty of Forestry of the University of Toronto established two 2 ha prototype willow plantations using 12 different clones. This research is to verify the yields of clones previously grown only on small plots, to provide figures on the survival and growth of the selected clones, to test prototype planters and harvesters, to produce large quantities of biomass and to assess the economics of biomass production. The used clones are not available for distribution yet because they are still experimental.

However, the Ontario Ministry of Natural Resources listed ten selected hybrid

poplar fast growing clones that are regularly planted. Some horticultural centers are also selling improved uncertified fast growing material.

Also, Resource Efficient Agricultural Production, (REAP) a cooperative of Quebec and Ontario farmers, has been involved in short rotation intensive culture, in Ontario, for the past four years. The farmers are trying different type of plantations with different tree species, such as establishing monoculture plantations with willows and establishing windbreaks with poplars, willows, black locus and Norway spruce in mixed systems.

This is a three years old *Salix miyabeana* (Austree) windbreak plantation growing on swine manure fertilized soil in south western Ontario.

According to the economist Girouard, working for REAP Canada, it appears that the windbreaks have significant advantages over the monoculture production systems. The preliminary economic assessments indicate that the average net increase in crop yield from a windbreak will cover all production costs associated with the short rotation windbreak and that the sale of the biomass crop will enable profitability.

In southern Ontario, in the near future, a large research project will begin to evaluate the use of mixed primary and secondary paper sludge in forest biomass production. This will occur on 1,400 ha of clay mineral soils. Pulp and paper sludge will be used as an organic soil amendment to improve soil qualities and to increase the yield of fast growing tree species and indigenous species. The effects of pulp and paper sludge on trees never have been evaluated in Canada. A large amount of data is available related to agricultural cultures but not to forestry.

The pulp and paper company Domtar Inc. owns a 12 year-old hybrid poplar plantation for pulp purposes of more than 2,100 ha.

In Quebec

In the province of Quebec, a genetic improvement program for poplars has been underway since 1968. Some 2211 clones have been evaluated. Of these, 53 were selected for testing in different regions of Quebec to verify resistance to frost, canker and leaf rust. Generally, hybrids with *Populus balsamifera* such as *P. Balsamifera* x *deltoides*, x *nigra*, x *euramericana*, and *P. balsamifera* with (*P.deltoides* and *trichocarpa*) are the most used.

These poplars will be used primarily for management of natural forest stands and fibre production and secondarily for energy purposes. The idea is to recuperate the logging and mill residues for energy use. The province now has 350 ha of land under monoculture poplar plantation.

Concerning willow, the city of Montreal has the largest urban nursery in North America, and is conducting extensive work with fast growing *Salix* plantations. Mr. M. Labrecque, a botanist at the Vegetal Biology Research Institute, is the leader of this field research. His team reforested abandoned landfill sites beside the municipal waste water plant. Wet or dry treated municipal waste waters have been used to successfully irrigate plantations. The objectives were to evaluate

effects on yield and to determine whether the chemical components contained in the soil dispersed into groundwater or translocated along the roots, the stems or the leaves. This project began in 1992, and after two years, initial conclusions were that the most soluble metals, such as nickel, cadmium and zinc, are accumulated in the plants. 50 percent stay in the roots and the stems; the other 50 percent is returned to the soil by leaves. There are no significant effects the first year of the application but by the second year the willow yields increase considerably. The amount of waste water applied is always proportional to the nitrogen available in the soil.

In Quebec, REAP Canada is also involved. In Quebec as in Ontario, its major activity in the spring and summer of 1993 was the establishment of three (side by side treatments with 6 replications) field scale experiments, each of approximately 5 ha in size, cultivated with trees and grasses. This design will provide effective comparable estimates of production costs and productivity assessments between short rotation forestry systems and warm season grasses systems of biomass production.

