

ECONOMIC POTENTIAL OF SHORT-ROTATION WOODY CROPS ON AGRICULTURAL LAND FOR PULP FIBER PRODUCTION IN THE UNITED STATES

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ABSTRACT

A model of the U.S. forestry and agricultural sectors is used to simulate the consequences of growing short-rotation woody crops on agricultural lands as a fiber source for pulp and paper production. Hybrid poplar, a short-rotation woody crop, annually produces 4 to 7 dry tons per acre of hardwood pulpwood over a 6- to 10-year rotation. When harvested, the material competes with pulpwood from traditional forests. The model-estimated optimal acreage varies from 1.5 to 2.8 million acres, less than 1 percent of cultivated U.S. cropland and less than 1 percent of U.S. existing timberland. That acreage generates about 10 to 16 million dry tons per year, depending on decade, and represents about 40 percent of current U.S. hardwood pulpwood output. The short-rotation woody crop production causes reallocation of existing forest lands across forest species types and ownerships. This level of short-rotation woody crop production reduces the timber management intensity of U.S. forests and promotes migration of some existing timberland into agricultural production.

A fundamental long-term resource issue confronting the pulp and paper industry is availability of raw material. The primary raw material, wood fiber, will come increasingly from plantations and recycling (8); however, fiber farming on agricultural lands using fast-growing, high-yield short-rotation woody crops (SRWCs) has been proposed as an im-

portant opportunity for both the forest and agriculture sectors (10). This paper reports on a national-level analysis¹ of the potential of SRWCs to become an economical source of pulp fiber supply. This study provides insights regarding options for sustainability in both sectors and information on possible changes in rural economic activities.

Industry- and government-supported research cooperatives have been formed to develop techniques for producing widely applicable, genetically superior SRWCs, principally in the form of hybrid poplars (19). Such SRWCs can be used to supply fiber for pulp and paper production, although energy is a co-product in most situations. Further, the

¹ This analysis is part of the ongoing 2000 Timber Assessment by the USDA Forest Serv., as directed by the Forest and Rangeland Renewable Resources Planning Act and amended by the National Forest Management Act of 1976, which analyzes the national timber resource situation to identify prospective changes in the forestland base and assess the cost and availability of timber products to meet the nation's demands (e.g., 17).

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Forest Prod. J. 50(5):67-74.

U.S. Department of Energy and American Forest and Paper Association's joint 2020 technology vision for America's forest, wood, and paper industries suggests that SRWCs will see increasing use in building products and power production (7). One remaining question is the availability and opportunity costs of agriculture land on which such SRWC plantings could be established in view of projected economic and population growth that will increase demand for land.

The timeliness of examining appropriate fiber sources for pulp and paper production is indicated by preliminary projections from the 2000 Timber Assessment (10). Historically, paper and paperboard consumption in the United States has increased from 327 pounds per capita in 1949 to 743 pounds per capita in 1997 (6). With anticipated economic and population growth, an 80 percent increase in paper and paperboard production is projected between 1997 and 2050 (10). To meet these growing demands, the Assessment projects increasing softwood pulpwood harvest, declining softwood residue supplies, and increasing harvest of hardwood pulpwood. In the near term, to around the year 2010, hardwood pulpwood harvest is projected to increase on private timberlands, but then gradually decrease as hardwood supplies become tighter. A substantial increase is also projected in the tonnage of paper recycled. Prices of hardwood pulpwood are projected to increase as hardwood pulpwood supplies from forests become more strained, eventually contributing to expansion in hardwood SRWC supply.

This study has two major objectives:

1. Estimate the potential supply of agricultural wood fiber to the U.S. pulp and paper sector from production of hardwood SRWCs on cropland during the next 50 years;

2. Estimate the potential market impacts during the next half-century of adoption of the SRWCs on the U.S. agricultural and forest products sectors.

BACKGROUND

We have witnessed unprecedented levels of industrial wood use in the United States during the last half century. Wood fiber use has increased substantially, mainly because of increased use by pulp and paper manufacturers (10). Despite gains in recycled fiber use,

it is expected that virgin wood fiber demand will increase in the decades ahead. Increasing fiber demand and changes in the product mix are leading to intensified management of existing forests, particularly on industrial lands, and conversion of some natural forests to plantations. More than 25 million acres in the South have been converted to plantations in recent decades (4), and timber stands are expected to exhibit younger stand-age structures with more frequent harvesting (8).

On the agriculture side, farmers have seen important changes. The 1996 Farm Bill introduced a decoupling of farm income support from production decisions, allowing farmers to change their crop mixes more easily in response to market forces. U.S. agricultural income has become increasingly dependent on exports, and changes in international agreements are creating new trade opportunities but also have opened the door to new foreign competitors (16). Some agricultural prices continue to fall in real terms and farmers continue to look for new markets.

