Modeling Pine as a Carbon-Sequestering Crop in Arkansas

S. Aaron Smith, Michael P. Popp, L. Lanier Nalley, and Kristofor R. Brye

This study estimates the impact of carbon offset payments on land use choices, net producer returns, and carbon sequestration. Loblolly pine is added to traditional cropping choices as a designated carbon-sequestering crop. With a carbon offset price of $15 per ton, pine enters land use on 10 percent of pasture acres. At $30, loblolly pine significantly increases in acreage in areas traditionally planted in row crops. The analysis suggests that the addition of pine as a carbon-sequestering crop can affect land use, add to producer returns, and sequester additional carbon relative to producer choice sets that exclude pine.

***Key Words*:** carbon offsets, carbon sequestration, loblolly pine

The U.S. federal government is currently considering several climate change policies aimed at either reducing greenhouse gas (GHG) emissions or increasing carbon sequestration, which would improve agriculture's carbon footprint and net GHG emissions (amount emitted minus amount sequestered in carbon equivalents). Climate change policies may affect agricultural production when they introduce market-based incentives for net GHG reductions, which alter the relative profitability of various land-use choices. While the precise shape of this future policy is not yet known, the proposals to date suggest that use of existing carbon markets like the Chicago Climate Exchange may increase, which would, in turn, likely increase the market price of carbon. Research that predicts the reactions of agricultural producers to market-based climate change incentives at the county level is thus needed to forecast the likely outcomes of such policy options. Some research has been completed on the ability of agricultural production to sequester atmospheric carbon and reduce emissions (Reilly and Paltsev 2009, Outlaw et al. 2009, McCarl 2007, Parton et al. 1987), but the literature on spatial, county-level, crop-specific estimates of carbon footprints is sparse. One example related to this study is Nalley, Popp, and Fortin (2011). They estimated carbon-equivalent (CE) emissions for the six largest crops in Arkansas (rice, corn, soybeans, cotton, wheat, and sorghum) plus pasture and hay. Subsequent analyses examined carbon sequestration for these crops (Nalley and Popp 2010, Popp et al. 2011). Those analyses took soil textures, yields, and the physiological parameters of the crops into account at the county level but evaluated only traditional land-use choices. The effect of alternative crops intended specifically to reduce net GHG emissions was needed to determine their potential impact on land reallocations, net returns, GHG emissions, and sequestration. One of the most promising crop alternatives for Arkansas in this regard is reforestation of marginal agricultural land with loblolly pine. Production of pine emits relatively small amounts of GHGs and can sequester carbon both in the soil and in harvested lumber (Smith 2010).

Across county, crop, and production method, this study focuses on the impacts of a potential carbon offset policy on net returns, net carbon footprints, and allocations of acreage when

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loblolly pine is added as a dedicated carbon sequestering alternative to traditional Arkansas crop enterprises, which include rice, cotton (irrigated and nonirrigated), corn, wheat, soybeans (double-cropped, irrigated, and nonirrigated), sorghum (irrigated and nonirrigated), hay, and pasture. Modeling at the county level provides a spatial estimate of where pine production is likely to occur in Arkansas under different, as yet unknown, carbon offset prices and the effects on producer net returns from both the carbon offset market and agricultural production.

Data and Methods

Loblolly Pine

Loblolly pine grows naturally and on plantations throughout the southeastern United States (Johnsen et al. 2004). It is the dominant species of commercial lumber for pulp/paper and saw timber on more than 29 million acres in the South (U.S. Forest Service 1990). Loblolly pine is attractive to the forestry industry due to its rapid rate of growth under a wide array of soil and weather conditions. Traditionally, it has been produced in coastal plain and Piedmont regions in the southeast, but managed plantations have extended well into the Ozark highlands region of northern Arkansas, providing evidence of the trees' adaptability to a multitude of conditions. Pine is also unique among crops considered for use in sequestering carbon and producing biomass. Unlike switchgrass, forage sorghum, and black willow, which have been considered for carbon sequestration and biomass production in earlier analyses, pine has the potential to substantially improve net GHG emissions from agriculture due to its ability (i) to sequester large amounts of atmospheric carbon not only in the soil but also in timber products and (ii) to provide returns to producers from an already established timber market rather than from a newly developing biomass market (Smith 2010, Popp and Nalley 2011). Additionally, pine branches, bark, and needles are used as mulch and as a renewable energy source.

We estimated costs of production and yields for loblolly pine using a pine growth model developed from the works of Pienaar, Shiver, and Harrison (1997), Jokela (2004), Brinker et al. (2002), and Adegbidi et al. (2002). We did not include spatial differences in the environmental parameters (soil depth, slope, previous crop, drainage, etc.) because those characteristics vary extensively across Arkansas. Similar to Smith (2010), a stand density of 700 seedlings per acre at planting with 30 percent thinning in the fifteenth year of the stand and with fertilization held constant across all counties generated a biomass yield of 8.77 tons per acre (Table 1). This yield estimate compares to the estimate by University of Arkansas Cooperative Extension Service (UACES) (2008) on medium- to high-quality sites of five to six tons per acre. Their estimate includes harvested biomass (pulp wood and saw timber) only and was predicated on conversion of agricultural land to forest. The UACES estimate did not contain our allowances for increased production in response to fertilization or for above-ground production of needles, branches, and bark.

We divided the pine production process into (i) establishment (chemical weed control, seeding, and fertilization), (ii) maintenance (fertilization in year 6 and year 18), (iii) thinning (year 15), and (iv) harvest (year 30). Establishment and maintenance costs are shown in Table 1. Further details about production as they pertain to this analysis are described in Smith (2010). Modeling pine as an alternative to traditional agricultural crops presents some complexities. Annual returns to conventional crop production need to be compared to cost and revenue streams that occur over an extended period of time. Pine takes approximately 25 to 35 years from the time of planting until harvest. Over this stand life, producers are not able to switch to other crops that at times provide better returns when relative prices favor those crops over timber. Compared to traditional crops, producers view this as an added risk to pine production that is the likely cause for pine's limited adoption as an alternative crop in Arkansas to date. To capture this risk, we added a long-term risk premium of 5.5 percent (Hardie 1984) to the discount rate used for calculating the long-term costs for equipment for all other enterprises. The risk premium reduced the present value of future revenues and costs and led to lower returns since positive cash flow does not occur until year 15 (thinning) and year 30 (harvest). Note that pine producers may thin stands two or three times over the stand life to enhance the quality of the wood and thereby the price generated by the stand. Because our goal

Table 1. Prorated Present-Value Estimates of Cost of Production, Yield, and Stand Life for Pasture, Hay, and Pine in Arkansas

	Hay		Pasture		Pine	
	Total Cost (dollars)	Prorated Present Value[a] (dollars)	Total Cost (dollars)	Prorated Present Value (dollars)	Total Cost (dollars)	Prorated Present Value (dollars)
Establishment						
Field preparation[b]	90.40	11.30	12.40	1.55	–	–
Pre-plant weed control[c]	9.39	1.17	9.39	1.17	35.67	1.19
Planting[d]	68.51	8.56	68.51	8.56	33.67	1.12
Post-planting weed control[e]	12.29	1.54	12.29	1.54	35.67	1.19
Operating interest[f]	12.22	1.53	3.68	0.46	11.60	0.39
Other[g]	–	–	–	–	63.82	2.13
Total establishment cost	192.81	24.10	106.26	13.28	180.43	6.02
Annual maintenance						
Rotary mower[h]	–	–	9.05	9.05	–	–
Fertilizer[i]	51.25	37.53	51.25	51.25	283.92	3.49
Harvest[j]	41.36	30.28	–	–	–	–
Other	3.03	2.22	6.97	6.97	–	–
Total specified expenses	95.64	70.03	67.27	67.27	464.35	9.50
Stand life	8 years		8 years		30 years	
Annual yield	2.23 tons		1.17 dry tons		8.77 tons	
Total specified expenses: Prorated present value over stand life	$94.13		80.55		$9.50	
Prorated present value of annual profit prorated over stand life	$38.04		–		$1.99	
Cash rental rate	–		$18.50		–	

[a] Prorated present value of total cost over stand life at a capital-recovery rate of 6 percent. Pine has an added 5.5 percent risk premium on the capital-recovery rate given the timing of cash flows and the long-term investment horizon associated with pine.