Currently, there is controversy between researchers. Some are pro-grasses while others are in favor of more fast growing trees. According to Labrecque and others, trees are more adapted to wet nordic lands and grasses to dryer and warmer sites. But, even if grass has the advantage of a harvest each year, it has been proven that this type of cultivation depletes the soil more rapidly than tree culture. I think both cultures could have applications on appropriate sites. Respect for the ecological zones for the planting of specific native tree species is very important. While genetic selection is a major factor, the species must be planted in their native zones for best performance.

In addition, the potential of mycorrhizal fungi to improve nutrient cycling and the evaluation of diversified technologies to reduce the production costs are studied by REAP Canada.

Expected Yields And Costs

In Canada, yields of SRIC biomass plantations and windbreaks vary widely with species, region, and management strategy.

At present, all energy plantation yield data come from small research plots. In some cases, yields as high as 28 odMg/ha/yr (Labrecque M., 1994) and as low as 2 odMg/ha/yr have been obtained. Nevertheless, it is not known what scaling up the experiment to commercial size plots would do to yields. Results will be available in the next two to three years, through mid-commercial size plots (2 to 3 ha) established in central Canada, in the spring of 1993 (Montreal City, REAP, U. of Toronto).

It is therefore very difficult to be certain which of the cost figures given by researchers are the most accurate. Variance between different cost calculations is enormous. With a revolution of 20 years and a rotation period of 4 years, average Short Rotation Tree yields range from 7 to 15 odMg/ha/yr, producing annual biomass costs between \$63 (U.S.) and \$11 (U.S.) (See Table 1). These numbers

do not include the cut- back cost of the first year and the chipping and transporting costs. Gambles and Kenney (1991) estimated the chipping and the transporting costs respectively at \$7.46 U.S./odMg and \$0.15 U.S./ odMg/km. These are the most accurate figures available.

According to Mr. P. Foody (1993), regarding ethanol production, if biomass (both woody and herbaceous) could be bought at \$22.5/odMg, these feedstocks would be competitive with other sources of energy. This scenario would be achieved on a no rental cost land with low harvest cost (\$450 U.S.) and high yields (20 odMg/ha/yr). At the present time, Short Rotation Forestry is not a viable feedstock for ethanol production. However, one of the ways to reduce SRF biomass cost is to use it on-site and to avoid transportation costs.

Harvesting And Processing

Many studies estimate that harvesting and delivery costs account for over 45 percent of the cost per MJ of energy produced per ha (Strauss and others, 1988), and can range from 35 percent (Ranney and others, 1985) to 73 percent of the total biomass production costs (Zsuffa and Gambles, 1992). The equipment alone is responsible for the greatest part of the costs. Logically, decreased harvesting costs would also greatly contribute to reduced operational costs and overall biomass cost.

The National Research Council of Canada, in the mid-1980's, developed a few single-row prototype machines. Only one, the FB7 used to harvest medium sized trees, (18 cm), was tried in the field and provided a basic understanding of field difficulties. FB7 harvested an average of 850 trees per productive machine hour while harvesting single trees from rows. Unfortunately, this research program was discontinued. After these trials, no specific machine has been developed for short rotation intensive culture.

In Canada, because of the new interest in short rotation intensive culture, no machine has been developed for this specific application. Harvesting is done manually with a brush saw and this simple method seems to be the most appropriate for small plots. The average productivity per person is estimated at 0.4 ha/day. On the other hand, it appears to be relatively easy to harvest the fast growing grasses with existing agricultural machines followed field bailing.

However, even though the country is well endowed with many diversified forest machines, their design is suitable only for conventional forestry and not for S.R.F. For example: Domtar Inc. in Ontario cuts its 12 year-old poplar plantation with a Timbco T435 feller-buncher. The entire tree lengths are removed from the site by a grapple skidder. Because the chips are produced for pulp, the trees are chipped with a Morbark flail delimber/debarker/chipper. Chips for energy purpose do not require such processing.

