Biofuel Production Impacts on the Management of Southern Pine Plantations in Mississippi*

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Abstract: This study evaluated and compared alternative forest management regimes of loblolly pine (*Pinus taeda*) plantations for producing both traditional timber commodities and biofuels. Land expectation values (LEV) and mean annual increments (MAI) of total biomass were applied as economic and biological criteria to determine the optimal management activities for different site indices and drainage classes in Mississippi. PTAEDA3.1 growth and yield model was used to predict the growth effects of different site preparations, initial planting density, fertilization, and thinning activity. Results indicated that on SI 50 to 60 lands, the average annual yields of stem residues were 0.76 to 1.14 tons per acre, or 30-45.1 gallons of ethanol. Wider planting spacings with a later thinning age and longer rotation length were financially optimal on lower quality lands. When maximizing MAI of total biomass, the intensive bedding combination became an optimal site treatment on poorly drained land. This site preparation practice, however, appeared unprofitable in terms of LEVs due to high operation costs. Results of sensitivity analysis indicated that the rise of relative biomass price to sawtimber will shorten the optimal thinning year and rotation age.

Keywords: Biofuels, biomass availability, forest biomass, Mississippi, optimal management strategy, southern pine plantations

Introduction

Recently, there has been an increased interest in biofuels and other forms of bioenergy by the general public in the United States because of a concern over energy prices, global climate changes, and energy security. Politically, it has the promising potential to revitalize rural America. Using forest biomass for biofuels not only reduces wildfire risk but also the pressure on agricultural land for biofuel production. Currently, the bio-technologies using woody biomass (i.e., fermentation, gasification, pyrolysis) have been in the development and demonstration stage. Specifically, pyrolysis technology uses small, modular, and transportable equipment that can be located near available feedstock sources. This can greatly lower

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transportation costs and generates a value-added product. The emerging use of woody biomass will create a desirable alternative market for small diameter wood on forest lands in the Southern U.S.

In Mississippi, approximately 20 million acres of forest land comprises 62% of the total land base and the forest products industry greatly contributes to state economy (Munn and Tilley 2005). Due to a declining demand for domestic wood pulp in global markets, forest management faces increasing challenges. Also, markets for thinning materials from young southern pine stands are limited because of the presence of high levels of juvenile wood. This condition may make first thinnings unprofitable, and consequently reduce the intensity by which timberlands are managed. Therefore, the utilization of forest biomass for biofuel production represents a real opportunity for forest management and rural economic development.

Various studies examining biomass supply for bio-production have been performed in the United States, and have looked at resource assessment, potential supply and cost, and land management (Young et al. 1991; Cook and Beyea 2000; McNeil Technologies 2003). Some research explored the supply of short-rotation woody biomass or energy crops regionally (Downing and Graham 1996; Rosenqvist and Dawson 2005). Other studies assessed the generation, availability, and costs of different categories of biomass regionally or nationally such as agricultural residue, wood product residue, urban wood wastes, logging residues, and other forest biomass for bio-production (Howard 1981; Walsh et al. 2000; Kerstetter and Lyons 2001; McNeil Technologies 2003). McNeil Technologies (2003) looked at three counties in eastern Oregon and indicated that there is a need to modify existing forest and agricultural practices to make biomass available for bio-production regionally. Recent studies have also examined increasing productivity of forestry management and compared eco-economic benefits among different land management alternatives for biomass (Cook and Beyea 2000; Bjornstad and Skonhoft 2002; Mead 2005). It was found that biomass derived from the forest was significantly less expensive than an energy crop and there were also institutional and infrastructural obstacles to large-scale energy crop production.

Based on the current wood market situation in Mississippi and the southern U.S., this study investigated the impact of biofuel production using small diameter wood on the management of loblolly pine *(Pinus Taeda)* plantations, which is widely distributed across Mississippi and the southern U.S., and the availability of forest biomass resulting from optimal management regimes on various sites within Mississippi. The specific study objectives were to: (1) evaluate and compare alternative forest management regimes and find economically and biologically optimal management strategies for forest landowners; (2) calculate available forest biomass for biofuel production resulting from economically optimal management regimes; and (3) explore how optimal forest management strategies and biomass availability are subject to changes in the relative price of biomass to sawtimber.