[b] Field preparation occurs in September and includes one pass with a disc to incorporate 1 ton of lime, 167 pounds of phosphate (0-45-0), and 83 pounds of potash (potassium) (0-0-60) fertilizer on hay. No fertilizers are applied on pasture during field preparation.

[c] Pre-planting weed control includes one herbicide application of one active-ingredient pound of glyphosate (Roundup®) in March by air for hay and pasture and ten pints per acre on pine.

[d] Planting includes one pass with a cultipacker and eight pounds of pure live seed applied using a no-till drill for accurate depth control. Hay and pasture are planted in April. Pine planting also occurs in April and involves a four-person planting crew and a planting density of 700 seedlings per acre at a cost of $0.035 per seedling.

[e] Post-planting aerial herbicide applications to hay consist of gramoxone in the establishment year. Pasture weeds are controlled with rotary mowing and Grazon P+D. Pine herbicide applications consist of a second treatment with ten pints of glyphosate per acre.

[f] Operating interest at an annual rate of 7.17 percent is charged on all expenses except capital recovery on owned equipment.

[g] The other cost for pine production is an initial application of a second type of fertilizer: 109 pounds of nitrogen (46-0-0), 111 pounds of phosphate (0-45-0), and 133 pounds of potash (0-0-60).

[h] Rotary mowing of pasture, which knocks down undesirable grass species and brush, is common in Arkansas. Two such operations are modeled.

[i] Pasture fertilizer applications consist of 200 pounds of lime, 125 pounds of ammonium nitrate (34-0-0), 100 pounds of phosphate (0-45-0), and 75 pounds of potash (0-0-60) per acre using a spin spreader. Fertilizer is calculated to reflect standard Cooperative Extension recommendations for lime, phosphate, and potash and sufficient nitrogen to support one cow/calf pair on two and a half acres with additional livestock (replacement heifers and herd sires). For hay, the fertilizer program to replace nutrients is 89 pounds of phosphate (0-45-0), 133 pounds of potash (0-0-60), and 220 pounds of ammonium nitrate (34-0-0) annually beginning in year 2. For pine, there are additional applications of fertilizer when the stand reaches year 6 and year 18; the applications consist of 435 pounds of nitrogen (46-0-0), 196 pounds of phosphate (0-45-0), and 192 pounds of potash (0-0-60).

[j] Hay is harvested using mower/conditioners, hay rakes (25 percent of acreage), large round balers (1,275 pounds of dry matter or 1,500 pounds at 15 percent moisture) with bale wraps, and automatic bale-movers for staging without tarps or storage pad preparation. For pine, we do not calculate a harvest cost since pine is presumed to be sold at the current stumpage price, and, as a result, the harvest cost is incurred by the mill or is subcontracted. The carbon footprints for the harvesting processes are held constant for all of the enterprises. We assume that harvesting and thinning consumes fuel at a rate of 12.64 gallons per acre for the feller buncher, cable skidder, and loader at a performance rate of approximately one acre per hour.

is estimating net GHG mitigation, we modeled a single thinning. Additional thinnings would result in greater GHG emissions from fuel use for the operations.

Carbon Sequestration

Carbon is stored in the biomass of agricultural crops both above and below the ground, and the quantity stored can be estimated by converting reported yields to biomass production using a harvest index and shoot-to-root ratios (Prince et al. 2001, Nalley and Popp 2010, Popp et al. 2011). A portion of the carbon that is trapped in the biomass remains sequestered in the soil. Carbon from the above-ground biomass can be sequestered in the soil through decomposition of organic matter on the surface with leaching of dissolved carbon into the soil or by incorporation of the plant matter into the soil through tillage. The below-ground biomass decomposes via microbial activity with some carbon sequestered as a function of soil texture and tillage. Clayey soils can sequester more carbon than loamy or sandy soils while tillage positively affects microbial decomposition and thereby increases GHG emissions from the soil, a negative for sequestration potential (Popp et al. 2011, Nalley and Popp 2010). Sequestration (S_{ijts}) was thus calculated by county (i), crop (j), tillage method (t), and county-specific soil texture (s). Pine sequestration was treated differently than traditional row crops because pine sequesters carbon not only in the soil but also in timber products. The soil sequesters pine carbon below ground via fine, coarse, and tap roots and above-ground debris (pine needles, branches, etc.) that comes in contact with the soil; the wood products produced from the trees provide above-ground sequestration. We did not include timber used in pulp wood, wood chips, and trash in our sequestration estimates due to the limited amount of time those products store carbon (typically less than five years). We treated all wood collected during thinning as pulp wood and excluded its carbon from the model as well. Poles and lumber produced during the final harvest, on the other hand, trap carbon for an extended period of time and we counted the carbon contained in those products as part of pine's carbon sequestration potential. The carbon sequestered by wood products and the soil was prorated over the 30-year stand life to obtain an annual estimate of the quantity of carbon sequestered that was then comparable to the other annual cropping enterprises.

Carbon Emissions

This analysis implemented a scan-level life cycle assessment approach that tracked GHG emissions in estimated CEs from Nalley, Popp, and Fortin (2011) for 78 of the most common production practices associated with the six largest crops in Arkansas—corn (7 practices), wheat (4 practices), cotton (31 practices), rice (8 practices), soybeans (20 practices), and sorghum (4 practices)—plus hay (1 practice), pasture (1 practice), and pine (2 practices). Our model included CE emissions from fuel, fertilizers, and chemicals used for each crop and production method. Both direct emissions (such as carbon dioxide (CO_2) from diesel fuel used by farm machinery) and indirect emissions from upstream manufacturing of inputs such as fertilizer and chemicals were included in the analysis. Also included were the CE emissions from nitrous oxide (N_2O) that is generated by nitrogen-based fertilizer applications (1.27 pounds of CE per pound of nitrogen applied) and methane from rice production at 1,367 pounds of CE per acre (Nalley, Popp, and Fortin 2011). For the pasture enterprise, no emissions were included in the model for livestock grazing. Livestock are a significant source of CE emissions as a result of methane produced from enteric fermentation and from urination and defecation. These emissions were not included in this analysis because they are a function of livestock profitability, an aspect that was not incorporated in our state model of crop returns. Further, we excluded CE emissions that result from downstream transportation, drying, and secondary processing for all of the crops considered, including pine, as the scope of this analysis was only up to the farm gate. When possible, the emission levels in the model (E_{ijn}) were specific to the county (i), crop (j), and production method (n) where production method specifics were exogenous to the model and dictated by information provided by commodity-specific experts. Spatial variation in emissions for hay, pasture, and pine production methods could not be calculated given the lack of available data.

