Forest Policy and Economics 38 (2014) 126–131

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

Assessing the economic feasibility of short rotation loblolly biomass plantations

Rapeepan Kantavichai *, Tom V. Gallagher, Larry D. Teeter

School of Forestry and Wildlife Sciences, Auburn University, USA

A R T I C L E   I N F O

Article history:
Received 8 November 2012
Received in revised form 30 April 2013
Accepted 1 May 2013
Available online 6 June 2013

Keywords:
Loblolly
Short rotation
Biomass
Bioenergy
Cellulosic biofuel
Forest management

A B S T R A C T

Recently, interest in short rotation loblolly plantations as a feedstock for cellulosic biofuel production has been growing. This study explored the potential of these plantations as an economically feasible alternative by validating a simulation growth model with two young loblolly plantations located in Coastal Plain Alabama and analyzing the breakeven price of a biomass plantation by comparing it to the expected value from a traditional timber management prescription on two typical AL sites in Piedmont and Coastal Plain. With three real discount rates; 5%, 7% and 9%, we found that landowners would find short rotation biomass plantations attractive when the stumpage price is approximately \$10.50 ton^{-1} on a Piedmont site with a 14-year rotation and approximately \$13.50 ton^{-1} on a Coastal Plain site with a 9-year rotation. Sensitivity analysis of the breakeven price suggests that biomass breakeven price would increase 15% on the Piedmont site and 22% on the Coastal Plain site when sawtimber prices increase by 50%.

Published by Elsevier B.V.

1. Introduction

America's high level of dependence on foreign oil and the increasing threats of adverse environmental impacts from fossil fuel use have led to calls for a switch to alternative forms of energy. The Energy Independence and Security Act of 2007 has mandated that the supply of transportation fuel sold in the US must contain at least 36 billion gal of renewable fuels annually by 2022 (Public Law 110–140, Dec 19, 2007). As part of this shift in government priorities, significant emphasis has been placed on development of cellulosic biofuels, and numerous research projects are being supported to develop our nation's capacity to produce large quantities of these fuels. As part of the overall effort to develop this capacity, insuring that adequate feedstocks are available to support a bioenergy industry has become a key area of research underpinning the projections of such a large quantity of biofuels being produced in the future. Most studies do not believe that residues resulting from forest harvesting operations will be sufficient to support an industry of the scale envisioned (i.e., Perlack et al., 2005). Energy plantations, including short rotation pine plantations, are being suggested as a possible efficient solution to meeting the feedstock supply challenge.

Numerous previous studies have examined the feasibility of energy plantations. There are feasibility findings for short rotation crops of many hardwood tree species and a few conifer species in temperate regions of the world (Dickmann, 2006). Loblolly pine (*Pinus taeda* L.) is among the few that has strong economic potential based on its rapid growth and established genetic improvement. Although studies have raised cautions regarding the frequent whole tree harvesting(WTH) of energy plantations and the potential for soil nutrient depletion and compaction (Lockaby and Vidrine, 1984; Kimmins, 1977), evidence at this stage on loblolly pine in the SE region varies widely depending on the site conditions examined. Long term loss in soil carbon has not been found (Johnson et al., 2002; Butnor et al., 2006), neither has soil nitrogen (Piatek and Allen, 2000). However, reduction in the microbial activity and water holding capacity in the forest floor from WTH organic removal has shown the effects to young stand volume on low quality sites (Scott et al., 2004). On the contrary, Carter et al. (2006) found volume reduction on the most fertile sites following WTH and suggested that it was a result of increased weed competition and not soil compaction or nutrient loss. Scott and Dean (2006) suggested that the productivity loss was compensable by appropriate site preparation treatment. These studies demonstrated that short rotation forest operations might be practiced sustainably.