In this regard, a few months ago, I began an inventory of small diameter tree harvesters and chippers available on the Canadian market. I contacted most of the Canadian manufacturers of forest equipment requesting as much detail as possible on these types of machines. Most of them were unaware of fast growing tree

plantations for energy and did not have any interest in harvesting such small diameter trees. Many of them sent me information on chippers. There are hundreds of different chippers on the market. Brucks, Comact, Hakmet, John Deere, Morbark, Nicholson, Rodrigue Metal, Timberjack...etc. sent me folders on their equipment, saying, of course, that they have the most efficient ones. But in fact, none of this equipment met my requirements for a machine which would cut and chip trees simultaneously. Because of the constraints mentioned at the beginning of my paper, for trees with diameters less than 7.6 cm, the most effective process is to harvest and chip in one operation thereby reducing labor costs (Johnson and Erickson, 1987) and becoming competitive with other energy sources.

However, it permitted me to reduce my list to include only those companies offering machines which were of some interest. None of them is perfectly suited to my requirements, but there is great potential for them to be adapted to our needs.

I would like to describe two of these machines:

I call this unnamed multi function head: "The Material Circuit Chipper". It has been designed and built by a gentleman who was involved in road construction and roadside brush clearing. He developed two different machine sizes for his purposes. One is 1.8 m wide and the other is 1.4 m wide with cutting openings of 1.2 and 0.9 m and 12 and 8 cutting blades respectively. The total weight of the two mobile chippers is, respectively, 499 and 363 kg. The motor R.P.M. is around 2,000.

These machines, which are very effective for the purpose for which they were designed are not yet in commercial production and have never been tried in S.R. Plantations. I have not seen them in operation, but, will attempt to explain how they operate.

A woodbrush cutting machine is comprised of two horizontal and adjacent cutting units, which rotate in opposing directions. The units consist of cylindrical surfaces to which longitudinal wood brush cutting blades are mounted.

In the region between the two cylinders, the blades of one cutting unit fit between the cutting blades of the other unit. The blade of unit A passes in the space between the cylinders followed by the blade of the unit B, in sequence.

The angular position of the blades of unit A is 90 degrees apart from the angular position of the blades of unit B, about the axis of rotation.

In action, opposite rotation of the cutting units forces the woody stems to pass between the cylinders where they are cut by the blades. Then the blades throw the woodchips upward. A tunnel like channel with a wide lower opening surrounds the cutting units to efficiently receive the wood chips. They are then directed toward the discharge opening. This opening is provided with a spout to discharge the chips into a container. When the container is full, (capacity is about 1 cubic meter) the boom-and-arm assembly is articulated to tilt the container and pour its contents. I believe this machine could be quite easily adapted to the harvesting of

small, fast growing trees. I intend to further examine the possibilities of this multi-function head.

Midiforst and Forst built by Seppi M., an Italian company, have been tried in many diversified forest stand conditions including a project on small trees on a private woodlot. The objective of this study was to evaluate machine performance in cutting and chipping various types of woody material. It is a really efficient machine in brush cutting and herbaceous control. The major impediment to use of this machine in SRIC is that it will cut and chip but does not harvest the chips. The cutting system consists of at least 20 hammers of 1.6 kg each.

These machines are perfectly suited for site preparation of abandoned brushy fields. There are also positive effects in stopping the herbaceous and ligneous competition because they blow away and spread the chips covering the soil and return nutrients to it.

CONCLUSION

Given the immense availability of marginal, abandoned farmland in Canada, plantation for bioenergy is an attractive possibility. The sustainable use of these lands as an alternative energy source would result in CO₂ absorption, land conservation, and a reduction in greenhouse gas emissions.

However, as when research began, the challenge is:

- to improve the technology and thereby reduce production costs,
- to develop a market for the final products, and
- to generate more interest among potential growers, buyers and policy makers.

There is some positive news. It is very encouraging that large hydro-electric utilities, such as Hydro Québec and Ontario Hydro are increasingly receptive of technologies and have indicated an interest in being involved in field trials in the near future.

Also, H. A. Simons, a private consulting engineering firm, working for the Canadian Electrical Association and Natural Resources Canada, is currently doing national research on the prospects for biomass for future electrical generation plants.