Arkansas Crop Model

We used the crop model for Arkansas developed by Popp, Nalley, and Vickery (2008) to track changes in net GHG emissions, sequestration, net returns (*NR*), and acreage in production for the fourteen crop enterprises included in the study (pine on crop land and pasture; rice; irrigated and nonirrigated cotton; irrigated corn; wheat; irrigated, nonirrigated, and double-cropped soybeans; irrigated and nonirrigated sorghum; pasture; and hay). The model assumed producer profit maximization and tracked county yields, use of fertilizers, seed, irrigation, chemicals, herbicides, labor, and fuel across production methods and counties to provide a spatial estimate of expected crop patterns. Given the lack of available data, yields could be differentiated only by whether they were from irrigated or nonirrigated production and whether the fields were single- or double-cropped. We included constraints to reflect historical values for the minimum and maximum number of acres harvested and irrigated by county and by crop. The constraints limit land-use changes to reflect typical crop rotations, secondary processing, and other factors. Profit maximization for the model was expressed in two components: (i) net returns from production (revenue minus production-related expenses) for each crop alternative and (ii) returns from a carbon offset market. Net production returns were defined as

$$(1)\ \text{Maximize } NR_{production} = \sum_{i=1}^{75}\sum_{j=1}^{13}\sum_{n=1}^{N_j}\left(p_j \cdot y_{ij} - c_{ijn}\right)\cdot x_{ijn} + \sum_{i=1}^{75} p_j \cdot x_{ijn}$$

where

p_j = the price of crop *j*. The prices for Arkansas' six largest crops were five-year commodity averages for 2005 through 2009 provided by Great Pacific Trading Company (2010). The price for hay was an average for 2005 through 2009 for "other hay" reported by the U.S. Department of Agriculture's (USDA's) National Agricultural Statistics Service (NASS) (2010). For pasture, p_j reflected cash rental rates, which were based on an average for 2005 through 2009 reported by NASS (2010) for Arkansas and surrounding states. The price for pine was the average quarterly stumpage price for 2005 through 2009 for northern and southern Arkansas reported by the University of Arkansas Division of Agriculture (2010).

y_{ij} = the yield in county *i* for crop *j*. The yields for the six largest crops in Arkansas were based on average yields by county for 2005 through 2009 reported by NASS (2010). Pine yield was a function of annual growth and was based on fertilizer applications, planting densities, and the timing of thinning and harvesting (Pienaar, Shiver, and Harrison 1997, Jokela 2004, Adegbidi et al. 2002, Smith 2010). Hay yields were based on information from USDA's *Census of Agriculture* for 1992, 1997, 2002, and 2007. Pasture yields were calculated to support a cow/calf pair on 2.5 acres using yield expectations from Hunneycutt, West, and Phillips (1998) and did not vary by county. The pasture yields were used not to calculate producer production returns but to determine the carbon sequestration potential of pasture land.

c_{ijn} = the total specified cost in county *i* for crop *j* using production method *n*. The production method for each crop was chosen exogenously for specific regions of the state from N_j production technology choices that varied by crop and reflected information available in 2007. The costs of production for the six largest crops in Arkansas were based on county- and crop-specific average total specified costs provided by UACES (2008). We estimated pine's cost of production using calculations from Smith (2010) that were in turn based on a review of the literature and expert opinion (see Table 1). The hay and pasture budgets consisted of the input costs required to establish and maintain these crops (fuel, labor, fertilizers, herbicides, and seed) as reported in Table 1. These were generic production costs based on two cuttings for hay and standard cow/calf production methods for pasture. Again, pasture's cost of production was used only to determine CE emissions because production returns to pasture were based on cash rent.

x_{ijn} = acres in county *i* for crop *j* by production method *n*.

Returns from the carbon offset market were defined as

(2) Maximize $NR_{carbon} =$

$$\sum_{i=1}^{75}\sum_{j=1}^{14}\sum_{n=1}^{N_j} \left(BCF_{ij} - (E_{ijn} - S_{ijts} \cdot x_{ijn})\right) \cdot p_c$$

where

BCF_{ij} = the baseline estimate of the carbon footprint in county *i* for all acres in that county planted to crop *j* and calculated by solving equation (1) and noting the estimated carbon footprint for each crop and county without a carbon offset market.

E_{ijn} = per-acre CE emissions (in pounds per acre) in county *i* for crop *j* produced by method *n*.

S_{ijts} = per-acre carbon sequestration (in pounds per acre) in county *i* for crop *j* adjusted for tillage *t* and soil *s*.

p_c = the price for carbon offsets (in dollars per pound).

Solving the following equation allows for analysis of land-use change under a carbon offset market in response to varying levels of p_c:

(3) Maximize $NR = NR_{production} + NR_{carbon}$

$$\text{subject to } xmin_{ij} \leq x_{ij} \leq xmax_{ij}$$

$$\sum x_{ijn} \cdot irr_{ijn} \leq irrmax_j$$

$$acresmin_i \leq x_{ij} \leq acresmax_i$$

where

$xmin_{ij}$ / $xmax_{ij}$ = county-level historical minimum and maximum crop acres that were based on the *Census of Agriculture* (USDA) for 1992, 1997, 2002, and 2007 for hay and pasture and data from NASS (2010) for 2000 through 2007 for other crops. These are separate for irrigated and nonirrigated production for soybeans, grain sorghum, and cotton.

$acresmin_i$ /$acresmax_i$ = county-level historical minimum and maximum number of acres harvested and in pasture. Since there was no historical record of acres converted from crops, hay, and pasture to pine, we limited the adoption of pine to 10 percent of available pasture acres and 3.3 percent of crop acres. These percentages were chosen so that pine would not encroach on the historical values for acres of pasture required for cow/calf production identified in Popp, Nalley, and Vickery (2008) and as a function of the long-term investment horizon of pine production (30 years).

$irrmax_j$ = the amount of irrigation water applied per acre in county *j* in the baseline model run that serves as a constraint for maximum allowable water use. This constraint is needed to limit potential policy alternatives from choosing a land-use choice that would use more water as a result of crop-specific irrigation needs (irr_{ijn}) that also vary by production method and county.

Table 2 shows the crop prices (p_j) and estimated per-acre state averages of the yield (y_{ij}), total specified expense (c_{ij}), emission (E_{ij}), sequestration (S_{ijts}), carbon footprint ($E_{ij}-S_{ijts}$), and net return (nr_{ij}) for each crop using baseline acreage numbers for the crop calculated in equation (3). These baseline values for the state as a whole are weighted by each county's acreage and production methods (including tillage) and by soil texture. Table 1 reports similar estimates of annualized costs and returns for hay, pasture, and pine as specified for the model.

Carbon Market

To model the impact of various carbon prices on land use, a necessary first step was to establish the profit-maximizing crop pattern under existing price levels. Thus, the baseline model solution represents the crop mix that maximizes the state's return under average commodity and input prices for 2005 through 2009 using 2007 production technologies that included pine as a cropping alternative. This model run also generated baseline carbon footprints that could be reported at the state ($\sum\sum BCF_{ij}$), county ($\sum BCF_j$), and crop ($\sum BCF_i$) level and even at each county's crop (BCF_{ij}) level with carbon footprint defined as quantity emitted (E_{ijn}) minus quantity sequestered (S_{ijts}). A negative carbon footprint thus represents net sequestration and a positive footprint implies that the crop or county is a net emitter of carbon.