The potential for SRWCs to become a significant new agricultural enterprise is the result of the convergence of the trends just mentioned. Forest sector fiber prices are likely to rise, creating a demand for new fiber sources. Agricultural sector trends create the opportunity for profitable crops to move into production. At the same time, improvements in SRWC yield and production costs are making SRWC production more viable (19). Estimated total area of SRWC plantings for fiber plantings to date is less than 200,000 acres, with a considerable amount in the Pacific Northwest region. However, the potential area suitable for hybrid poplar production is thought to be much larger (19), with SRWC production particularly well-suited for some marginally productive croplands.

METHODS

Forest sector models used to make projections in regional and national studies, such as the periodic Timber Assessments and Updates (e.g., 8), by the USDA Forest Service, have not included SRWC options. We drew upon elements of the earlier network of models (e.g., 1, 9, 13) to build a model with endogenous land-use changes and investment decisions to use in analyzing SRWC op-

tions. We did this using a linked model of the U.S. forest and agriculture sectors: the Forest and Agricultural Sector Optimization Model (FASOM). The FASOM model accounts for opportunity costs of alternative land uses, which can vary across time and space (2,5). FASOM is an intertemporal, price endogenous, spatial equilibrium model in which market solutions for the forest and agriculture sectors are obtained jointly for each decade in the projection period. Other sector models that can provide national-level pulp projections (e.g., 15) have not included full land base interaction between the forest and agricultural sectors. A primary objective of the subject study is to assess the economic potential for converting agricultural land to wood pulp production.

The FASOM model employs a joint objective function, maximizing the present value of producers' and consumers' surpluses in the markets of the two sectors, with restrictions on disposition of the land base that is suitable for use in either sector. The optimizing spatial equilibrium market model simulates prices, production, consumption, and management actions in the two sectors. Simulations proceed on a decade time step, with a nine-decade time horizon to accommodate treatment of terminal inventories. We limit policy analysis to results for the first five projection decades. All prices and costs are deflated (in 1990 dollars) and the real discount rate is 4 percent.

FASOM MODELING OF SRWCs

Simulation of SRWC production on agricultural land using FASOM requires the introduction of SRWC production possibilities. Costs and yields for SRWC activities on cropland differ by region. In this application of the FASOM model, we introduced SRWC production possibilities in five regions: Southeast, South Central, Corn Belt, Lake States, and the Pacific Northwest (refer to citation (2) for definitions of regions).

The FASOM model selects land uses on private forest and agricultural land that have the largest expected present value of economic returns, where activities on a land unit (e.g., agricultural crop or forest rotation) can vary over time. The model will reallocate land in view of changing supply and demand conditions in both sectors. Producers are assumed to have full knowledge of current

and future market conditions and access to perfect capital markets. The model endogenously projects the land allocation (e.g., acreage allocation to SRWC fiber farming) and regional supply and demand equilibrium of forest and agricultural products. The equilibrium reflects projected wood fiber crop production and prices by region, along with projected production of traditional forest products.

On the agriculture side, commodity coverage in the FASOM model includes 40 primary commodities and 46 secondary commodities (2,12). Cropland, pasture land, animal-unit-month grazing, and irrigation water availability are modeled, including the allocation of cropland to SRWC for fiber farming.

As a datum for comparison when SRWCs are introduced, we made projections under a BASE scenario. Timber demand and production cost relations were derived from the 1993 Timber Assessment Update's BASE projection (8).

DATA ON SRWC PRODUCTION

SRWCs in this study consist of hybrid poplar plantations. Yield, rotation length, and cost estimates for SRWC hybrid poplar plantings (Tables 1, 2, and 3) are based on data from the U.S. Department of Energy Oak Ridge National Laboratory (18). To provide conservative estimates, SRWCs on irrigated land and pastureland are not considered. Costs for any subsequent replanting of hybrid poplar plantings include necessary site preparation.

Areas of cropland in each region suitable for hybrid poplar planting (Table 3) were obtained from Walsh et al. (18). The U.S. land base in the FASOM model includes private timberland, cropland, and pastureland. The 167 million acres of cropland biophysically suitable for planting to hybrid poplars is a majority of the U.S. total cropland. More than 70 percent of the suitable acres are in the North Central region (consisting of the Lake States and Corn Belt) (Table 1); however, opportunity costs for agricultural cropping options are also relatively high in this region, especially in the Corn Belt.