Natural Resources Canada also wishes to complete an analysis of policies to create opportunities to increase the contribution of forest biomass to energy production in Canada. To this end, it will award a contract to develop a national technical-economic database for forest biomass to support its policy analysis. I believe that these initiatives, will have significant impact on the use of biomass for energy and will result in enlightened and effective new policies.

Cost for Commercial SRIC Plantations with a Revolution of 20 Years and a 4 Years Rotation

Researcher

ReapCan Labrecque U. of Toronto

	Estimat.on farmer's land			et al *4 Montreal Nursery	Estimation for a:	
					Contract	Farmer
Annualized Establishment Costs *1 (US \$/ha)	55			78	65	75
Maintenance and annual charges *2 (US \$/ha)	203			56	214	120
Annualized Harvesting Costs *3 (US \$/ha)	18			149	149	75
Yield (odMg/ha/yr)	7	7	7	15	12	14.4
Production Cost (US \$/odMg) Before transportation	63	63	30	11	45	21
Comparison with switchgrass Production cost before transportation (US \$/odMg)	36	22	19			

*1. Includes: herbicide application, plowing, discing, harrowing, planting

*2. Includes: herbicides, fertilizers, spraying, land lease

*3. Estimated costs from literature review

*4. Real costs on small plots in Montreal, Quebec



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Mechanization of Short Rotation Intensive Culture Forestry (in the UK)

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*Paper presented at the Mechanization in Short Rotation,
Intensive Culture Forestry Conference, Mobile, AL, March 1-
3, 1994*

SUMMARY

Wood as a fuel is currently used in the UK in the domestic sector and in the wood processing industry although there is now an incentive to generate electricity from it. Short rotation intensive forestry crops are being considered as an energy crop on land set aside from agriculture. A 2- TO year cycle coppicing system is being developed using willow and poplar. Agricultural techniques and machines will be used and the husbandry techniques will be similar to those employed in Sweden.

Work on the development of mechanization of the crop is being funded by the UK Government's Department of Trade and Industry (DTI) under a program managed by ETSU. Work on harvesting machines has already started and work on transport and supply is due to start shortly. Modelling of the drying and storage of bulks of wood chips has already been advanced leading to some understanding of the processes involved. This work continues and will be applied to short rotation crops.

INTRODUCTION

In the UK, wood as a fuel is used mainly in the domestic sector of the energy market. Other applications for wood as a fuel are in the wood processing industry. In situations where wood residue is a disposal problem then it is often economic to use it on-site for generating process steam for kilning; examples of this application exist.

Short rotation forestry in the U.K. is seen as a pure energy crop and is not planted for paper pulp manufacture as it is the U.S.A., although some traditional coppiced woodland of hazel and sweet chestnut is still harvested for hardwood pulp in the south of England. Another use for all types of short rotation forestry is for stabilizing soil embankments around roads and waterways.

The advantage of energy cropping in a short rotation forestry system over using by-products from conventional forestry is that energy cropping allows the production of wood fuel in a concentrated area. The crop can then be sited close to the heat or power plant without experiencing the high transport costs which are often incurred when using forest residues as a fuel. A further incentive which applies throughout Europe is that some agricultural land is now surplus to requirements for food production and cropping of energy is seen as a way of usefully employing some of this resource. Short rotation forestry crops usually grown as coppice fit into the existing agricultural systems better than traditional forestry crops.

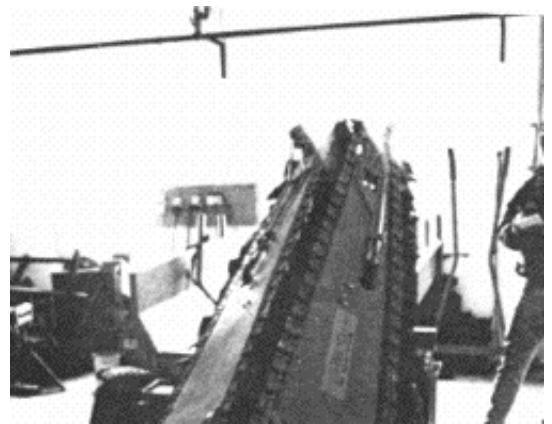
The research to date has covered a number of areas including clonal selection, spacing, disease control and harvesting. Willow and poplar are the clear leaders from a yield point of view in the British climate and the trial plots are based on these two species. In 1991, 5 commercial demonstration plots at various sites around the south of England were established by a group of farmers brought together by ETSU. These growers will act as market centers in their locality and will generate wood fuel markets and encourage other local farmers to contribute by growing extra material. Each of the initial growers is committed to plant at least 10 ha, each has planted around 6 ha so far with the final area due to be planted in spring 1994. In addition to these research plots other areas are planted around the country and the total area is around 100 ha.