Deviations from the baseline as a result of modifying the price of carbon in equation (2) would thus allow us to determine whether producer incomes and crop patterns change. We modeled the carbon price at $0.10 per ton, the most prevalent 2010 trade price for carbon on the Chicago

Climate Exchange, and at \$5, \$15, and \$30 per ton as a result of policy interactions exogenous to the model. This range of carbon prices was similar to previous analyses (Nalley and Popp 2010, Popp et al. 2011) and provided estimates of carbon footprint responses to a market-based incentive.

Carbon-offset cash flows for producers were thus based on deviations from the baseline. Carbon-offset revenues for producers are available if, compared to the baseline, the carbon footprint declines. The opposite is true if climate change is impacted adversely (i.e., the carbon footprint increases). For example, if producers replaced rice acres (rice, on average, emits the most carbon of the crops commonly grown) (Figure 1) with pine acres, they would earn carbon-offset revenue in the amount of the change in carbon footprint (1,601 pounds per year emitted by rice replaced by net sequestration of 2,802 pounds per year for pine for a carbon-offset payment for 4,403 pounds (2.2 tons) at the current carbon price). Production returns per acre would change as well since \$181 per acre returned from rice production (Table 2) would be lost and would be replaced by a minimal production return from pine at \$2 per acre (Table 1). In this particular case, a producer thus would not choose to reduce rice acres in favor of pine production until the carbon price was approximately \$81 per ton, at which point the loss in production return would be offset by a gain from selling 2.2 tons of carbon offset per acre. The model accounts for these substitutions for all crops in all counties and optimizes returns to crop production and carbon trading pending different carbon price levels within the resource constraints employed in the model. Note that the model predicts the change in total county acreage for each cropping enterprise and does not speak to direct substitution of specific crops on a particular acre. For example, even in a single county a simultaneous loss of acres devoted to cotton and gain in acres of pine does not imply that the cotton acres were shifted to pine production unless those two enterprises were the only crops affected and total harvested acres did not change. More often, several crops are affected in a particular county so analyses of

Table 2. Baseline Weighted-average Price, Yield, Total Specified Expense, Net Return, Emission, Sequestration, and Carbon Footprint by Crop for Arkansas

	Price[a] (*P*)	Yield[b] (*Y*)	Total Specified Expense[c] (*C*)	Net Return (*NR*)	Emission (*E*)	Sequestration (*S*)	Carbon Footprint (*E* – *S*)
Crop	dollars per unit	units per acre	dollars per acre		pounds per acre		
Rice	9.48	68.94	472.21	181.40	2,193.05	592.34	1,600.71
Corn	3.03	153.48	378.02	87.97	788.76	1,219.83	(431.07)
Wheat	4.74	51.80	187.81	56.41	452.21	302.69	149.52
Hay	72.80	2.23	94.13	37.70	221.83	786.06	(564.23)
Irrigated soybeans	7.34	40.58	268.80	29.16	225.45	237.23	(11.78)
Irrigated sorghum	3.05	103.52	287.48	34.33	516.90	771.60	(254.70)
Nonirrigated sorghum	3.05	70.97	190.25	24.15	387.08	517.63	(130.55)
Nonirrigated soybeans	7.34	27.20	175.02	24.35	99.70	197.67	(97.97)
Pasture	18.50	1.17	80.55	18.50	151.07	668.57	(517.50)
Nonirrigated cotton	0.57	896.07	497.06	14.82	462.29	305.14	157.15
Irrigated cotton	0.57	1,098.19	619.24	8.15	596.61	372.79	223.83
Pine	28.59	8.77	9.50	1.99	52.82	2,854.47	(2,801.65)
Double-crop soybeans	7.34	32.74	259.79	(11.55)	190.36	176.50	13.87

[a] Price is the five-year GWT average price for rice, corn, cotton, sorghum, and soybeans (2005–2009). Pine prices are based on the five-year quarterly average stumpage price for north and south Arkansas (2005–2009). Pasture price is a five-year average cash rental rate from USDA for the delta states. Hay is the five-year average price reported by USDA.

[b] Yields for the six largest crops are based on 2005–2009 average county yields as reported by NASS. Pine yield is a function of annual growth and is based on fertilizer applications, planting density, and timing of thinning and harvest. Hay yields are based on information from the *Census of Agriculture* for 1992, 1997, 2002, and 2007. Pasture yields are used not to calculate producer returns but to determine the carbon sequestration potential of pasture.

[c] Total specified expenses for each crop and production method are calculated based on five-year average input prices for fuel, fertilizers, chemicals, and labor (2005–2009).

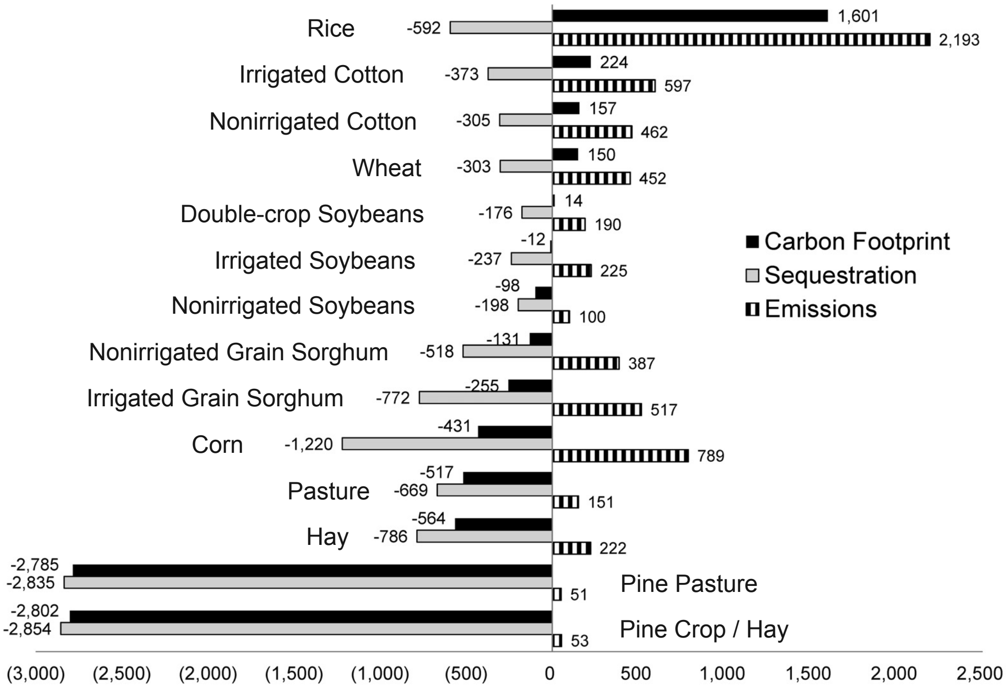

Figure 1. Estimated State Carbon Footprints, Sequestrations, and Emissions for Arkansas in 2007

crop-substitution patterns are cumbersome for the large number of counties and crops entertained in this model. Hence we report changes in crop patterns without discussing spatially different crop substitutions for each county; instead, we report returns and net GHG emission changes on a more aggregated basis by county with changes in yield, cost of production, and soil texture for each crop.