In addition to estimates of current hybrid poplar yields per acre (Table 1), yields increase over time because of assumed technological improvements. For example, current yields in the Lake States are approximately 4.8 dry tons

TABLE 1. — Average hybrid poplar pulpwood yields on dryland.^a

Region	Projection year			Rotation length
	2000	2005	2030	
	----- (dry tons/acre/yr.) -----			(yr.)
Pacific Northwest	5.015	5.525	6.885	6
Lake States	4.080	4.505	5.695	10
Corn Belt	4.250	4.675	5.865	10
Southeast	3.740	4.080	5.100	8
South Central	4.165	4.590	5.780	8

^a In the FASOM modeling of SRWCs, we assumed that 2000 yields were available in the first and second projection decades, 2005 yields available in the third decade, and 2020 yields were available in the fourth and fifth decades. In the alternative "optimistic yield" scenario, we assumed that 2020 yields were available for all five decades. We assume that one needs to remove the bark so that dark color material is not greatly introduced in wood fiber.

TABLE 2. — Harvest costs by yield.^a

Dry tons harvested	Harvest cost per acre	Harvest cost per dry ton
	----- (\$) -----	
20	539.81	26.99
30	699.07	23.03
40	885.16	22.13
50	990.75	19.81
60	1,096.34	18.27

^a Harvest cost data were provided by Marie Walsh, Oak Ridge (18).

per acre per year. Annual per-acre yields increase to 5.3 dry tons if planted in 2005 and 6.6 dry tons if planted in 2020, with production costs also rising. Corresponding estimates for cost of production were obtained from Walsh et al. (18), and hauling cost assumptions are based on McCarl et al's approach (11).

Ince's (10) preliminary analysis generally indicated that there could be some potential for SRWC demands, given marginal shifts in the outlook for pulpwood supply and demand in general. The application of the FASOM model in this study is our first attempt to evaluate in greater detail the fiber supply potential of SRWC on agricultural lands in the United States and related implications.

RESULTS

The future outlook for SRWC acreage by region and decade as projected by FASOM is displayed in Figure 1. Total U.S. plantation area rises from 2.1 million acres in the first decade to a peak of 2.8 million acres in the second decade, drops in the following decade to a low of 1.5 million acres, ultimately rising to 2.6 million acres by the fifth decade. At the peak of enrollment in the second decade, SRWC area is less than 1 percent of cultivated U.S. cropland area.

TABLE 3. — Cropland suitable for hybrid poplar plantings, by region.^a

	(1,000 acres)
Pacific Northwest	1,274
Lake States	33,910
Corn Belt	85,040
Southeast	14,022
South Central	36,816

^a Estimates of amounts of land potentially suitable for hybrid poplar plantings were provided by Marie Walsh, Oak Ridge (18). Pastureland was not included in this analysis, in line with the conservative perspective of potential opportunities. Only dryland opportunities are explicitly included in the model. Irrigated plantings occur in places such as in the Columbia River Basin east of the Cascade Mountains, and are important for local production of pulp fiber, but estimates are that total irrigated area is not likely to exceed 200,000 acres.

Pulp fiber production from SRWC acres is concentrated in the Pacific Northwest and the Lake States region. Throughout the projection, 1.3 million acres are enrolled each decade in the Pacific Northwest region, representing the suitable land limit. The Lake States contains most of the remaining SRWC area and projected decadal amounts fluctuate notably. The Lake States peak at 1.5 million acres is reached in the second

