STATUS OF SHORT ROTATION FORESTRY IN THE USA

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Introduction

Woody biomass remains a relatively small component of the total energy supply in North America (Energy Information Administration, 1992). United States industrial consumption of wood energy has remained steady for about the last ten years at 1.6 trillion MJ. Total wood energy consumption for 1990 was about 2.9 trillion MJ, or 3.4% of the national total.

It is unlikely that wood fuels will become an important energy source in the foreseeable future. Demand for fossil fuel energy sources has risen slowly. Over the last ten years in the United States, energy consumption has increased an average of less than 1% annually. And that small increase has come mainly in the residential sector where the potential for SRIC biomass energy utilization is low. Availability of fossil fuels, except for the brief interruption seen during the Persian Gulf war, **has been** steady, keeping real costs of heating oil and gasoliie below the levels of the early 1980's. Without a drastic change in the world energy situation, costs are unlikely **to** reach a point to make SRIC biomass a realistic alternative in the near future.

As the market for biomass energy remained weak, the demand for hardwood fiber increased dramatically. From 1976 to 1990, consumption of hardwood for pulp in the United States increased from 31% to 39% of the total. By the year 2020, the USDA Forest Service predicts hardwoods will account for nearly 50% of the total pulpwood consumption in the U.S. Because of increased environmental concerns and the longer rotation period of hardwoods, interest in the U.S. has turned from using SRIC exclusively for energy, to fiber production with secondary energy usage.

Although the potential uses have changed, the challenges associated with SRIC production of woody biomass remain the same. This paper summarizes the status of industrial SRIC programs in the United States, as well a review of research with an emphasis on felling technology for harveasting operations.

SRIC : Research **Summary**

Species

Commercially viable species for SRIC production have been identified in **many growth and** yield trials throughout the U.S. The **choice of species for** a particular site is highly dependent on both regional and local conditions, as well as the intended function of the plantation. Although many species have been identified as feasible, relatively few are currently in use. Consideration in the U.S. **is** given mainly to the potential for fiber production. The major species in use include black locust *(Robinia pseudoacacia)* on generally poorer soils, sycamore (*Platanus occidentalis*) on wetter soils, *Eucalyptus* spp. in warmer climates, and several *Populus* species on more productive soils. Although they tend to yield at lower levels than other species, some nitrogen-fixing *Alnus* species have been identified as appropriate for the U.S. (Hall and Burgess, 1990). There are additional potentially important regional species, but so far none have been used in a significant plantation production system.

Cultural Practices

Stand establishment procedures in the U.S. generally call for soil treatments similar to agricultural production, with significant tillage for seedbed preparation and control of competing vegetation (Hansen et al., 1984, Christopherson et al., 1989). Tillage has been shown to enhance early productivity of SRIC plantations in Sweden (Ledin, 1992), which is important for competition-intolerant species such as *Populus* (Zsuffa and Gambles, 1992). Hansen (1991) reported that stand establishment in the northern U.S. usually includes primary tillage (agricultural equipment) in the fall, with additional broad-spectrum herbicide application if needed. In the spring, the site is disked and a preemergence herbicide applied just prior to planting.

From our survey of industrial SRIC fiber plantations in the U.S., trees are planted at a density of about 1800 trees/hectare. This density is typical of energy plantations in the north-central U.S. as well (Hansen, 1991), but for energy production stand densities can be higher. Moran and Nautiyal (1985), for example, recommended 16,000-35,000 stems/ha for *Populus* in Canada under 3-year rotations. Rotations for fiber production are generally long enough to produce 13-25 cm dbh trees, about 5-7 years.

Much research has been done on nutrient requirements in SRIC plantations, especially in *Populus* spp. (Mitchell, 1990; Hansen et al., 1988). Nitrogen is assumed to be limiting in production of SRIC hardwoods (Mitchell, 1992), but factors affecting the uptake of nitrogen are not as well known. Nutrient concentration does not seem to be important, but rather the total root surface area available for uptake, implying that enhancing root development is key to increasing productivity. Since the plant can shift resource allocation dynamically in response to nutrient availability, timing of fertilizer application would also seem important, as well as method and form of application and type of incorporation.

Research is needed into the level of nutrient availability required to optimize production in short rotation forestry (Anderson et al., 1983). Strauss et al. (1988) reported a 21% increase in second rotation yields of poplar using fertilization rates developed for corn production. Costs of the treatment were about 6% higher. With increasing environmental concerns over agricultural sources of water contaminants, there is an acute need for information on the minimum nutritional and chemical vegetative control levels needed to make SRIC plantations profitable. In the Western U.S., concerns over the availability of water will also impact the level of management possible on fiber plantations.