Price Response to Acreage Shifts

Commodity prices may change due to acreage shifts. However, since commodity prices are driven to a large extent by global forces, significant commodity-price effects were not expected for the cropping enterprises modeled, and price responses to acreage changes were not included in the analysis. As an example, Arkansas is the largest rice producer in the United States and rice is also the most profitable and highest net emitter of GHGs of the crops in this analysis. A shift away from rice production should thus affect domestic and world prices more than acreage changes in the other crops considered. To account for this effect, we used the Arkansas Global Rice Model (Wailes and Chavez 2010) to determine the price effects of a 12.9 percent reduction in Arkansas rice acreage as a result of irrigation restrictions. Results of that analysis showed a domestic price increase of approximately 1.1 percent and a world price increase of 0.9 percent. Such large shifts in acreage were not expected in this analysis so these price effects were not analyzed.

Production vs. Carbon Market Effects on Producer Returns

Since carbon-offset revenues and production returns are determined separately as shown in equations (1) and (2), the impact of policy-induced changes in carbon prices can be tracked to offer insight into changes in production returns and carbon-market trading as a result of land-use changes. This analysis allowed us to determine how much a carbon policy might shift the source of returns to producers from production revenue to payments received from carbon trading. Also, since the analysis was performed at the county level, spatial changes in pine production could be tracked by county.

Results

Baseline Model Results

The baseline model generated crop mixes, annual net returns, and annual carbon footprints for Arkansas crop agriculture as previously defined (see Table 2). We estimate the net state return as \$574 million with a carbon footprint of 287,000 tons of carbon sequestered annually on 8.01 million acres of land harvested (Tables 3, 4, and 5). Table 3 shows how land is used under each carbon price by highlighting the number of acres allocated to each crop. The baseline results are within $^{+}/_{-}$15 percent of actual acreage allocations recorded by NASS in 2007. Of note, the model predicts pine planting on 73,000 acres in the baseline model, which indicates that pine is already part of the agricultural cropping mix. This is considered reasonable since approximately 2.5 million acres of pine were grown throughout the state according to estimates for 2007 (U.S. Forest Service 1990). No detailed information is available about the previous use of those acres (whether it was used continuously as forest land or was converted from pasture or crop land) or whether the stands represent natural growth or commercial planting. We know that some agricultural land has been converted to commercial pine planting but do not have data that identify exactly where, when, or to what extent this has happened.

Relative Per-Acre Crop Profitability and Carbon Footprint

The estimated state carbon footprint improves as carbon-offset prices increase (Table 4). Estimated carbon sequestration increases from 3.28 million to 3.88 million tons while emissions drop from 2.99 million to 2.95 million tons as p_c increases to \$30 per ton. Improvement in the state carbon footprint, then, is driven by changes in sequestration and not by emission reductions as the price of carbon increases. This result holds for all carbon-offset price levels. The change in the carbon footprint is

Table 3. Baseline Acreage (in thousands) and Percentage Change in Acres by Crop from the Baseline for Three Carbon-Offset Prices for Arkansas

	Carbon Price \$0.10 per Ton	\$5.00 per Ton	Carbon Price of \$15.00 per Ton	\$30.00 per Ton
		Percentage Change from Baseline Carbon Price of \$0.10 per Ton		
Total Acres in Production[a]	8,005	0.05	0.05	0.15
Corn	418	8.20	8.67	16.90
Cotton – nonirrigated	181	–	(5.93)	(5.93)
Cotton – irrigated	544	–	–	–
Soybeans – nonirrigated	903	(1.31)	(2.17)	(4.38)
Soybeans – irrigated	1,659	–	–	–
Soybeans – double-cropped	145	–	–	–
Rice	1,521	(0.77)	(0.82)	(1.55)
Wheat	1,019	(1.41)	(2.32)	(7.66)
Sorghum – nonirrigated	64	(2.72)	(15.15)	(22.59)
Sorghum – irrigated	43	(6.08)	(5.61)	(22.32)
Hay	1,434	–	(0.10)	(0.58)
Pasture	3,857	–	(10.00)	(10.00)
Pine on pasture	0	–	NA[b]	NA
Pine on crop / hay	73	16.66	65.63	172.04

[a] Total of all acres in production for the fourteen crops listed, including pine and pasture.

[b] Pine pasture acreage enters into the production mix at a carbon offset price of \$15 per ton on 385,657 acres, the adoption limit set on pasture acres. Percentage changes could not be calculated as there were no acres under the baseline scenario.

primarily a function of acreage being reallocated from crops that are net emitters (rice, nonirrigated cotton, and wheat) or from crops that sequester relatively small amounts (sorghum, soybeans, and pasture) to pine and corn, crops that are capable of sequestering relatively large amounts of carbon. Hence, the model accounts for county-level changes in net GHG emissions as crop substitutions occur.

However, the relative carbon footprint per acre of each crop, as shown in Figure 1, is not the entire story. The relative profitability of individual crops is also important. This is demonstrated by the relatively small reduction in acres of rice (Table 3),

Table 4. State Emission and Sequestration Levels and Carbon Footprints (in thousand tons) for Three Carbon-Offset Prices with Percentage Changes from the Baseline p_c of $0.10 per Ton for Arkansas

Carbon Price	Emissions[a] $(\sum\sum\sum E_{ijn})$	Sequestration[a] $(\sum\sum\sum\sum S_{ijts})$	Carbon Footprint[a]	Percent Change in Emissions from Baseline	Percent Change in Sequestration from Baseline	Percent Change in Carbon Footprint from Baseline
$0.10 per ton	2,989	(3,276)	(287)	–	–	–
$5.00 per ton	2,985	(3,308)	(322)	(0.13)	0.96	12.28
$15.00 per ton	2,960	(3,772)	(811)	(0.96)	15.13	182.66
$30.00 per ton	2,947	(3,883)	(936)	(1.41)	18.53	226.08

[a] Total state emissions, sequestration levels, and carbon footprints (emissions – sequestration) are calculated from fourteen crops aggregated across seventy-five counties and production methods to obtain state totals.

Table 5. Baseline Net State Returns (in million dollars) with Percentage Changes from the Baseline for Three Carbon-Offset Prices for Arkansas

	Carbon Price $0.10 per Ton	$5.00 per Ton	Carbon Price of $15.00 per Ton	$30.00 per Ton
		Percentage Change from Baseline Carbon Price of $0.10 per Ton		
Total Net[a] Returns	574.67	0.02	0.25	1.81
Corn	36.80	9.04	9.68	16.87
Cotton – nonirrigated	2.76	–	(4.94)	(4.45)
Cotton – irrigated	4.44	–	–	–
Soybeans – nonirrigated	21.99	(0.33)	(0.92)	(3.15)
Soybeans – irrigated	48.36	–	–	–
Soybeans – double-cropped	(1.67)	–	–	–
Rice	275.95	(0.80)	(0.81)	(1.36)
Wheat	57.48	(1.57)	(1.79)	(5.13)
Sorghum – nonirrigated	1.55	(0.96)	(10.31)	(16.86)
Sorghum – irrigated	1.47	(7.59)	(7.13)	(35.82)
Hay	54.06	–	(0.05)	(0.48)
Pasture	71.35	–	(12.10)	(14.20)
Pine on pasture	–	–	NA[b]	NA
Pine on crop / hay	0.15	76.15	762.11	3,809.27

[a] State net returns from production and carbon markets for all crops listed.