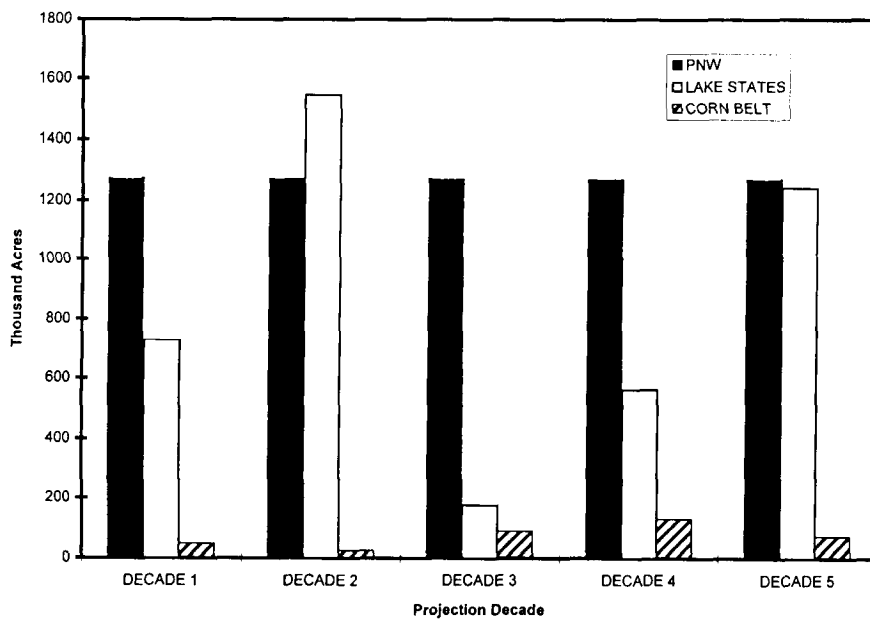


Figure 1.—Projected U.S. SRWC planted areas by projection decade and region.

TABLE 4.—Annual average projected pulpwood production from SRWCs, by region and decade.

Decade	Region			Total
	Lake States	Corn Belt	PNW	
	----- (million dry tons) -----			
1	3.0	0.2	6.4	9.6
2	6.9	0.1	7.0	14.0
3	1.0	0.5	8.8	10.3
4	3.2	0.8	8.8	12.8
5	7.1	0.4	8.8	16.3

decade, before dropping down to 0.2 million acres and then rising to 1.2 million acres in the fifth decade. SRWC production in the Corn Belt does not exceed 0.1 million acres, and is insignificant in the South throughout the first five decades.

The small amount of SRWC land in the Corn Belt is driven by the high values of agricultural land that represent opportunity costs relative to a landowner's decision to plant SRWCs. Opportunity costs associated with competing agricultural land uses (e.g., corn production) in the Lake States are sensitive to changes in agricultural supply and demand conditions over time. Although the South generally has lower agricultural land values than the North Central region, and therefore smaller land use opportunity costs, enrollment of SRWC acres in the South does not be-

come significant until after 2040. Most plantations are then concentrated in the South Central region. In contrast to the Lake States situation, projected large investments in southern softwood production and relative availability of smaller trees for pulp fiber on the larger southern timberland base act to reduce the financial attractiveness of hardwood SRWCs. In the South, this tends to offset the favorable regional differential in opportunity costs represented by competing land uses.

PULPWOOD SUPPLY VOLUMES FROM SRWCs

Growing hardwood SRWCs on agricultural land produces 9.6 million dry tons of pulpwood on average each year in the first decade (Table 4). This represents the equivalent of about 40 percent of 1997 U.S. roundwood receipts of hardwood pulpwood at woodpulp mills.

In the next decade, the total production grows to 14.0 million dry tons, then drops to 10.3 million dry tons before peaking at 16.3 million tons in the fifth decade. Projected levels of fiber supply from agricultural SRWCs would represent a substantial share of hardwood pulpwood supply in the future, according to this analysis.

The time pattern of SRWC pulpwood production, with the largest amounts in the second and fifth decades, corresponds to different supply and demand conditions in those two periods. The supply response in the second decade occurs within a setting of relatively tight softwood supplies, particularly for sawtimber. Reduced availability of sawtimber from public lands this decade in the West shifted some timber demand to the South, in particular. Increased timber harvests in the South have reduced the amount of private timber inventory at or above merchantable limits. Growing SRWCs allows U.S. softwood sawtimber harvest to increase by 4 percent in the first decade, in view of prospective increases in total timber supplies from SRWC. The FASOM model allows substitution (at a cost) or downgrading of sawtimber material for use in pulp production. Projected volumes of wood consumption are largest for the pulp and paper component of the forest sector, and softwood pulpwood production is projected to more than double after two decades.

IMPACTS ON PRODUCTION FROM EXISTING TIMBERLAND

The time patterns of SRWC production just described suggest that economic incentives to plant SRWCs are strongly influenced by the current status and prospective conditions on existing timberland. Fairly intensive production of SRWC pulpwood on former agricultural land acts to reduce some pressures on existing timberland, but also causes reallocations across species and ownerships. Growing SRWCs on agricultural land leads to 9 percent less softwood plantations on nonindustrial private forest (NIPF) lands in the next decade. The corresponding reduction on industry lands is 1 percent.

Although the area of softwood plantations established on previously softwood acres goes down in response to introduction of SRWCs as an option on NIPF lands, the conversion of hardwood

timberland acres to softwood plantations increases in the next decade on both private ownerships. The largest potential source of convertible hardwood stands is on NIPF timberlands, and the amount converted to softwood plantations in the next decade increases by approximately 2 million acres over the base case. The additional converted amount on industry timberlands is about 1 million hardwood acres. The increased availability of hardwood fiber from the SRWCs lowers the opportunity costs of retaining hardwood stands on existing timberland and increases the relative economic returns from converting to softwood plantations.