Cultural Practices



(Plate 1. Salix Maskiner Four Row Step Planter From Sweden) Cuttings are planted at around 10,000/ha into a pre-prepared seedbed using a mechanical planter. A modified cabbage planter can be used although other mechanized techniques have been developed such as the Salix Maskiner step planter from Sweden .

(Plate 2. Fröbbesta Cuttings Harvester from Sweden) Herbicide is applied in the early stages of growth when the crop is particularly susceptible to competition from weeds. After one year of growth, the sticks are cut back to ground level to encourage coppicing and to provide cuttings for subsequent plantings. This can be done by hand although Swedish machines have been developed to carry out this operation. Following the 1 year cut



back, the crop is allowed to mature for a full rotation which in the U.K. is between 2 and 5 years. Crops are then cut at the end of each rotation when weed treatment may be applied. For planning purposes yields of 10 to 12 dry tonnes of wood per ha per year can be expected on a reasonably fertile site.



Economics

If short rotation forestry must compete for land with agricultural crops, the opportunity cost associated with not growing food crops would, in most cases, mean that the crop would not be economic. Within the European Union, reform of the Common Agricultural Policy has led to a need to 'set aside' some of the land previously used for food production. The growing of short rotation coppice on set aside land has been agreed so this overcomes the opportunity cost problem.

Another incentive for wood fuel in Britain is given to generators of electricity from non-fossil fuel sources. Such generators are receiving premium prices and a guaranteed market under a system known as the 'Non Fossil Fuel Obligation' (NFFO) designed to stimulate development of these technologies. Although no schemes are yet producing power from short rotation forestry, projects are being planned under the current round of this scheme. The results of the current competitive bidding process will be known at the end of 1994.

UK DEVELOPMENT EFFORT ON THE MECHANIZATION OF SHORT ROTATION COPPICE

Two projects are currently being conducted under the ETSU managed program which are relevant to this conference. These are on the harvesting of short rotation forestry and on the drying and storage of the crop. A further project on transport and supply logistics is also due to start shortly and this will cover all the biomass crops. The work on harvesting and on drying and storage which has already started is described below.

Harvesting

The development of effective mechanization from harvest through to the utilization plant is critical to reduce the delivered cost of the fuel. Costs must be reduced to levels similar to those for comparable agricultural crops if the coppice is ever to compete with fossil fuels while still giving some return to the growers. The British program aims to do this in the following ways:

- Provide data on the best of the harvesting machines available in the UK and Sweden under British conditions.
- Demonstrate to the industry the best of the systems available.
- Provide data on the costs of comminution of coppice material which has

been stored as sticks.

- Adapt or modify existing machines developing them so that they operate effectively under British conditions.

In Sweden energy cropping is more advanced: they have around 9,000 ha of willow coppice planted with further plantings scheduled for 1994. As a result, their harvesting machines are more developed than those in the Britain and there exists the possibility of transferring this technology. However, transfer of the technology may not be as straight- forward as might be hoped because of climate and differences in the end use. Also, a significant proportion of the British crop is likely to be poplar and not willow.

Harvesting machines which currently exist fall into two categories, those which in a one pass operation 'cut and chip' the coppice material and those which simply cut the material leaving the product as a pile of full length shoots (sticks). A full review of the harvesters which are available resulted from the early part of the study (Ref. 1).