[b] Not applicable since pine did not compete with pasture returns in the baseline until p_c = $15 per ton, at which point returns to pine production were approximately $9.3 million and were $17.4 million at p_c = $30 per ton.

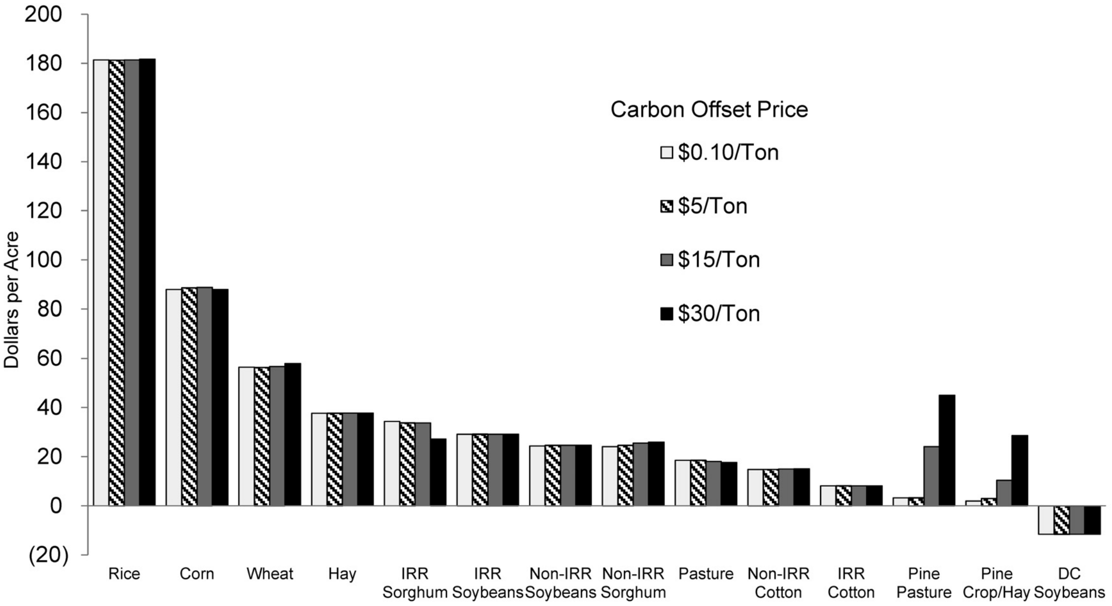

Figure 2. Weighted Per-Acre Average Net Returns to Traditional Crop Production and Carbon Offset Markets for Crops under Four Carbon-Offset Prices for Arkansas in 2007

Note: IRR = Irrigated, Non-IRR = Nonirrigated, DC = Double-cropped.

which is the lead emitter but also the most profitable crop in the state (Table 2). Individual crops' state average net returns per acre from production (baseline of $0.010 per ton) and carbon markets are shown in Figure 2. These returns change with the carbon-offset price (p_c), the total number of acres of the crop grown, and differences across counties in the spatial allocation of exogenous production methods and yields. These relative changes in profitability for individual crops drive the crop mix, the net state carbon footprint, and allocation of overall agricultural returns between crop production and carbon trading. For example, the average per-acre state return from wheat increases from $56 under the base scenario to $58 under the $30-per-ton carbon-offset price. Since the number of acres of wheat declined, the increase in return came from carbon-offset payments earned for fewer emissions (since wheat is a net emitter) and from replacing the least profitable (across the state) wheat acres with crops that generate greater relative returns. So, while wheat, as a net emitter, suffers a reduction in acreage in a carbon offset market, the per-acre return from the remaining acres of wheat increases on average. It is the relative return per acre across crops that drives acreage allocation. Figure 2 shows that pine's relative state average profitability increases as the carbon-offset price rises, to the point where only rice, corn, and wheat are relatively more profitable. Note that Figure 2 does not hold for each individual county with differences in yields and costs of production across counties. In addition, the acreage reallocation to pine is subject to the availability of acres of crop, hay, and pasture, which is a function of the traditional crop-acreage minima and the imposed constraint on pine adoption for pasture (10 percent) and crop land (3.3 percent).

Overall, increases in p_c lead to decreases in acres of wheat, nonirrigated soybeans, nonirrigated cotton, sorghum, hay, pasture, and rice. By the same token, crops with greater sequestration capability (corn and pine) gain acres. Again, these changes are driven by the changes in relative profitability of various crops discussed earlier. Pine on pasture enters the model at p_c = $13.45 per ton and realizes its maximum allowable 10 percent of pasture acres at p_c = $15 per ton. Allocation of pine to crop land continues to increase with each step up in p_c. Compared to the baseline, pine acreage increases when the carbon offset price is as little as $0.65 per ton and does not reach the allowed maximum of 3.3 percent of crop and hay land. The increase in p_c also adds an additional 10,000 harvestable acres (fallowed land brought into production as a result of increased returns to producers) to overall crop production in the state (from 8.01 million baseline acres to 8.02 million under $p_c = \$30$).

Sources of Changes in State Profitability

Increasing the carbon-offset payments adds a revenue source and therefore increases the state's net returns. Base net returns and percentage increases from the baseline for the three levels of p_c are shown in Table 5. These changes are from carbon-offset revenue and shifts in production returns as previously defined and are highlighted for the state by crop in Table 6. For example, at p_c of $15 per ton, total carbon revenue for the state is $7.84 million while overall net revenue (*NR*) for the state increases by only $1.45 million. Hence, production returns decline by $6.39 million. Since the shift in crops involves more long-term plantings of pine (a 30-year production horizon), this breakdown of the state's returns between the carbon market and traditional markets is offered to demonstrate the exposure of agricultural returns to fluctuations in carbon prices. It also shows how individual crops are affected differently by carbon

Table 6. Total State Carbon Payments and Changes in Production Returns by Crop and Carbon-Offset Price with Resulting Total Changes in Net Returns to Producers (in thousand dollars) for Arkansas

	Carbon Price								
	State Carbon Trading Return[a]			Change in Production Return[b]			Total Change in Net Return[c]		
	$5 per Ton	$15 per Ton	$30 per Ton	$5 per Ton	$15 per Ton	$30 per Ton	$5 per Ton	$15 per Ton	$30 per Ton
Rice	47.1	150.3	565.4	(2,266.5)	(2,382.9)	(4,329.3)	(2,219.4)	(2,232.5)	(3,763.9)
Cotton – irrigated	–	–	–	–	–	–	0	0	0
Cotton – nonirrigated	–	12.7	25.3	–	(149.1)	(148.3)	0	(136.5)	(123.0)
Corn	37.6	119.0	457.2	3,288.7	3,442.0	5,749.6	3,326.2	3,561.0	6,206.8
Soybeans – irrigated	–	–	–	–	–	–	0	0	0
Soybeans – nonirrigated	(2.9)	(14.3)	(58.1)	(70.2)	(188.5)	(634.6)	(73.1)	(202.8)	(692.7)
Soybeans – double-cropped	–	–	–	–	–	–	0	0	0
Sorghum – irrigated	(1.7)	(4.8)	(36.5)	(109.8)	(99.9)	(489.7)	(111.5)	(104.8)	(526.2)
Sorghum – nonirrigated	(0.5)	(9.2)	(28.5)	(14.2)	(150.2)	(232.3)	(14.8)	(159.5)	(260.7)
Wheat	5.5	26.7	175.0	(910.7)	(1,058.0)	(3,124.1)	(905.2)	(1,031.3)	(2,949.0)
Hay	–	(5.8)	(70.8)	–	(23.7)	(189.8)	0	(29.5)	(260.7)
Pasture	–	(1,496.8)	(2,993.7)	–	(7,134.6)	(7,134.6)	0	(8,631.5)	(10,128.3)
Pine on crop / hay	85.2	1,007.3	5,280.1	25.6	101.3	261.3	110.8	1,108.7	5,541.4
Pine on pasture	–	8,054.4	16,108.8	–	1,252.1	1,252.1	0	9,306.5	17,360.9
Change in state net return	170.1	7,839.5	19,424.2	(57.1)	(6,391.6)	(9,019.8)	113.0	1,447.9	10,404.5