By the end of the fifth decade, there are 3 million fewer acres of private hardwood timberland in the SRWC scenario than in the base case. Most of the reduction is in the first several projection decades when softwood supplies are relatively tight. The reduction in hardwood area is tempered later in the projection period when hardwood supplies become relatively scarcer due to reduced total hardwood area. After 50 years, total NIPF timberland area, both softwood and hardwood types, is projected to be 3 percent or 7.5 million acres smaller with the SRWC option (Table 5). Establishing high-yielding SRWCs on former cropland for pulp fiber production could result in an overall net shift of timberland to agriculture, more than double the area of SRWCs present in the fifth projection decade.

TIMBER PRICES

Under the SRWC scenario, the index of hardwood pulpwood prices² is lower over the five projection decades compared to baseline projections without SRWC supply (Fig. 2). Relative to baseline projections, hardwood pulpwood prices are projected to drop by 2 percent in the first decade. Growing hardwood SRWCs on agricultural land would add wood fiber and the overall effect of expanding any portion of the timber supply is to reduce the average price of all products. Hardwood sawtimber prices fall by 1 percent in the first decade, while softwood prices drop by less than 1 percent. Price changes are associated

TABLE 5. — Differences between the baseline and SRWC projections for selected land base attributes. Positive number indicates that the baseline value is large.

Attribute	Projection decade				
	1	2	3	4	5
	----- (millions of acres) -----				
Traditional plantation area	0.1	0.6	1.9	2.3	4.6
NIPF timberland area	1.8	2.4	1.8	3.0	7.5
Traditional hardwood area	3.8	2.3	0.9	1.3	3.3

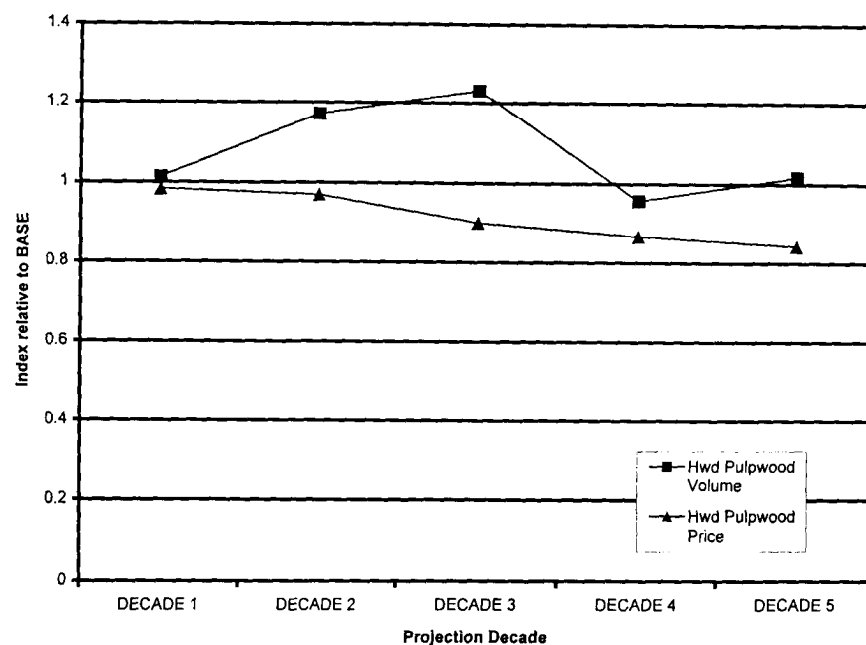


Figure 2. — Indices of SRWC hardwood pulpwood production and price relative to BASE (= 1.0) levels.

with temporal redistribution of harvest on existing timberland. Although overall consumption of timber products would rise by several percent in the first two decades, production from traditional forest lands falls by 1 to 2 percent.

ECONOMIC IMPACTS IN THE FORESTRY AND AGRICULTURAL SECTORS

SRWCs as a land use option increase the net present value of economic well-being of the agricultural and forest sectors by about \$6 billion. This is the change in the net present value of surpluses accruing to producers, consumers, and foreign interests in the market. The producers here are the private owners of forests and agricultural land in all U.S. regions who harvest timber for commercial products or sell agricultural products. Their economic welfare is measured by their profits in the sale of

timber or agricultural products beyond their costs of production. In the case of forestry, consumers comprise all users of harvested timber (for housing, manufacturing, shipping, paper, and board, etc.). Their welfare or benefit from the market transaction is measured as the difference between their expenditures if forced to pay the highest price they would be willing to pay to still consume the timber and their actual payments at the equilibrium market price. This difference represents a "savings" or "surplus" to consumers. Foreign interests are exporters (suppliers) of timber and agricultural products to, and importers (consumers) of timber and agricultural products from, the United States. Their welfare arising from this trade is measured in essentially the same way as for domestic producers and consumers.

