Effect of CO_2 Mitigation Incentives on the Profitability of Short-Rotation Woody Cropping of Eucalyptus amplifolia on Clay Settling Areas in Florida

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Phosphate-mined lands in central and northern Florida exceeded 69,000 ha through December 2002 and are increasing by 2,000-2,500 ha annually (Florida DEP, 2003). During phosphate mining, clays are washed from phosphate ore, and the resulting slurry is pumped into clay settling areas (CSAs). CSAs comprise about 40% of the phosphate-mined lands and can take about 15 years to dry and stabilize. While CSAs may be leased for cattle grazing for \$35-\$40 ha^{-1} $year^{-1}$, they are typically left idle. Fast growing, short-rotation tree plantations provide unique opportunities to sequester carbon on CSAs and, if used as a biofuel, can reduce CO_2 emissions associated with electricity generation. *Eucalyptus amplifolia* (EA) on a CSA produced maximum sustained yields (total above-ground biomass) of 17 and 32 dry Mg ha^{-1} $year^{-1}$ from initial plantings of 4,200 and 8,400 trees ha^{-1}, respectively.

Langholtz *et al.* (in press) report Land Expectation Values (LEV) for EA on CSAs in central Florida. EA production is likely to be profitable under reasonable scenarios, with LEVs ranging from \$762 to \$6,507 ha^{-1} assuming real discount rates of 10% and 4%, respectively, establishment costs of \$1,800 ha^{-1}, planting costs of \$1,200 ha^{-1}, planting density of 8,400 tree ha^{-1}, and a stumpage price of \$20 dry Mg^{-1}. Incorporating environmental services provided by SRWC production on CSAs can improve the profitability of this system. We extend the economic optimization model of a SRWC biomass production system by Langholtz *et al.* (2006) to include an incentive for atmospheric CO_2 mitigation recognizing benefits of a) *in situ* sequestration in a mulch production scenario and b) *in situ* sequestration coupled with emissions reduction through fossil fuels displacement in a biofuels scenario. We then use these models to investigate how these incentives would influence profitability and optimal management of the SRWC production system.

METHODS

Langholtz *et al.* (2006) assessed the profitability of EA cultivation on CSAs using a modified Faustmann model as described by Medema and Lyon (1985), accounting for multiple growth stages (harvest rotations) for each coppice cycle (life of a tree) in calculating LEV. The basic Faustmann model modified by Medema and Lyon (1985) to calculate net returns given a fixed number of stages (n) is

$$LEV = \frac{\sum_{s=1}^{n}\left[V(t_s)\cdot e^{\left(-r\cdot\sum_{j=1}^{s}t_j\right)} - C_s\cdot e^{\left(-r\cdot\sum_{j=1}^{s}t_{j-1}\right)}\right]}{1-e^{\left(-r\cdot\sum_{j=1}^{n}t_j\right)}} \qquad (1)$$

where $t_0=0$; n=the number of stages, s; $V(t)$=the growth function for stage s at time t times biomass price; r =the real discount rate; and C_s=costs of stage s at the start of the stage.

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We expand Eq. (1) to account for societal benefits of carbon (C) sequestration in the stand and subsequent decay of C in mulch products assumed to decay linearly over 5 years as

$$LEV_{mulch}\left(t\right)=\frac{\sum_{s=1}^{n}\left[\begin{array}{l} V(t_s)\cdot e^{\left(-r\cdot\sum_{j=1}^{s}t_j\right)}+\left[\int_0^t\left(\tfrac{d}{dt}\left(C_S{}^{A}\left(t\right)\right)\cdot e^{\left(-r\cdot t\right)}\right)dt\right]\cdot e^{\left(-r\cdot\sum_{j=1}^{s}t_{j-1}\right)}- \\ \left[\dfrac{C_S{}^{A}\left(t\right)}{5}\cdot\left(\dfrac{1-e^{\left(-r\cdot 5\right)}}{r}\right)\right]\cdot e^{\left(-r\cdot\sum_{j=1}^{s}t_j\right)}-C_s\cdot e^{\left(-r\cdot\sum_{j=1}^{s}t_{j-1}\right)}\end{array}\right]}{1-e^{\left(-r\cdot\sum_{j=1}^{n}t_j\right)}} \qquad (2)$$

where $C_s^A(t)$ is the value of standing aboveground C at time *t* for coppice stage *s.*