[a] Payments made to producers for lowering carbon footprint from the baseline. A negative number in the case of nonirrigated soybeans indicates a loss of net sequestration as nonirrigated soybeans are net sequesterers and decline in acres. The positive number for carbon trading for rice implies revenue for rice producers for reducing net emitting acres. The source of payments for carbon offsets is not addressed but as a result of market interactions with individuals or agencies interested in either retiring carbon offsets for the betterment of climate or purchasing the offsets for allowing emissions in sectors outside the crop agricultural model as defined here.

[b] Changes in production returns are the result of acreage reallocation among crops and changes in production practices within crops. These production returns are from traditional agricultural markets for feed, food, and fiber and are relative to the baseline.

[c] The total change in net return is the net return predicted by the model estimations under each carbon-offset price relative to the baseline. The total net return represents the sum of carbon trading returns and changes in the production returns for each carbon-offset price.

trading at the aggregate state level. While the rice sector gains from carbon payments, the payments are insufficient to offset the losses in production returns from rice. The same holds for nonirrigated cotton and wheat as they are also net emitting crops and lose acreage. In contrast, soybeans produced without irrigation only reduce the state's revenue. Acres of nonirrigated soybeans decline as the carbon price rises, and that loss of acres reduces both the amount of carbon sequestered (since soybeans are net sequesterers) and returns from soybean production. The same holds for sorghum, hay and pasture. Finally, pine and corn gain from both the carbon market and increased production returns. To be clear, this does not imply that individual producers of nonirrigated soybeans lose with the implementation of a carbon market. They can reallocate their land resources to pine or another more profitable crop that offers added returns through carbon-offset revenue.

Spatial Changes in Pine Acres

Figure 3 shows spatial pine acreage allocation by county for the four carbon-offset prices. Pine acres under the base price are predominately in the northwestern and southern portions of the state, a finding that is consistent with existing lumber mill locations. As the carbon price increases to $15 per ton, the number of acres devoted to pine increases in the northwest part of the state (replacing pasture). At a carbon-offset price of $30 per ton, the relative profitability of pine increases such that it makes significant in-roads into the delta counties, where row crops are traditional.

Conclusions

This study examined the implications of adding pine to a traditional crop model as a designated carbon sequestering crop in Arkansas and increasing

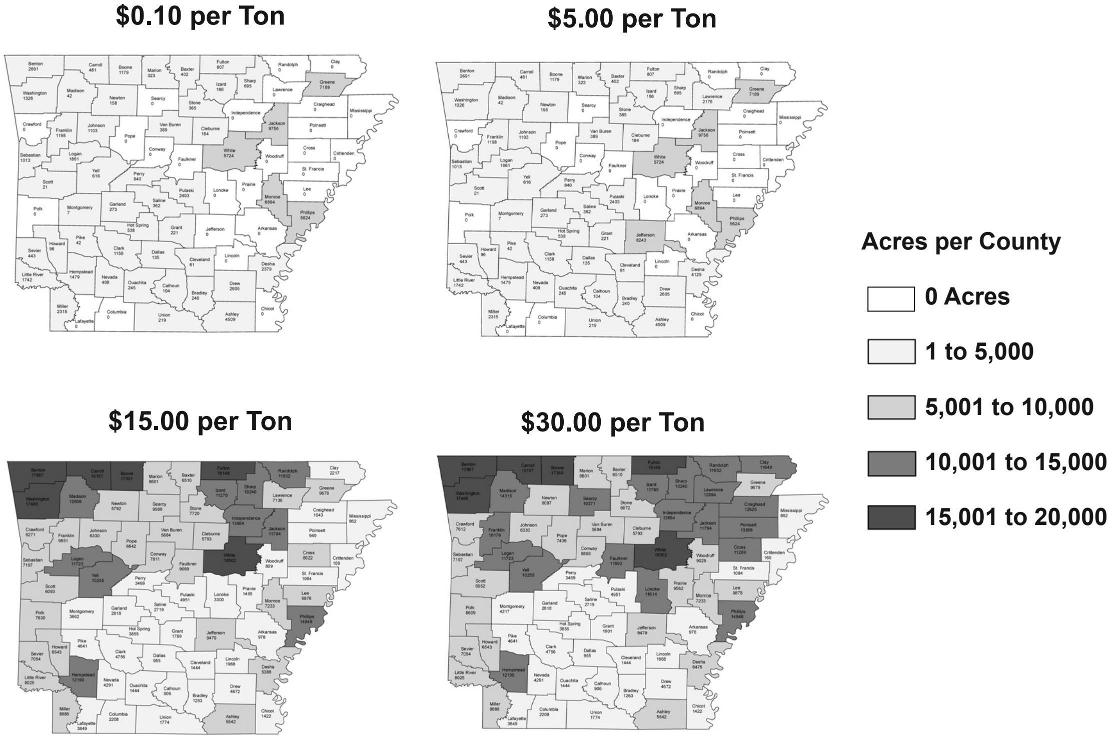

Figure 3. Pine Acres by County under Four Carbon-Offset Prices (dollars per ton) for Arkansas in 2007

the price of carbon offsets. Our model increased the price of carbon offsets from a baseline level ($0.10 per ton) to $5, $15, and $30 per ton of carbon to determine the effects of higher carbon prices on the state's carbon footprint, acreage reallocations, and changes in the source of returns to agricultural crop production activities. The analysis shows that increasing the price of carbon leads to improvements in the state's carbon footprint and net return. Acreage is reallocated among crops based on their relative profitability; crops with relatively small returns (primarily pasture, nonirrigated soybeans, and sorghum) are replaced by crops that provide greater returns (pine and corn). This relative profitability is affected by the carbon-offset price. However, the allocation and profitabiity of crops with high production returns (rice) change only slightly; carbon prices have to be quite high before payments from the carbon market for reducing acres can offset losses in production returns. Finally, as the carbon price increases, producer returns from a carbon market take on a larger role than changes in returns from production and land use choices. While the extent of the effect of carbon payments on overall profitability varies across crops and crop production methods, increases in the carbon price have an overall positive effect. Especially in the case of pine, the added returns from a higher carbon price result in greater reliance on the carbon market as a primary source of producer income. Further research is needed to determine how such acreage shifts would affect secondary processing industries and net GHG emissions. For example, would lumber mills locate in crop-producing regions?