² This is an index of the average price of logs, in this case hardwood pulpwood, delivered to mills across all regions in the U.S.

The projected total of economic surpluses in the agricultural sector drops by several billion dollars, but this is more than offset by the gain in the forestry sector. The largest gains would be for consumers of forest products, as timber product prices would drop. Owners of traditional forests would lose due to lower timber prices. Owners of agricultural land on which SRWCs are planted gain, but in aggregate all agricultural producers suffer a loss because of higher agricultural land prices and reduced production in the early decades. Agricultural consumers would also face a loss, but not as large as that for agricultural producers. Agricultural producers have projected net gains in later decades, but early losses outweigh those gains with respect to the net present value.

The distribution of SRWCs across regions leads to relatively small impacts on the national agricultural economy. In the first projection decade, agricultural grain prices increase by less than 1/2 percent, as less land is available for grain crops. The percentage reduction in grain production is similarly small in the first decade. Land use shifts between cropland, timberland, and pastureland are interconnected in the FASOM modeling, but impacts on the livestock sector are smaller than for grain crops. In the long run, the agriculture sector would have a net gain of land and grain and livestock prices fall, based on net conversion of timberland to agriculture in decades after 2020. Establishing high-yielding SRWCs for pulp fiber production ultimately makes more existing timberland economically attractive for conversion to agriculture, by lowering forestland values.

DISCUSSION

The potential contribution of SRWC volumes to hardwood supplies for the U.S. pulp and paper sector appears significant, representing about two-fifths of the volume of recent annual hardwood pulpwood receipts at woodpulp mills. Our results also generally indicate that hardwood SRWC contributions could be relatively large compared to the land area involved. The broad-scale application of the FASOM model in this study

is our first attempt to evaluate the economic supply potential for wood fiber from agricultural lands. Several key factors in our analysis influence the projected levels of SRWC plantings and merit close attention.

A crucial input is expected SRWC fiber crop yields per unit area.³ Clearly, yield improvements resulting from future research are quite uncertain. Currently, available hybrid poplar strains can reach heights of 50 to 60 feet and diameters of 5 to 6 inches in 7 to 10 years; however, several research cooperatives are actively researching genetic improvements in different strains that may boost yields considerably. In a sensitivity analysis, we used SRWC yields, estimated by Oak Ridge researchers (18) to be attainable by the year 2020, for each of the next five decades to test whether higher yields would cause a significant difference in land reallocation and SRWC wood fiber production.

Having higher yields immediately would increase the projected SRWC area in the first decade by 0.8 million acres or 40 percent compared to the original SRWC scenario. Production of SRWC hardwood pulpwood in the first decade would be 17.4 million dry tons under the higher-yield scenario, more than 80 percent larger than under original SRWC yields. SRWC area differences due to the higher yields fluctuate over the remaining decades, with a total net increase in SRWC area over the five decades of about 0.8 million acres. Increases in SRWC areas are mainly in the North Central region, with some minor expansion in the South Central region.

Potential impacts of altered forest management intensity and productivity on the economics of SRWC production could arise from a range of developments or policies, including increased forest plantation productivity, forest product "green certification," and sustainable forestry initiatives. Under an alternative forestry scenario, we examined the impacts of increasing planted pine yields by 15 percent for all future plantations in the South. Increased timber yields from traditional plantations are projected to alter the economic attractiveness of SRWC production across regions, related to changes in timber prices and revenues. This leads to inter-regional and intersectoral impacts. More SRWC plantings are undertaken in the

Lake States in the first three decades (sum of 0.4 million acres); however, that is offset by a similar decrease during the following two decades. Intersectoral impacts include increased countervailing conversion of timberland to agriculture in regions where lower timber prices result from increased supply from the increases in traditional plantation yields. Effects grow with time, as more pine plantations mature. By the end of the fifth decade about 1 million acres of timberland are converted to agriculture beyond that under the SRWC case.