There are two commercially available cut and chip machines operating in Sweden :

An unmodified Claas Jaguar self propelled forage harvester fitted with a header developed by Claas themselves. This is currently being developed but is expected for the 1995 harvest. Several hundred of these forage harvesters operate within Britain, harvesting grass and maize for silage in the summer and autumn. These machines, therefore, would be available for harvesting coppice in the winter. **Plate 3, Claas Jaguar Forage Harvester With an Earlier Model of the Header,** shows the harvester with the 1993 prototype header.



The other cut and chip machine is a self propelled sugar cane harvester imported from Australia and known as the Austoft machine (**Plate 4. Austoft Sugar Cane Harvester**).

Several stick harvesters also exist both in Sweden and in this country. These range from simple tractor mounted hedge cutters through to Swedish self propelled machines which will cut the sticks and carry them to the end of the row.





The project on harvesting, which is part of the DTI's program managed by ETSU, is co-funded and being carried out by the Forestry Authority. The first harvest under this project was conducted during January 1994. The Austoft sugar cane



harvester and the Fröbbesta tractor-trailed stick harvester (Plates 4 and **5, Fröbbesta Coppice Harvester from Sweden (1992 prototype)**) were brought over from Sweden and tested under British conditions. Both were found to be capable of handling poplar crops of up to three years old as well as the willow for which they were developed. The Austoft sugar cane harvester which runs on steel tracks coped

remarkably well on a very wet, sloping clay site in Northern Ireland.

Drying and Storage

Since 1989, drying and storage work has been a part of the DTI program managed by ETSU. The work has been conducted by Silsoe Research Institute (SRI). The work is directed towards coming to an understanding of the behavior of wood chips as they are dried and stored. This will enable us to make some sense of the experimental data coming from all sources. The same techniques as are used for the drying and storage of grain have been employed. The characteristics of forestry wood chips rather than grain have been quantified and the computer models used for predicting the behavior of grain have been adapted accordingly. Some limited validation of the models has been carried out under the project already completed.

Various low cost techniques for storing wood chips have been devised using the models and the theoretical understanding which has been gained has allowed interpretation of some of the experimental work reported in the literature. Until this modelling work, individual experiments were valid for the conditions in which they were tested, but extrapolation of results from one experiment or set of conditions to another was not possible.

The objectives of the current study are to establish effective methods for the storage and drying of coppiced willow and poplar intended for fuel. This means that storage will continue without excessive deterioration by microbial action and will be at an acceptable cost. A further objective of the current project is to show how these methods can be implemented in practical situations.

The program to fulfil these objectives will :

- Determine the relevant properties of coppice wood chips which will be different to those for forestry residues on which data exists; also data is

needed in order to model the behavior of coppice wood chips in waste heat dryers.

- Design storage regimes for coppice wood chips which can be tested at full scale.
- Test the optimal storage regimes suggested by the models at full scale, monitoring all the data needed to further validate the model and to give the operating costs, storage losses and relevant quality parameters.
- Update the models, refine the techniques and repeat the process for two more storage periods using a variety of on farm stores taking the opportunity to demonstrate the techniques to the industry.
- Produce an information pack for industry on how to store wood chips.
- Examine the storage of coppice wood as whole shoots.
- Model the drying of wood chips by use of waste heat from power generation plants.

The expectation is that sufficient understanding of the behavior of stored coppice chips will be achieved, to predict with some confidence, the performance of any practical store or drying technique. This will result in reliable data which can be used to advise the industry on the cost and performance of any particular store before and after commissioning. The results of this study will also be applicable to any chip store anywhere in the world by feeding in the relevant in the U.K.

CONCLUSION

Short rotation intensive culture forestry is being developed in Britain for energy use and may be used for electricity generation in the future. Under the U.K. development program, the first harvesting trial has been successful with Swedish machines performing well under wet British conditions even on poplar. Work on drying and storage of short rotation forestry crops is proceeding. The work is based on an understanding of the drying and storage processes which are now incorporated into a computer model. This means that the work can be applied to any store anywhere in the world.

REFERENCES

1. Technical Development Branch Report no.1/94. This is available from the British Forestry Authority, Technical Development Branch Headquarters, Ae Village, Dumfries, DG1 1QB phone 44 387 86264.