In our survey, the use of mechanical cultivation was widely reported as a means of controlling weeds. Anderson et al. (1983) listed additional benefits of cultivation, including incorporation of surface biomass into the soil for nutrient retention, slowing of soil moisture loss, and preservation of soil tilth. Herbicide is also commonly used with cultivation until canopy close (Anderson et al., 1983). Christopherson et al. (1989) recommended cultivation every 10 days to two weeks to a depth of 5 cm in first year stands. Hansen (1991) reported the common use of a variety of agricultural implements for cultivation, including rotary hoes, sweep cultivators, or disks.

Decision criteria are needed for choosing between regeneration alternatives. The long term effect of multiple harvestings on growth and yield of coppiced vegetation is not quantified

(Zsuffa and Gambles, 1992; Mitchell, 1992; Ferm and Kauppi, 1990), especially for the variety of species and conditions found in the U.S. Coppicing response of short rotation poplar has been documented in the U.S. (e.g., Strong, 1989; Strauss et al., 1988; Ek et al., 1983), but the studies have been geographically limited and don't always report the effect of harvesting method. Research is needed to determine the optimal balance between the economic and productivity tradeoffs arising from harvest treatments, including acceptable levels of stump damage, time of harvest, and soil impacts of trafficking.

Expected Yields

Yields of SRIC biomass plantations in the U.S. vary widely with species, region, and management strategy. Cannell and Smith (1980) give an early review of yields. In a later summary for the Great Lakes region of the U.S. (Meridian Corp., 1986), yields of initial rotations of clonal cottonwood plantations were reported to be from 4.9 to 11.2 dry Mg/ha/yr. Tree spacings ranged from 0.3 m to 2 m apart. Ranney et al. (1985) reported yields of from 1.6 to 5.7 dry Mg/ha/yr at a 2 m spacing, and 4 to 7 dry Mg/ha/yr at 1.2 m spacing. In a recent report, Hall et al. (1992) found yields of 5.5 dry Mg/ha/y from *Populus* hybrids in Minnesota. Small-scale studies in the Midsouth region (Tennessee) found yields of between 9 and 11 Mg/ha/yr of dry matter on first rotations of cottonwood, sycamore, and sweetgum on converted farmland (Energy Performance Systems, 1992). Initial findings on a first-rotation sycamore plantation in southern Alabama indicate yields of about 11 green Mg/ha/y for trees grown an a 1.8 m x 2.7 m spacing.

Harvesting Methods

The financial component of SRIC production having the greatest immediate opportunity to reduce overall system costs is harvest and transport (Strauss et al., 1988). The magnitude of the savings is difficult to gauge, however, since the opportunities to study integrated commercial biomass operations are few. What studies there have been have shown that harvest and transport costs generally account for over 45% of the cost per MJ of energy produced per hectare (Strauss et al., 1988), and can range from 35% (Ranney et al., 1985) to 70% of the total production costs (Zsuffa and Gambles, 1992). On an energy basis, harvest and transport contribute about 30% of the total input (Strauss and Grado, 1992). In a study of irrigated poplar plantations in the North-Central region, Ferguson et al. (1981) found that a 20%-40% change in harvest costs influenced rate of return by about 2%, which was comparable to an 18%-20% change in yield. As planting density and yield of SRIC plantations increase through genetic and cultural improvements, the opportunities to gain significant advantages from improvements in harvest and transport technologies will magnify in importance (Woodfin et al. 1987).

Research in the area of biomass harvest mechanization has concentrated on integrating biomass utilization technology into conventional harvesting practices (Hudson and Mitchell, 1992; Goulding and Twaddle, 1990; Stokes, 1992). In contrast, because of the unique cultural practices and conditions, early research efforts in SRIC mechanization focused on development of specialized harvesters (Christopherson and Mattson, 1990; Christopherson et al., 1989). Perlack et al. (1986) stated that production costs with specialized harvesting equipment could be lowered by 30% over those incurred using conventional systems.