Methods

To explore the impact of this emerging wood use on forest management, this study focused only on stem wood, whereas the other biomass from branches, twigs, leaves, and roots were beyond the scope of this research. In achieving the stated objectives, PTAEDA3.1 was used to predict the yield data of the total stem and three wood classes: sawtimber, chip-n-saw, and pulpwood. The weight of stem residue[1] was then calculated by subtracting the weight of three wood commodities from total stem biomass. Using this yield information, land expectation value (LEV) and mean annual increment (MAI) of total stem biomass were calculated to evaluate and compare alternative management regimes. A sensitivity analysis was then conducted to show how optimal forest management strategies and biomass availability were subject to changes in the relative price of biomass to sawtimber.

Economic and Biological Evaluation

This study assumed that stumpage prices were stable and no inflation would occur. LEVs were calculated for each management scenario using a before-tax, real annual discount rate of 5%, which is similar to a forest landowner's real rate of return. Revenues from stem residues from thinning and harvesting were included in the Faustmann model for determining economic returns. The management regime which maximized the LEV was considered optimal for each specific site.

The optimal management regimes which culminate the MAI of total stem biomass for biofuel production was also determined for each site to allow for more options in the decision making process. MAIs were calculated by dividing the green weight of the total stem by rotation age. This biological model helped find the maximum sustainable annual output of total stem biomass for biofuel production on each site. LEVs of these optimal regimes were calculated using exclusively the biomass price (i.e., stem residue price), since whole stands were managed for biofuel production.

Available Biomass and Biofuel Production Estimation

Average annual yields of stem residues and pulpwood resulting from optimal management regimes were calculated by dividing those outputs from thinning and harvesting by rotation age. This information can serve as a basis for estimating annual biofuel production. This study estimated the annual ethanol production on a per acre basis. First, green tons of stem biomass were converted to dry weight according to the moisture content of loblolly pine sapwood (106 grams of water per 100 gram of dry wood) (FPL, 1999). That is, a green ton of stem biomass can be converted to 0.485 ton of dry wood. The theoretical ethanol conversion rate for feedstock from forest thinnings is 81.5 gallons per dry ton, which was then used to calculate the potential ethanol production per acre of loblolly pine plantation (DOE, 2006).

Management Scenarios

Site indices of 50 and 60 (base age 25) combined with two drainage classes (i.e., poor, well) represent the potential sites that exist across loblolly pine plantations in Mississippi. This site index range will help examine how site productivity influences economic returns, available biomass, and optimal management strategies. The site preparation practices for well-drained land considered in this study included a combination of chop and burn, herbaceous weed control,

[1] Stem residue in this study refers to small diameter trees with a DBH less than 6 inches and topwood from three wood commodities: sawtimber, chip-n-saw, and pulpwood.

and fertilization. For poorly drained land two more bedding combinations were included: bedding and fertilization; bedding, herbaceous weed control, and fertilization. The growth effects of these site treatment combinations were simulated with the growth and yield software PTAEDA3.1. Projection of regimes with no site preparation was also included for comparison.

A total of six initial planting densities were examined in this study to represent the range of possible plantings employed in the State: 436, 485, 545, 623, 727, and 872 trees per acre, (i.e., tree spacings of 10 × 10, 9 × 10, 8 × 10, 7 × 10, 6 × 10, and 5 × 10 ft). Rectangular spacings were considered because they allow for the use of mechanized equipment between rows and do not affect diameter and height growth of loblolly pine plantations, thus they are often preferable to square spacings (Sharma et al. 2002).

It was assumed that no thinning and one thinning, and the combination of low and row thinning were conducted for all management regimes. Thinning age was set between year 15 and 45 whereas all stands were low thinned to targeted residual basal areas of 70% and 80%. It was assumed that the time interval between thinning and final harvest could not be less than five years. A total of 49,524 scenarios were examined on poorly drained land and 24,762 on well drained land. All simulated scenarios were listed in Table 1.