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MECHANIZATION IN SHORT ROTATION, INTENSIVE CULTURE (SRIC) FORESTRY



SRIC Tour and Demonstration

First Stop: Elberta Forest Tree Nursery, Scott Paper Company
29650 Comstock Road, Elberta, AL 36530
Phone: (334) 986-5210 FAX: (334) 986-5211

Host: Sam Campbell, Scott Paper Company

Scott Paper Company has committed itself to an environmentally responsible program of natural resource management and conservation. On this stop, we saw an example of this commitment at the Elberta Forest Tree Nursery. At the nursery, bare root seedlings are prepared for reforestation, wetland reclamation, and ornamental planting. Pine seedlings and over 25 hardwood species are grown. Some of these species include genetically improved loblolly pine (*Pinus taeda*) and slash pine (*Pinus elliottii*), southern magnolia (*Magnolia grandiflora*), dogwood (*Cornus florida*), water oak (*Quercus nigra*), river birch (*Betula nigra*) and many others.

Because of inclement weather, no operations were scheduled for the day of the tour. Equipment used in planting, lifting, and packaging of seedlings, however, was on static display and an introduction to their use and development history was given by Sam Campbell.

Second Stop: SRIC Management Stands, Scott Paper Company, Sullivan Unit
Compartment 64, Jack Springs Road, Escambia County, AL

Host: Tracey Broussard, Scott Paper Company

The SRIC Management Stands viewed on the tour were part of a sycamore plantation consisting of 37 ha of former agricultural land, and 28 ha of former natural woodlands. The agricultural site consisted of 3-year-old sycamore in a 2 m x 3 m spacing. The woods site was newly planted with sycamore seedlings established in a 3 m x 3 m spacing. The site prep procedures, planting procedures, vegetation control, and fertilization information for the two sites were as follows:

Site Prep Procedures

Woods Sites: Shear, rake, double disk, 1 t lime/acre applied

Agricultural Sites: Disk and rip with farm tractor, no lime is applied

Planting Procedures

Seedlings are grown in Scott's nursery in Elberta from seed stock provided by Scott's seed orchard at Wildfork

Woods Sites: Machine planted

Agricultural Sites: Hand planted

Vegetation Control

Woods Sites: Atrazine/Oust tank mix (3 qt. & 2 oz. respectively) during year of establishment and year 2, to be applied early spring by aerial spray.

Agricultural Sites: Atrazine/Oust tank mix (3 qt. & 2 oz. respectively) during year of establishment and early spring of year 2 by farm tractor.

Atrazine is effective on pre-emergent broad leaves. Oust is effective on pre- and post- emergent grasses. Subsequent application of glyphosate (Roundup) are applied to control post-emergent and broadleaf vines. 2, 4D-glyphosate (Campaign) is also used to control post-emergent morning glories (*Ipomoea sp.*).

To control competition from broadleaf weeds and vines, these plantations are occasionally bush-hogged during the year of establishment and in year 2, depending on severity of competition.

Fertilization

Woods Sites: Fertilizer applied in the year of establishment and every year after as needed according to foliage and soil samples.

Agricultural Lands: Fertilizer is not applied in the year of establishment, but in the following year and every year after that as needed according to foliage and soil samples.

Third Stop: Harvesting Demonstration, Sullivan Unit,
 Compartment 67 and 68, Three Mile Road,
 Escambia County, AL

The harvesting demonstration featured several types of equipment typical of southern logging operations used in harvesting short rotation sycamore. Specialized equipment, such as Texas A&I's biomass harvester, a flail delimber/chipper and a tubgrinder, were also shown.

Scott Paper Company produces whole-tree chips for fiber using 4-wheel feller-bunchers, skidders, and chippers. An alternative felling system, a 3-wheel feller-buncher from Morbark, was also demonstrated. Morbark also showed a chain flail

delimber/debarker for production of clean chips. A tubgrinder, also provided by Morbark, was on site for comminution of residues.



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