Another key assumption involves the future rates of economic and population growth, which may impact land use changes and sustainability. The peak of SRWC production of hardwood pulpwood in the fifth decade is governed largely by reduced projected availability of naturally-regenerated hardwood forests, due to shifts in preceding decades. Some traditional hardwood area is converted to urban and developed uses due to increasing population, and many hardwood acres are projected to be converted to softwood plantations in the South over the next several decades (4) in line with prospective economic returns on these investments. After the second projection decade, a relatively large amount of pine plantations matures in the South and considerably boosts softwood timber supplies. At the same time, total area of hardwood forests is shrinking and few hardwood stands are managed intensively (e.g., hardwood plantations). By the fifth decade, tighter hardwood supplies from traditional forests lead to a peak in SRWC hardwood production. Total area of hardwood SRWC plantations is relatively small, however, less than 3 million acres, compared to more than 490 million acres of U.S. timberland.

Other factors that could influence the level of future SRWC plantings include the potential for using SRWC wood for non-pulp wood products, such as in engineered or panel products (7). Some leading forest products firms have already begun to install production capacity for laminated veneer and wood panel products that will be based on fast-growing poplar species. If such technology proves to be profitable, the social benefits of higher yields from SRWCs available in the first decade would be expanded. Although many acres are suitable for SRWC production, it remains

³ Our SRWC yield assumptions derive from a biomass energy generation analysis by McCarl et al. (11).

unclear if private owners would be willing to undertake such enterprises. Pulp prices have tended to be cyclical in the past, and delaying SRWC harvests by several years may be more financially risky than with traditional plantations. Also, most agricultural production involves annual crops. The production of tree crops requiring 5 or more years for maturation is a novel concept to most agricultural producers. Actual adoption rates for government-subsidized afforestation have been lower than normative engineering analyses would have suggested (e.g., 3, 14). Adoption of a new technology such as wood fiber farming presents challenges to both the forest and agriculture sectors. Expanding wood fiber farming would require production and research investments and may involve contractual arrangements with farmers that differ from those of the current industry.

CONCLUSIONS

The forest products industry is in the early years of a potentially significant increase in the use of hardwood fiber to replace softwood fiber in the manufacture of some categories of wood products. This transition is driven by a tighter domestic softwood supply situation, higher prices for softwoods since the 1980s and increases in wood fiber demand that are expected to last through at least the next several decades (10). Use of SRWCs to produce hardwood fiber on agricultural cropland is projected to be economically attractive to landowners of 2 to 3 million acres, spread across the Lake States and Pacific Northwest regions. Hardwood pulpwood production from the SRWCs could provide 10 to 15 million dry tons of pulpwood per year in the decades ahead, the annual equivalent of about two-fifths of 1997 U.S. roundwood receipts of hardwood pulpwood at woodpulp mills.

Growing wood fiber demand and tightening supply have contributed to higher and more volatile wood fiber prices; however, introduction of SRWCs could act to temper price rises and bolster reliable supply streams of fiber. Augmenting fiber supplies with SRWCs could lessen supply constraints arising from the age class structure of existing timberland. Expanded fiber farming could reduce management pressures on existing forest resources and enhance sustainability prospects in both the agri-

cultural and forestry sectors. The role of fiber farming in agriculture is projected to be modest when one looks at the total enrolled area as a percentage of U.S. cropland, approximately less than 1 percent in future decades. However, given the high SRWC yields per acre, expanded SRWC supply could: 1) reduce forest plantation area in the United States and lead to lower forestland values; and 2) allow more U.S. forestland to be converted into agricultural production to meet expanding world demands for food and fiber production.

This latter implication may be striking from the perspective of broad policies or approaches to conservation of forests. If forest productivity is enhanced relative to agricultural productivity, forestland values will be lower and more forestland area may be converted into agricultural land in the longer term. This is counter to some forest sustainability concepts, where conventional wisdom is that increased forest productivity could "free up" more timberland for natural forest production or more non-timber emphasis. These perspectives assume that substantial areas of marginal forestland will not be converted into higher value agricultural use. However, economic forces could result in conversion of some of the timberland to other uses in line with relative prices of factors of production across sectors. This is the reverse case of historical land market outcomes, where tens of millions of acres of forestland have been "saved" due to productivity increases on the agricultural side. Although the projected shift of forest area to agriculture in this study is relatively small, the implications warrant use of multi-sector analyses when examining sustainability options for forestry.

Future analyses should also consider the influence of non-timber amenities and conservation concerns in land allocation and management decisions. NIPF owners, in particular, are thought to base forest management decisions on non-timber values, such as aesthetics and wildlife, in addition to timber production, which can cause them to respond to economic forces in complex ways. For example, some private landowners may be more willing to establish riparian SRWC buffers, including enterprises integrated with agroforestry, if the owners can manage such SRWCs for economic products while providing conservation benefits.