Table 1. Hypothetical management scenarios in Mississippi for loblolly pine plantation growth and yield projections based on site index, drainage classes, site preparation methods, tree spacings, thinning frequencies, and rotation age.

Site Index[1]	Drainage Class	Site Preparation	Tree Spacing	Thinning Frequency/Year	Thinning Intensity	Rotation Age
50	Well	B[2]+F[2] (P)[4]	10 x 5	No	20%	20-50
60	Poor	B+H[2]+F (P)	10 x 6	1/15-45	30%	
		CB[2]+H+F (PW)[4]	10 x 7			
		None[3] (PW)	10 x 8			
			10 x 9			
			10 x 10			

[1] Base age 25.
[2] B, F, H, and CB indicate site preparations: bedding, fertilization, herbaceous weed control, and chop and burn, separately.
[3] ‘None’ indicates that there was no site preparation for the control projection.
[4] P in brackets indicates that the combination of site preparations are only conducted on poorly drained lands, whereas PW indicates that they occur on both poorly and well-drained lands.

Growth and Yield Data

The PTAEDA3.1 growth and yield model was used to predict the growth effects of different site preparations, initial planting density, thinning activities, competition, and mortality of loblolly pine plantations. Yield tables included green weight of the total stem (for all trees 1 inch DBH and greater) and the three mutually exclusive product classes of pulpwood, chip-n-saw and sawtimber.

All management scenarios were initiated at age zero and simulated in the Coastal Plain region as it encompasses the majority of the Mississippi land base. The PTAEDA3.1 default merchandising limits for three product classes were applied and included sawtimber (12+ inches DBH to a 8-inch diameter), chip-n-saw (8-11 inches DBH to a 6-inch diameter), and pulpwood (6-7 inches DBH to a 5-inch diameter). Small diameter trees with DBHs less than 6 inches and topwood from all the three product classes were considered as stem residue potential for biofuel production.

Price and Cost Data

The 2005 yearly average stumpage prices for Mississippi used were obtained from Timber Mart-South. According to Daniels (1999), many mills in Mississippi are paying \$1 to \$2 less per ton for 'juvenile pine pulpwood' specified as thinnings of age 17 years or less. Therefore we assume that \$1.50 per ton represented a typical deduction for small diameter wood such as stem residue. The average stumpage price of pine pulpwood in Mississippi in 2005 was \$8.35 per green ton; the price for stem residue available for biofuel production would be \$6.85 per green ton. The weighted average costs of forestry practices in the Coastal Plain were applied for the economic analyses (Smidt et al. 2005). Other site preparation costs were acquired by personal communication with relevant experts. Assumed forestry management practices and costs in the Mississippi Coastal Plain are presented in Table 2.

Table 2. Forestry management practices and costs for pine plantations in the Mississippi Coastal Plain.

Activity	Cost (\$/acre)	Frequency (Year)
Administration	5	Every year
Bedding	45	Once (Year 0)
Herbaceous weed control	76.68	Once (Year 0)
Fertilization	54.47	Once (Year 0)
Chop and burn	118	Once (Year 0)
Planting	0.099 \$/seedling	Once (Year 0)
Seedling	0.043 \$/seedling	Once (Year 0)

Sources: Silvicultural experts and Smidt et al. (2005)

Sensitivity Analysis on the Change of Relative Biomass Price

Biomass prices may fluctuate with the rapid development of bio-technology and other market powers. Sensitivity analyses are therefore needed to show how it will influence optimal landowner management strategies and availability of forest biomass for biofuel production. In this study, biomass prices expressed as percentages of sawtimber price were used to illustrate the change of relative biomass price to other wood products (Henderson 2004). According to the price reports from Timber Mart-South (from 1994-present), average prices for chip-n-saw and pulpwood were around 70% and 22% of sawtimber prices in Mississippi. Therefore it was assumed that when biomass price increases to 25% of sawtimber price, forest landowners will sell pulpwood for biofuel production. When biomass price increases to 70% or 100% of sawtimber prices, even chip-n-saw or sawtimber can be considered for biofuel production. When biomass price falls at or below 10% of sawtimber prices, only stem residues are available for biofuel production.