In general, SRIC-specific systems were designed to take advantage of the structure of the typical stand, i.e. the dense, small, relatively uniform trees, while providing some initial processing to decrease bulk density of the harvested product by either bunching, chipping, or crushing. The VPI/DOE harvester (Stuart et al., 1983) used counter-rotating saws to fell stems, and a belt conveyor to move them to a crusher system. The authors recommended that future versions of the system be designed as towed implements for use with an agricultural tractor. This would eliminate some of the problems the machine had with power requirements and manueverability, but a revised prototype was never built. The U.S. Forest Service developed a prototype felling system for SRIC plantations that used an auger to sever the stems coupled with an accumulating area to bunch them. In theory, the auger has advantages over the saw-type fellers (Curtin and Barnett, -1986) since the auger is less likely to bind and, therefore, should do less damage to stumps and roots. The auger, however, has yet to be field tested.

Despite demonstrated potential with specialized biomass harvesters, U.S.-based research in this area has virtually ceased, mainly because of the lack of a specific market for any developed products. Currently the only on-going biomass harvester development project in the U.S. is being conducted in the state of Hawaii (Paquin et al., 1989). The project is on hold at present because of low funding.

Recent research in SRIC harvest mechanization in the U.S. has adapted to meet industrial needs for integrated production of fiber for pulp furnish with secondary byproducts for energy. The relative scarcity of SRIC plantations has necessitated use of conventional harvest systems, with some instances of adapting components or operational practices for the unique conditions. In a study by Stokes et al. (1986) a feller buncher-type biomass harvesting head was mounted on a tractor and used along with two methods of primary transport systems (tractor and skidder) to produce chips for fuel. Their results indicated the advantages of using a large-capacity bunching felling head. They also reported cost savings were possible using smaller scale transport and chipping equipment in conjunction with the feller buncher.

In the Pacific Northwest, Hartsough et al. (1991) compared a feller buncher/skidder with a small-scale manual fell/cable yarding system, both feeding a chain flail/chipper system, for use in producing clean pulp furnish from SRIC *Populus* stands. The cable yarder was proposed as an alternative to be used when site conditions precluded the use of ground-based equipment. They found that stump-to-truck pulp chip costs were increased over 70% when using the yarder. They also reported that, for the ground-based equipment, the chain flail represented the limiting function in the harvest system and could be adequately supplied using a single feller buncher and skidder. The flail had been modified to accomodate smaller stems.

In a study of the potential for agroforestry operations in the interior of California, Hartsough (1990) examined potential markets and costs associated with harvest and transport of SIRC-*grown Eucalyptus* spp. Large- and small-scale pulp and fuel producing operations, as well as production of firewood for urban markets, were examined for economic viability. They reported the firewood operations, although having higher costs, had a significant advantage in value of product produced and returned the highest annual yield on investment. Of the other operations, chipping for fuel or pulp yielded the greatest returns, with whole tree systems bringing the lowest. Mechanized systems (feller- bunchers / skidders) also tended to have a higher return than manual.

Currently, the majority of SRIC plantations in the U.S. are being used as a source for chips. Other product forms, however, have been investigated. Besides firewood, SRIC biomass has also been converted into fuel in the form of bales after crushing, a form Curtin and Bamett (1986) suggest could offer the best opportunity for making SRIC wood crops economically competetive. Another proposal has been made to retrofit a currently-inactive coal-fired generating facility in Tennessee to use whole trees as a fuel source (Energy Performance Systems, 1992). Myers and Crist (1986) pointed out that the cell structure of SRIC-grown trees makes them suitable for composite wood products as well.

Table 1 summarizes whole-tree felling productivity data covering the last decade of research in the U.S. Several combinations of equipment type, species, and stem size are represented. Unreferenced data arc from studies by the U.S. Forest Service Engineering Research Unit, Auburn, AL. The Hydro-Ax 411, in both cases, and the Morbark Mark V were fitted with 16" shear heads. Roth the Barko and the John Deere were equipped with 18" shears. The Barko was a drive-to-tree type feller-buncher, the John Deere a swing-type.

The results show that average dbh is the most critical factor in predicting productivity of conventional felling systems in SRIC stands. For stem sires in the 4 cm dbh range, productivity of conventional feller-bunchers was about 2 times higher than manual felling, but still less than half that for 7 cm dbh trees at a 10% higher stand density. For larger trees (7.6 cm dbh), feller-buncher (Morbark Mark V) productivity was comparable to mechanically-assisted manual felliig, although more recent studies under the same conditions with a larger machine (Hydro-Ax 411) indicated significantly higher production rates. Increasing tree size by a factor of 2.6, to 19.8 cm dbh, resulted in a further 2- to 4-fold increase in productivity.