References

Adegbidi, H., N. Comerford, H. Li, E. Jokela, and N. Barros. 2002. "Determining Nutrient Requirements for Intensively Managed Loblolly Pine Stands Using SSAND (Soil Supply and Nutrient Demand) Model." In *Proceedings of the Eleventh Biennial Southern Silviculture Research Conference*. General Technical Report SRS–48, U.S. Forest Service Southern Research Station, Ashville, NC.

Brinker, R.W., J. Kinard, B. Rummer, and B. Langford. 2002. "Machine Rates for Selected Forest Harvesting Machines." Circular 296, Alabama Agricultural Experiment Station, Auburn, AL.

Great Pacific Trading Company. 2010. "Charts and Quotes." GPTC, Grants Pass, OR. Available at http://www.gptc.com/charts-quotes (accessed November 2010).

Hardie, I.W. 1984. "Comparative Rents for Farmland and Timberland in a Subregion of the South." *Southern Journal of Agricultural Economics* 16(2): 45–53.

Hunneycutt, H., C. West, and J. Phillips. 1998. "Responses of Bermuda Grass, Tall Fescue, and Tall Fescue-Clover to Broiler Litter and Commercial Fertilizer." Bulletin 913, Arkansas Experiment Station, Fayetteville, AR.

Johnsen, K., B. Teskey, L. Samuelson, J. Butnor, D. Sampson, F. Sanchez, C. Maier, and S. McKeand. 2004. "Carbon Sequestration in Loblolly Pine Plantations: Methods, Limitations, and Research Needs for Estimating Storage Pools." In *Southern Forest Science: Past, Present, and Future*. General Technical Report SRS–75, U.S. Forest Service Southern Research Station, Asheville, NC.

Jokela, E. 2004. "Nutrient Management of Southern Pines." In *Slash Pine: Still Growing and Growing! Proceedings of the Slash Pine Symposium*. General Technical Report SRS–76, U.S. Forest Service Southern Research Station, Asheville, NC.

McCarl, B.A. 2007. "Biofuels and Legislation Linking Biofuel Supply and Demand Using the FASOMGHG Model." Paper presented at Duke University, Nicolas Institute Conference: Economic Modeling of Federal Climate Proposals: Advancing Model Transparency and Technology Policy Development, Washington, D.C.

Nalley, L., and M. Popp. 2010. "Modeling the Effects of Cap and Trade and a Carbon Offset Policy on Crop Allocations and Farm Income." Selected paper presented at Agricultural and Applied Economics Association 2010 AAEA,CAES, and WAEA Joint Annual Meeting, July 25–27, Denver, CO. Available at http://ageconsearch.umn.edu/bitstream/60931/2/Nalley_Popp.pdf.

Nalley, L., M. Popp, and C. Fortin. 2011. "The Impact of Reducing Green House Gas Emissions in Crop Agriculture: A Spatial and Production Level Analysis." *Agricultural and Resource Economics Review* 40(1): 63–80.

National Agricultural Statistics Service, U.S. Department of Agriculture. 2010. "Arkansas County Data—Crops." NASS, U.S. Department of Agriculture, Washington, D.C. Available at http://www.nass.usda.gov/QuickStats/Create_County_Indv.jsp (accessed 2010).

Outlaw, J.L., J.W. Richardson, H.L. Bryant, J.M. Raulston, G.M. Knapeck, B.K. Herbst, L.A. Ribera, and D.P. Anderson. 2009. "Economic Implications of the EPA Analysis of the Cap and Trade Provisions of H.R. 2454 for U.S. Representative Farms." Agricultural and Food Policy Center Research Paper 09-2, Texas A&M University, College Station, TX.

Parton, W.J., D.S. Schimel, C.V. Cole, and D.S. Ojima. 1987. "Analysis of Factors Controlling Soil Organic Matter Levels in Great Plains Grasslands." *Soil Science of America Journal* 51(5): 1173–1179.

Pienaar, L.V., B.D. Shiver, and W.M. Harrison. 1997. "Growth Potential of Loblolly Pine Plantations in the Georgia Piedmont: A Spacing Study Example." PMRC Technical Report 1997-1, Plantation Management Research Cooperative, Daniel B. Warnell School of Forest Resources, University of Georgia, Athens, GA.

Popp, M., and L. Nalley. 2011. "Modeling Interactions of a Carbon Offset Policy and Biomass Markets on Crop Allocations." *Journal of Agricultural and Applied Economics* 43(3): 399–411.

Popp, M., L. Nalley, C. Fortin, A. Smith, and K. Brye. 2011. "Estimating Net Carbon Emissions and Agricultural Response to Carbon Offset Policies." *Agronomy Journal* 103(4): 1132– 1143.

Popp, M., L. Nalley, and G. Vickery. 2008. "Expected Changes in Farm Landscape with the Introduction of a Biomass Market." Farm Foundation proceedings paper presented at the Transition to Bioeconomy: Environmental and Rural Development Impacts Conference, October 15–16, St. Louis, MO.

Popp, M., L. Nalley, and G. Vickery. 2010. "Irrigation Restriction and Biomass Market Interactions: The Case of the Alluvial Aquifer." *Journal of Agricultural and Applied Economics* 42(1): 69–86.

Prince, S.D., J. Haskett, M. Steininger, H. Strand, and R. Wright. 2001. "Net Primary Production of U.S. Midwest Croplands from Agricultural Harvest Yield Data." *Ecological Applications* 11(4): 1194–1205.

Reilly, J., and S. Paltsev. 2009. "The Outlook for Energy Alternatives." Invited paper of the Transition to Bioeconomy: Global Trade and Policy Issues Conference, March 30–31, Washington, D.C. Available at http://www.farmfoundation.org/news/articlefiles/1698-John%20Reilly%20Paper%20 3-27-09.pdf (accessed October 22, 2009).

Smith, S.A. 2010. "Carbon Sequestration Potential of Loblolly Pines in Arkansas: A Production Level Analysis." Master's thesis, Department of Agricultural Economics and Agribusiness, University of Arkansas, Fayetteville, AR.

U.S. Department of Agriculture. 1994. *1992 Census of Agriculture*. USDA, Washington, D.C.

U.S. Department of Agriculture. 1999. *1997 Census of Agriculture*. USDA, Washington, D.C.

U.S. Department of Agriculture. 2004. *2002 Census of Agriculture*. USDA, Washington, D.C.

U.S. Department of Agriculture. 2009. *2007 Census of Agriculture*. USDA, Washington, D.C.

U.S. Forest Service. 1990. "Loblolly Pine." *Silvics of North America, Volume I*. USFS, U.S. Department of Agriculture, Washington, D.C. Available at http://na.fs.fed.us/pubs/silvics_manual/Volume_1/pinus/taeda.htm (accessed January 3, 2012).

University of Arkansas Cooperative Extension Service. 2008. "2007 Crop Production Budgets for Farm Planning." UACES, Fayetteville, AR. Available at http://www.uaex.edu/depts/ag_economics/previous_budgets.htm (accessed February 23, 2010).

University of Arkansas Division of Agriculture. 2010. "Timber Price Reporting for Arkansas." UADA, Fayetteville, AR. Available at http://www.arnatural.org/News/Timber_Report/default.htm (accessed 2010).

Wailes, E.J., and E. Chavez. 2010. "Updated Arkansas Global Rice Model." Department of Agricultural Economics and Agribusiness Staff Paper 01, Division of Agriculture, University of Arkansas, Fayetteville, AR.