Results

Optimal Management Regimes Maximizing LEV

Land expectation values for all management scenarios were calculated. The combination of initial planting density, site preparation practice, thinning, and rotation age which resulted in the highest LEV was identified as financially optimal. The optimal management regime and its LEV at a 5% real discount rate for each combination of site index and drainage class were listed in Table 3. LEVs ranged from $579 to 797 from site index 50 to 60. The regimes with site preparation treatments were not cost effective in comparison to scenarios with no site preparation for all the sites. The optimal initial planting density varied in response to differences in site productivity. Wider spacings with longer thinning ages appeared optimal on lower productivity land, whereas closer spacings with earlier thinning ages appeared optimal on higher productivity sites. When site index increases, the optimal rotation length decreases. The optimal thinning intensity results showed no relevance to site quality; however, it does vary with the interaction of all factors which include site index, initial planting density, thinning age, and rotation length.

Table 3. Financially optimal management regimes of loblolly pine plantation in Mississippi and land expectation values (LEV) by site index and drainage class at 5% real discount rate.

Site Index[1]	Drainage Class	Optimal Regimes				LEV $/acre
		Site Preparation	Density (tree/acre)	Thinning (year)	Rotation Age (year)	
50	Poor	none	436	21 (20%)[2]	35	579
	Well	none	436	18 (30%)	34	581
60	Poor	none	545	16 (30%)	29	759
	Well	none	545	17 (20%)	28	797

[1] Base age 25.
[2] Percentage numbers in brackets are the percentage of basal area removed during low thinning.

Average annual yields of stem residues potentially available for biofuel production from financially optimal management regimes at a 5% discount rate for different site combination are presented on a per acre basis (Table 4). According to the current market condition for small diameter wood, it was possible to include pulpwood for biofuel production. Thus, the sum of annual yields of stem residues and pulpwood was also listed. Ethanol production per acre of loblolly pine plantations were calculated and presented in brackets. They ranged from 58.5 to 80.2 gal/ac/yr from site index 50 to 60. Results indicated that higher site quality yields more annual stem residue and pulpwood; therefore, more ethanol can be produced.

Table 4. Available average annual yields of biomass and ethanol production from financially optimal management regimes of loblolly pine plantation in Mississippi at a 5% real discount rate by site index and drainage class.

Site Index[1]	Drainage Class	Stem Res. (Ethanol) tons/ac/yr (gal/ac/yr)	Stem Res. and Pulpwood (Ethanol) tons/ac./yr (gal/ac/yr)
50	Poor	0.76 (30.0)	1.48 (58.5)
	Well	0.79 (31.2)	1.49 (58.9)
60	Poor	1.06 (41.9)	1.88 (73.9)
	Well	1.14 (45.1)	2.03 (80.2)

[1] Base age 25.

Comparison of Optimal Management Regimes with Different Objectives

Biologically optimal management regimes which culminate MAIs of total stem biomass were presented by site index and drainage class and compared with the economically optimal management activities (maximizing LEV at 5% discount rate) (Table 5). Results suggested that thinning activities combined with relatively longer rotation lengths were optimal on lower productive sites, whereas no thinning and shorter rotation lengths were optimal for high productive lands. Results also indicated that close initial planting spacings and intensive site preparations, the combination of bedding, were needed to maximize the MAI of total stem biomass on poorly drained lands. Treatments with no site treatment and relatively wider initial planting densities appear optimal on well-drained lands. The optimal management regimes culminating in sustainable annual outputs of total biomass were unprofitable on poorly drained lands. The difference in LEVs showed the trade-offs between these two optimal management strategies.

Table 5. Comparison of optimal management regimes maximizing land expectation value (LEV) at 5% discount rate with culminating MAI of total stem biomass by site index and drainage class.