Recent research has shown that advances in loblolly pine breeding and selection programs have substantially improved the species' productivity potential for consideration as a bioenergy feedstock (Johnson et al., 2007; Talbert et al., 1985; Kaya et al., 1999). Using intensive silvicultural practices, loblolly pines can now produce up to 8 green tons $\cdot$ ac^{-1} $\cdot$ yr^{-1} (Stanturf et al., 2003; Fox et al., 2007). The largest yield improvement comes from site preparation activities including bedding, herbaceous weed control (HWC), and fertilization. Bedding in lowland clay soils with impeded drainage generally leads to short term productivity gains that can increase site index approximately 3 to 10 ft, depending on site conditions (Allen et al., 1990). Chemical site preparation is often used to kill the root systems of competing woody vegetation thereby providing increased water and nutrient availability leading to enhanced plantation growth without the topsoil

* Corresponding author. Tel.: +1 334 844 4000; fax: +1 334 844 1084.
E-mail addresses: rzk0022@auburn.edu, kantavichai@gmail.com (R. Kantavichai).

1389-9341/\$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.forpol.2013.05.003

damaging effects of mechanical site preparation methods. HWC treatments have also demonstrated their ability to greatly improve stand volume. Tiarks and Haywood (1986) indicated that HWC increased tree volume by 63% and increased survival rate from 0.78 to 0.89 at age 5. Martin and Shiver (2002) showed that 12 years of complete herbaceous and woody competition control increased stand volume by 45% and 39% in Coastal Plain and Piedmont regions, respectively.

These gains from site improvement are quite evident in young pine stands but are expected to diminish before first thinning. Implementing changes of new technology in seed selection for new rotations would be more spontaneous due to shorter rotation. Despite the available enhancements to productivity, today's planning for supplying bioenergy feedstock demands in the future requires reliable growth and yield simulations, in conjunction with the understanding of stand dynamics and effects of treatments in young loblolly pine plantations in different ecoregions as powerful decision support tools for foresters.

Many research efforts in economic analysis of short rotation loblolly pine plantation for bioenergy have been conducted and there is evidence that the integration of traditional forest products and biomass showed highly profitable returns (Munsell and Fox, 2010; Guo et al., 2010). Though Munsell and Fox (2010) found that returns to growing for biomass only were not attractive in their fixed study regimes at 500 and 750 trees $\cdot$ ac^{-1} with 8-year rotations, we hypothesized that with the relaxation over a range of initial planting densities and rotation ages, growing for biomass might have feasible solutions.

The goal of this study was to evaluate the economic feasibility of managing loblolly pine plantations for biomass on short rotations (<15 years). As a first step, we identified a growth and yield simulator that could accurately estimate tree and stand characteristics in young plantations. Several studies have reported that simulated yield from the growth and yield simulator, PTAEDA 3.1 (Burkhart et al., 2003) agreed with the field data in Alabama (VanderSchaaf and South, 2004; South et al., 2011). In this study, we derived biomass yields from the PTAEDA 4.0 simulator (Burkhart et al., 2008a), which is based on Southeast region-wide data and allows for the assessment of site preparation treatment effects (Burkhart et al., 2008b; Westfall et al., 2004). We confirmed the reliability of the simulator by comparing actual growth of young loblolly pine grown on two sites near Greenville and Evergreen, AL with simulated yields from PTAEDA 4.0. Following these tests showing good estimation from PTAEDA 4.0, we then selected it for providing growth and yield data to compare scenarios devised for biomass plantations on short rotations with the financial returns available from managing stands on a typical (contemporary) plantation for a traditional mix of stumpage products; pulpwood, chip and saw, and sawtimber. The minimum biomass stumpage prices that would be required to encourage landowners to manage for biomass rather than for traditional products were calculated over a range of site conditions and rotation lengths in both the Piedmont and Coastal Plain regions. The following sections of the paper reflect the basic research processes undertaken by this study.