Calculation of the societal costs associated with biofuels emissions must be handled differently than Eq. (2). As described above, CO_2 emissions from sustainably produced (i.e., closed-loop) biofuels are re-sequestered in the subsequent rotation, displacing the use of fossil fuels with closed-loop biofuel resulting in no net CO_2 emissions from biomass combustion, and reducing fossil fuel emissions. However, recognizing that there are fossil fuel inputs to the cultivation, harvest, and processing of SRWCs consuming up to 10% of the energy produced by the bioenergy system (based on Heller *et al.*, 2004), 10% of the C sequestration benefit achieved at stage age *t* is discounted to the beginning of the stage and subtracted from the carbon benefit, resulting in

$$LEV_{biofuel}\left(t\right)=\frac{\sum_{s=1}^{n}\left[\begin{array}{l} V(t_s)\cdot e^{\left(-r\cdot\sum_{j=1}^{s}t_j\right)}+\left[\int_0^t\left(\tfrac{d}{dt}\left(C_S{}^{A}\left(t\right)\right)\cdot e^{\left(-r\cdot t\right)}\right)dt\right]\cdot e^{\left(-r\cdot\sum_{j=1}^{s}t_{j-1}\right)}- \\ \left[\left(0.1\cdot C_S{}^{A}\left(t\right)\right)\right]\cdot e^{\left(-r\cdot\sum_{j=1}^{s}t_j\right)}-C_s\cdot e^{\left(-r\cdot\sum_{j=1}^{s}t_{j-1}\right)}\end{array}\right]}{1-e^{\left(-r\cdot\sum_{j=1}^{n}t_j\right)}} \qquad (3)$$

Thus, Equations (2) and (3) are used for incorporating C externalities in mulch and biofuel production scenarios, respectively. To assess the impact of CO_2 mitigation incentives *vis-à-vis* the basic SRWC economic analysis, the model was run using the range of assumptions described by Langholtz *et al.* (2006).

RESULTS AND DISCUSSION

Under all combinations of assumptions under a fixed C price of \$5 Mg^{-1} C, LEVs range from \$-2,789 to \$4,616 ha^{-1} and \$-224 to \$18,121 ha^{-1} assuming stumpage prices of \$10 and \$30 Mg^{-1}, respectively. Table 1 shows LEVs, optimum number of stages per cycle, and optimum stage lengths by C benefit scenario and stumpage price assuming a base scenario of 7% discount rate, \$1,800 ha^{-1} site preparation cost, \$1,200 ha^{-1} planting cost and a C price of \$5 Mg^{-1}. Increasing stumpage price decreases the optimum number of stages per cycle.

Table 1. LEV ($/ha) and optimal number of stages and harvest age (years) for each stage by planting density (trees ha^{-1}), C benefit scenario, and biomass price.

Planting Density	NTB Scenario	$10 dry Mg^{-1}		$20 dry Mg^{-1}		$30 dry Mg^{-1}	
		LEV	Optimum harvest age	LEV	Optimum harvest age	LEV	Optimum harvest age
4,200	None	-2,207	3.0, 3.1, 3.2, 3.4, 4.2	-715	2.8, 2.9, 2.8, 2.7	895	2.8, 2.7, 2.6
4,200	Mulch	-2,126	3.0, 3.1, 3.2, 3.3, 3.9	-659	2.9, 2.9, 2.8, 2.7	996	2.8, 2.8, 2.6
4,200	Biofuels	-1,885	3.0, 3.0, 3.1, 3.2, 3.3	-376	2.8, 2.8, 2.9, 2.7	1,313	2.8, 2.7, 2.6
8,400	None	-798	3.3, 3.3, 3.3, 3.1	2,413	3.2, 3.1, 2.9	5,864	3.1, 3.0
8,400	Mulch	-616	3.3, 3.3, 3.3, 3.1	2,608	3.2, 3.1, 2.9	6,029	3.1, 3.0
8,400	Biofuels	-88	3.3, 3.3, 3.2, 3.0	3,197	3.2, 3.1, 2.9	6,677	3.1, 3.0

Under the base case scenario, incorporating an aboveground *in situ* C sequestration benefit of $5 Mg^{-1} C increases LEVs 24% and 3% to ($946 and $6,715 ha^{-1}) at discount rates of 10% and 4%, respectively. Recognizing the additional CO_2 mitigation benefits associated with the biofuel scenario increases, LEVs 73% and 21% (to $1,315 and $7,869 ha^{-1}), assuming real discount rates of 10% and 4%, respectively. In addition, the societal value of belowground C sequestration (roots + SOC at $5 Mg^{-1} C) is estimated at $700 and $1,137 ha^{-1} at discount rates of 10% and 4%, respectively. These results emphasize both the potential for SRWCs on CSAs to mitigate atmospheric CO_2 and for CO_2 mitigation incentives to contribute to the profitability of SRWC production. The influence of stumpage price, C sequestration benefit (CO_2 mitigation scenario or C price) or discount rate (from 4% to 10%) on optimum stage lengths is less than one year.

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