Site		Max. LEV Regime	Biomass ton/ac/yr	LEV $/ac	Max. MAI Regime	Biomass ton/ac/yr	LEV $/ac
50	Poor	436[a]-21[b](20%)[c]-35[d]	0.76	579	BHF[2]872-20(20%)-31	4.29	-117
	Well	436-18(30%)-34	0.79	581	727-20(20%)-31	4.16	66
60	Poor	545-16(30%)-29	1.06	759	BHF872-none[3]-24	5.11	-87
	Well	545-17(20%)-28	1.14	797	545-none-27	5.11	133

[1] The superscript a, b, c and d indicate optimal initial planting density, thinning year, removal of basal area and rotation length, separately.
[2] 'BHF' indicates the site treatment combination of bedding, herbaceous weed control, and fertilization.
[3] 'none' indicates that no thinning is required for this optimal management regime.

Sensitivity Analysis on the Change of Relative Biomass Price

The sensitivity analysis results for site index 60, well-drained lands represented the general trend that appeared on various sites considered in this study. It indicated that when relative biomass price changed from 10 to 100% of the sawtimber price, the initial planting density increased from 545 to 727 trees per acre. The changing trends of rotation age, optimal thinning activities, and available biomass were presented in Figure 1. It showed that when relative biomass price increases, optimal thinning year and rotation age decreased; optimal thinning intensity appeared irrelevant to biomass price change, whereas the available mean annual stem biomass increased because pulpwood, chip-n-saw and even sawtimber can be included for biofuel production.

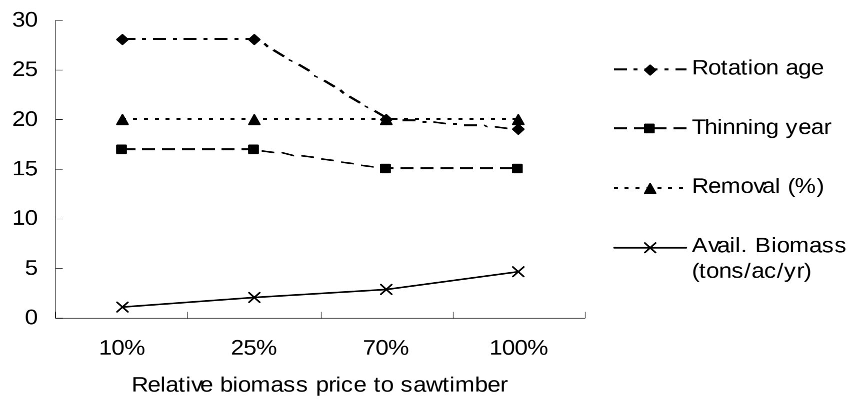

Figure 1. Comparison of optimal thinning activities, rotation age, and mean annual yield of forest biomass available for biofuel production from loblolly pine plantation on site index 60, well-drained lands when relative biomass price to sawtimber price changes.

Discussion

Both LEVs and sustainable annual yields of total biomass were maximized using proper management activities, such as site preparation, initial planting density, thinning age, and rotation length. Combinations of site preparation treatments considered were not cost effective in comparison to no site preparation for all sites, (i.e., cost inputs were greater than gains from growth). Possible reasons may be: 1) the stand growth predicted by the PTAEDA simulator was too conservative in terms of fertilization effects; 2) the economic evaluation is overly sensitive to higher costs of intensive site preparations.

Wider spacings with a later thinning age and longer rotation length were financially optimal on lower quality lands. The optimal thinning intensity showed an irrelevance to site quality only but varied with the interaction of all factors: site index, initial planting density, thinning age, and rotation length. When maximizing MAI of total biomass, the intensive bedding combination became an optimal site treatment on poorly drained land. This site preparation practice, however, appeared unprofitable in terms of LEVs due to high operation costs.