2. Materials and methods

2.1. Validation of PTAEDA 4.0 with young plantations in AL

To determine if PTAEDA 4.0 would meet our needs, we used field data collected from two study sites located in Greenville and Evergreen, AL. Ten 0.05-acre random plots in Greenville and forty-six random plots in Evergreen were sampled, measuring dbh for every tree on the plot and height for 3 random trees on each plot. In total, 288 and 30 trees were measured for dbh and height on the Greenville site and 803 and 138 trees were measured for dbh and height on the Evergreen site.

Trees at the Evergreen site were planted in 1999 and harvested in 2011 after 12 growing seasons. We projected individual tree height from dbh. Measured height fits well in nonlinear regression (Eq. (1), Burkhart and Strub, 1974). Trees on the Greenville site were planted in 2001 and harvested after 11 growing seasons in January 2012. Unlike those of Evergreen, tree height was calculated using a linear relationship (Eq. (2)), due to better goodness of fit, adjusted r-squared.

$$\mathrm{Ht} = 4.5 + \alpha \cdot e^{\left(\frac{\beta}{\mathrm{dbh}}\right)} \quad (1)$$

$$\mathrm{Ht} = \alpha + \beta \cdot \mathrm{dbh} \quad (2)$$

Individual tree stem biomass and merchantable biomass were calculated from Bullock and Burkhart (2003). Site index on these two sites was calculated from Eq. 7 in Sharma et al. (2002) using average height of dominant trees from the upper 20% dbh classes.

Stem green weight and merchantable green weight yields were simulated from PTAEDA 4.0 based on planting density, age and site index similar to Greenville and Evergreen sites. The simulated results were compared with the measured tree yields to evaluate the simulation accuracy.

The measured survival rate is lower than PTAEDA 4.0 simulated survival. We tested the hypothesis that the mean dbh of the measured data set and simulated data set were statistically different. We used the *t*-test statistic in proc ttest in SAS (SAS, 2003). Results showed that the mean of the measured dbh at the Greenville site was not statistically different from that of the simulated (p-value = 0.84, Table 1) and the mean of measured and simulated dbh at the Evergreen site were not different at a high significance level 0.05 (p-value = 0.08). So, the null hypothesis that the mean of measurement and simulated dbh at the two sites are equal cannot be rejected. Means of measured height and simulated height on both sites were statistically different (p-value < 0.01). However, the means of tree biomass between measured and simulated for the Greenville site were not different at a high significance level 0.05 (p-value = 0.07). Similarly, means of tree biomass were not statistically significant for the Evergreen site (p-value = 0.45). As a result, simulated total stem biomass per acre, which includes number of trees per acre, produced marginal differences at −2.5% and +1.4% compared to the measured data from the Greenville and Evergreen sites respectively. With our presumptions for planting and site prep conditions, PTAEDA 4.0 provided good estimates of stand biomass on two Coastal Plain sites. The statistical tests showed the favorable result that the sampling and simulated dbh and biomass datasets were not statistically different at 0.05 significance level.

Table 1
Stand characteristics for loblolly pine measured sites (Greenville, Evergreen) and PTAEDA 4.0 simulated sites (P_greenville, P_evergreen).

Stand characteristic	Unit	Greenville	P_greenville	Evergreen	P_evergreen
Planting density	tree $\cdot$ ac^{-1}	720	727	454	454
Harvest density	tree $\cdot$ ac^{-1}	576	602.5	360	374.8
Harvest age	yr	11	11	12	12
Site index	ft	83	83	82	82
Merchantable biomass	tree $\cdot$ ac^{-1}	54.43	52.86	55.76	55.83
Stem biomass	tree $\cdot$ ac^{-1}	65.31	63.68	60.73	61.55
Mean dbh	in	6.00	6.02	7.38	7.22
p-Value		0.8362		0.0770	
Mean height	ft	40.86	38.25	39.40	42.98
p-Value		<0.001		<0.001	
Mean tree biomass	lbs $\cdot$ $tree^{-1}$	226.75	210.62	336.57	328.83
p-Value		0.0745		0.4504	