Other factors combined to affect felling productivity of conventional systems. If dbh were the single factor involved, one would expect productivity to increase with the square of stem size. From the table, this does not seem to be the case. The increase in dbh from 7.6 cm to 19.8 cm, for example, would mean a 6-fold change in productivity instead of the 4-fold increase observed. It seems the operator was able to compensate somewhat for the smaller trees by accumulating more trees per cycle, and the slightly higher planting density afforded some advantages in reducing travel and position times. The advantages, however, would likely disappear at very high planting densities.

The conventional felling systems represented in the table were tested at stand densities typical of current SRIC practice in the U.S. It is not clear how well conventional systems would respond if used in stands with planting densities in excess of 10,000 trees/ha. Woodfin et al. (1988) showed plots of productivity for feller-bunchers that chopped exponentially with increasing stand density. The specialized harvesters, on the other hand, did not seem as sensitive to the number of trees per hectare. In stands of comparable tree size, the VPI/DOE machine had nearly the same productivity as a feller-buncher (Hydro Ax 411) operating at one tenth the stand density. This seems intuitively reasonable in that the SRIC-specific harvesters were designed to operate continuously and are limited by forward progress speed rather than the rate at which a sequence of tasks can be performed. This suggests that SRIC-specific harvesters would maintain a relatively high rate of productivity in a coppiced stand, which is indeed the observed result for the VPI/DOE machine. No data were available for the effect of coppiced vegetation on conventional equipment, but it would likely cause significant reductions in productivity.

There appears to be no consensus regarding the future direction of SRIC harvest machinery research. With the trend in the U.S. towards production of fiber rather than fuelwood, piece sizes of SRIC-grown trees will likely remain somewhat larger at harvest than is optimal for biomass production, making conventional harvesting equipment sufficient for the short term. The long-term viability of SRIC energy plantations, however, could require the development of specialized systems with clear advantages for the conditions encountered. Machines will have to be adaptable to the wide variety of rotation lengths and stand densities found in multi-product SRIC plantations. Harvest systems will also have to do minimal damage to stumps and roots, perhaps the most important limitation of conventional harvest systems which are geared toward large, single-purpose machines. The effect of heavy trafficking by these machines on regeneration is not known, but the potential for residual stand damage seems high. Specialized SRIC harvesters, on the other hand, could be used to optimize the total harvest system, perhaps centered around a single, multi-purpose machine that would require only a single pass through the stand, delivering a transportable product to the roadside.

USA SRIC : Plantation Operations Update

Currently there are few SRIC activities in the U.S. All operational ventures are primarily for fiber with some secondary energy products. Most intensively-managed plantations for energy production were experiments conducted in the 1970's and early 1980's. They were established to determine appropriate species and expected yields. In the late 1980's, and into the 1990's, industrial establishment of SRIC plantations increased to provide hardwood fiber resources. The energy recovery from these stands is not known.

James River Corporation (Western Operations) has established about 3,400 hectares of SRIC hybrid cottonwood plantations along the Columbia River in Washington and Oregon. Expected annual harvest will be 400 hectares. Each rotation is from cuttings. The sites are prepared and subsequently cultivated 2-3 times during rotation. Plans are for year-round logging since the mill has only a three day supply of chips on hand. Conventional feller-bunchers (Bell) and rubber-tired skidders (109 cm tire) are used for harvesting. In the winter wet season, November to May, a flexi-track FMC will be used for extraction. The wood is flailed at the deck and chipped. About 6-9 btd of clean chip residues are generated per acre in conjunction with the 29-34 btd of clean chips produced. Currently, the residue (hogfuel) is not being recovered. Plans are to use it for cogeneration beginning in 1995.

The Eastern Operations of James River Corporation have a commercial cottonwood operation in the Mississippi Delta. The plantations are grown for fiber. The rotation age is 8-10 years and at harvest is 20-24 cm in dbh and 25-30 m in height. Growth rate is about 6 tonnes/acre/year with approximately 60 green tonnes removed at harvest. They are planting and harvesting about 1,000 hectares annually. All rotations come from cuttings. Sites are well prepared and cuttings are on 4X4 m spacing. Over the rotation, there is intensive cultivation: 6 the first year and 2 the second year. Conventional feller-buncher and skidder systems are used to harvest the stands as tree-length material.

Scott Paper Company has sycamore plantations in South Alabama that provide hardwood fiber. Original plans were to harvest 400 hectares annually. Current harvest levels seem to be around

90 hectares per year. Conventional harvesting equipment will be used. A chipper will convert the whole trees to chips. The WTC (whole tree chips) are used after screening to make pulp.