Further research that examines more closely the short-term outlook for SRWCs over the next 10 to 20 years would be a useful addition to this study. A shorter time interval (perhaps annual) would be advantageous. Opportunities will exist to incorporate updated forest growth and inventory data after the ongoing 2000 RPA Timber Assessment. Analyses could also be broadened to cover SRWC opportunities on irrigated land and on pastureland. Geo-referencing of such lands would be useful, with consideration of factors such as distances to mills. Imports of pulpwood are projected to grow more rapidly than exports (10), and relative costs of domestic and off-shore sources of pulp fiber under different short-term scenarios should also be examined. The potential impacts of SRWCs appear to be potent relative to the land area involved.

LITERATURE CITED

1. Adams, D. and R. Haynes. 1996. The 1993 Timber Assessment Market Model: Structure, projections and policy simulations. Gen. Tech. Rept. PNW-GTR-368. USDA Forest Serv., Portland, Ore. 58 pp.
2. _____, R. Alig, B.A. McCarl, J. Callaway, and S. Winnett. 1996. The forest and agricultural sector optimization model: Model structure and applications. Res. Pap. PNW-RP-495. USDA Forest Serv., Portland, Ore.
3. Alig, R. 1986. Econometric analysis of the factors influencing forest acreage trends in the Southeast. *Forest Sci.* 32(1): 119-134.
4. _____ and D. Wear. 1992. U.S. Private Timberlands: 1952-2040. *J. of Forestry* 90(5):31-37.
5. _____, D. Adams, and B. McCarl. 1998. Impacts of incorporating land exchanges between forestry and agriculture in sector models. *J. of Agri. and Appl. Economics* 30(2):389-401.
6. American Forest and Paper Association. 1998. AF&PA statistics of paper, paperboard & wood pulp. AF&PA, Washington. D.C. 86pp.
7. Department of Energy and American Forest and Paper Association. 1994. Agenda 2000: A Technology Vision and Research Agenda for America's Forest, Wood, and Paper Industry. Booklet. AF&PA, Washington, D.C. 27 pp.
8. Haynes, R., D. Adams, and J. Mills. 1995. The 1993 RPA Timber Assessment Update. Gen. Tech. Rept. RM-259. USDA Forest Serv., Rocky Mountain Forest and Range Expt. Sta., Fort Collins, Colo.
9. Ince, P. 1994. Recycling and long-range timber outlook. Gen. Tech. Rept. RM-242. USDA Forest Service, Rocky Mountain Forest and Range Expt. Sta., Fort Collins, Colo.
10. _____ 1998. Long-range outlook for U.S. paper and paperboard demand, technology, and fiber supply-demand equilibria. In: *Proc. of the Society of American For-*

- esters 1998 National Convention, Traverse City, Mich. Society of American Foresters, Bethesda, Md. pp. 330-343.
11. McCarl, B., D. Adams, R. Alig, and J. Chmelik. 2000. Competitiveness of biomass-fueled electrical power plants. *Annals of Operations Res.* (in press).
 12. _____, CC. Chang, J.D. Atwood, and W.I. Nayda. 1994. Documentation of ASM: The U.S. agricultural sector model. Unpublished Pap. Dept. of Agri. Economics, Texas A&M Univ., College Station, Tex.
 13. Mills, J. and J. Kincaid. 1992. The Aggregate Timber Land Analysis System (ATLAS). GTR PNW-GTR-281. USDA Forest Serv., Pacific Northwest Res. Sta., Portland, Oreg.
 14. Plantinga, A. 1997. The cost of carbon sequestration in forests: A positive analysis. *Critical Reviews in Environmental Sci. and Technology* 27(November):S269-S278.
 15. Sedjo, R. and K. Lyon. 1990. The long-term adequacy of world timber supply. *Resources for the Future*, Washington, D.C.
 16. U.S. Department of Agriculture. 1996. U.S. agricultural production estimates and farm outlook. Economic Res. Serv. Misc. Rept. Washington, D.C.
 17. U.S. Department of Agriculture. 1989. RPA Assessment of the forest and rangeland situation in the United States. Forest Resource Rept. No. 26. USDA Forest Serv., Washington, D.C. 72 pp.
 18. Walsh, M., D. De La Torre Ugarte, S. Slinsky, R. Graham, H. Shapouri, and D. Ray. 1998. Economic analyses of energy crop production in the U.S.: Location, quantities, price, and impacts on traditional agricultural crops. In: *Bioenergy 98: Expanding Bioenergy Partnerships*. www.cglg.org/bioenergy98
 19. Wright, L. and S. Berg. 1996. Industry/government collaboration on short-rotation woody crops for energy, fiber, and wood products. In: *Bioenergy 96: The Seventh National Bioenergy Conf.* www.bioenergy.ornl.gov/pubs