Site index has a substantial effect on LEV, available stem residue biomass, and the optimal management strategies whether to maximize LEV or culminate MAI of total biomass. When site index increases, the average annual stem residue biomass available for biofuel production increases. The other effects in terms of LEVs, financially optimal thinning age, and rotation length were consistent with results of previous studies. Results of this sensitivity analysis indicated that the rise of relative biomass price to sawtimber will shorten the optimal thinning year and rotation age, which was also reasonable because management strategies will gradually evolve to maximize total biomass.

Conclusions

The emerging use of wood has the potential to provide new opportunities and markets for forest landowners in Mississippi and the Southern U.S. This study showed that on SI 50 to 60 lands, the average annual yields of stem residues were 0.76 to 1.14 tons per acre, or 30-45.1 gallons of ethanol. Culminating sustainable annual outputs of total stem biomass were unprofitable on poorly drained lands due to high site preparation costs at currently low biomass prices. This study extended previous research by examining the influence of various site preparation techniques on optimal management strategies. Examining changes in relative biomass prices to sawtimber prices was useful in evaluating the availability of biomass for bio-production. The results can be beneficial to both the bio-production industry and private forest landowners in the southern United States, especially in Mississippi. Future research should include additional site preparation practices for economic evaluations and comparisons.

Literature Cited

Bjornstad, E. and A. Skonhoft. 2002. Wood fuel or carbon sink? Aspects of forestry in the climate question. *Environmental and Resource Economics* 23(2): 447-465.

Cook, J. and J. Beyea. 2000. Bioenergy in the United States: progress and possibilities. *Biomass and Bioenergy* 18(6): 441-455.

Daniels, R.A. 1999. Mississippi timber price report - March/April 1999. Mississippi State University Extension Service, Mississippi Agricultural and Forestry Experiment Station. 4 p.

Downing, M. and R.L. Graham. 1996. The potential supply and cost of biomass from energy crops in the Tennessee Valley Authority region. *Biomass and Bioenergy* 11(4): 283-303.

Forest Products Laboratory. 1999. Wood Handbook – Wood as an engineering material. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, USA. Gen. Tech. Rep. FPL-GTR-113, Madison, WI, 463 p.

Henderson, J.E. 2004. The impact of relative product prices on the optimal management regime for loblolly pine plantations. M.Sc. thesis, Mississippi State University. Mississippi State. 194 p.

Howard, J.O. 1981. Ratios for estimating logging residue in the Pacific Northwest. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, USDA Forest Service. 26 p.

Kerstetter, J.D. and J.K. Lyons. 2001. Logging and agricultural residue supply curves for the Pacific Northwest. Washington State University Energy Program. 45 p.

McNeil Technologies, Inc. 2003. Biomass resource assessment and utilization options for three counties in Eastern Oregon. Lakewood, Colorado. 177 p.

Mead, D. J. 2005. Opportunities for improving plantation productivity. How much? How quickly? How realistic? *Biomass and Bioenergy* 28(4): 249-266.

Munn, I.A. and B.K. Tilley. 2005. Forestry in Mississippi - The impact of the forest products industry on the Mississippi economy: An input-output analysis. Mississippi State University: 27 p.

Rosenqvist, H. and M. Dawson. 2005. Economics of willow growing in Northern Ireland. *Biomass and Bioenergy* 28(1): 7-14.

Smidt, M., M.R. Dubois and B.d.S. Folegatti. 2005. Costs and cost trends for forestry practices in the South. *Forest Landowner* 64(2): 25-31.

U.S. Department of Energy. 2006. Energy efficiency and renewable energy biomass program. http://www1.eere.energy.gov/biomass/printable_versions/ethanol_yield_calculator.html

Walsh, M.E., R.L. Perlack, A. Turhollow, D.d.l.T. Ugarte, D.A. Becker, R.L. Graham, S.E. Slinsky and D.E. Ray. 2000. Biomass feedstock availability in the United States: 1999 state level analysis. Biomass Feedstock Information Network. Available from http://bioenergy.ornl.gov/resourcedata/index.html.

Young, T.M., D.M. Ostermeier, J.D. Thomas and R.T. Brooks. 1991. The economic availability of woody biomass for the southeastern United States. *Bioresource Technology* 37(1): 7-15.