Poise Cascade in the Columbia River Basin in Washington has planted 1,740 hectares of cottonwood with a plan to eventually harvest 1,200 hectares annually. The main product will be fiber.

Simpson Paper Company is planting Eucalyptus for fiber and energy. They have not reached the harvesting stage of their plantations.

A fuelwood pilot study is beiig conducted in Nebraska. The concept is to use SRIC plantations to supply a wood-heating burner for a large conference center at the Arbor Day Foundations. Poplars, silver maple, and green ash are being planted at the rate of 8.1 hectares annually. They will cut on a 7-year rotation, hopefully by farmers as an extra crop. The SRIC plantations will only furnish approximately 12 percent of wood for the boiler; the remaining will be wood waste.

Table 1. Productivity summary of machine and manual felling in short rotation, intensive culture (SRIC) plantations.

Type of Machine.	Species	Average DBH (cm)	Spacing (m) (Trees/ha)	Rotation	Productivity[1] (Dry mt/PMH)
Hyd-Mech FB-7[2/3]	Sycamore	6.3	1.5 x 3 (1824)	1	8.7
Hydro-Ax 41 1[2]	"	4.3	"	1	2.2
Hydro-Ax 411	"	7.6	1.8 x 2.7 (2017)	1	13.0
Morbark Mark V[2]	Sycamore	7.6	"	1	5.3
Chainsaw w/felling frame[2]	"	7.6	"	1	5.1
Chainsaw2	"	4.3	"		1.3
VPI/DOE Harvester[4]	Poplar	8.0	**0.5 x 0.9** (21,607)		10.9
John Deere 493D	Cottonwood	19.8	**3.9 x 3.9** (670)		26.2
Barko 775	"	19.8	"		45.4
UH Harvesters	Eucalyptus	7.0	1 x 1 (10,116)		9.0
USFS Harvester[4]	Poplar	11.4	2.4 x 2.4 (1700)	1	5.86

[1]Productivity converted from green tonnes to dry tonnes assuming 50 % moisture content.
2Woodfin et al., 1987.
[3]Stokes et al., 1986.
[4]Stuart et al., 1983.
[5]Paquin et al., 1989.
[6]Christopherson et **al., 1989. Assumed** 15 trees/cycle, & 50% moisture content. Used an average green tree weight of 49 lbs/whole tree from USFS GTR WO-42. Tables of Whole-Tree Weight for Selected U.S. Tree Species. p.6.

Table 2. Commercial Status of Short-Rotation Woody Crops in the U.S.[1,2]

INSTITUTION	STATE/REGION	PLANTING YEARS	ACRES PLANTED	ACRES PLANNED
Westvaco Corporation	southeast	1975-92	5,700	>5,700
James River Corporation	Mississippi	197692	7,300	8,100
C. Brewer Subsidiaries	Hawaii	1976-92	290	?3,200 [3]
Union Camp Corporation	southeast	1980-92	400+ [4]	>400
Reynolds Metal Company	New York	198 l-88	120	120
James River Corporation	Oregon	1982-92	3,400	>3,400
William Heckrodt	Wisconsin	1986-92	8	>8
Edenton (municipality)	North Carolina	1987-88	150	150
DOE/USDA scale-up	Minnesota	1887-88	80	80
Amana Corporation	Iowa	1987-9 1	20	20
Federal Paper Board	North Carolina	1987-88	120	> 120
Woodland (municipality)	North Carolina	1988-89	20	20
Conservation Reserve Land	Minnesota	1988-92	400	>600
Conservation Reserve Land	Michigan	1988-92	120	?>120 [5]
Simpson Timber	California	1988-92	2,000	4,000
Scott Paper Corporation	Alabama	1988-92	490	> 810
MacMillan Bloedel	Washington	1988-92	160	>160
Scott Paper Corporation	Washington	1991-9 1	40	>40
Boise Cascade	Washington	1991-92	1,700	8,000
			22,518	35,048

[1]Information courtesy of L. Wright, DOE, Oak Ridge National I&oratory, Oak Ridge, TN.

[2]Short-rotation woody crops are defined as intensively managed hardwoods with an expected rotation age of 10 years or less.

[3]Sugar industry land becoming available in 1993, discussions of planting to woody crops is being considered.

[4]Union Camp Corporation has 7,300 hectares of plantation hardwoods that will be harvested between ages 10 and 20.

[5]Location of acreage and future plans are unknown, number is based on hybrid poplar planting stock sold by a Michigan nursery.

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