Modeling Pine as a Carbon Sequestering Crop in Arkansas

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Introduction

Many climate change policy options are currently under consideration to either reduce emissions of greenhouse gases (GHG) or increase carbon sequestration. Currently it is unknown which policy framework might be implemented but the use of existing carbon markets, like the Chicago Climate Exchange, may increase with some form of policy interaction that would likely increase the market price of carbon. Research that translates market based climate change incentives into potential producer reactions at the county level is thus needed to inform decision makers of policy outcomes. Research on the ability of agriculture to sequester atmospheric carbon and reduce emissions exists (Reilly, 2009; Outlaw et al., 2009; Beckman et al., 2009; McCarl, 2007; Parton et al., 1987) but spatial, county level, crop specific estimates of carbon footprint is sparse. Specific to this study, for example, Nalley et al., (2011) estimated carbon equivalent emissions of the six largest crops in Arkansas (rice, corn, soybeans, cotton, wheat and sorghum) along with pasture, and hay. Subsequent analyses also took carbon sequestration for these crops into consideration (Nalley and Popp, 2010; Popp et al., 2011). Those analyses took soil texture, yield and crop physiological parameters into account at the county level but again only for traditional land use choices. Additional cropping alternatives, specifically intended to reduce carbon footprint, are thus needed to examine their potential impact on land reallocation, net returns, GHG emissions and sequestration. One of the most promising crop alternatives for Arkansas in this regard is loblolly pine due to its low GHG emissions during production and its potential to sequester carbon in both the soil and lumber (Smith, 2010).

This study focuses on the impacts of a potential carbon offset policy on state net returns, acreage reallocation and carbon footprint of loblolly pine, as a dedicated carbon sequestering crop, in addition to traditional crops in Arkansas. The analysis also provides a spatial estimate of where pine acreage is likely to occur in the state under different carbon offset price levels 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). Pine is unique from other novel crop alternatives (switchgrass, forage sorghum and black willow) due to its ability to i) sequester large amounts of atmospheric carbon in timber products as well as in the soil; and ii) provide returns to producers from a timber market that is currently established. As such, pine has the unique potential to serve a carbon market by way of sequestering carbon in the soil and timber, a timber market, and also a future renewable energy market.

Cost of production and yield estimates for loblolly pine were determined using a pine growth model developed from the works of Pienaar et al (1997), Jokela (2002), Brinker et al (2002) and Adegbidi et al. (2002). Since spatial differences in environmental parameters (soil depth, slope, previous crop, drainage, etc.) vary too extensively across Arkansas, the only parameters that were varied included fertilizer response as well as stand density (700 seedlings per acre at planting with 30% thinning in the 15th year of the stand). Further production details as they pertain to this analysis may also be found in Smith (2010). In addition to production details, modeling pine as an alternative to traditional agricultural crops presents added complexities in that annual returns to conventional crop production are substituted with sporadic cost and revenue streams over an extended period of time. Pine takes approximately 30 years from the time of planting until harvest. This provides significant added risk to producers as they cannot switch to other crops for enhanced returns from alternative land use choices over the stand life. This added risk is the likely reason that pine has not been adopted on a larger scale as an alternative crop in Arkansas. To capture this risk, pine revenue and production costs have been adjusted with a long term risk premium of 5.5% (Hardie 1984). This risk premium reduces the present value of future revenue and cost leading to lower returns as positive cash flows do not occur until year 15 (thinning) and year 30 (harvest).

Carbon Sequestration

Carbon is stored in above and below ground biomass of agricultural crops and can be estimated by converting reported yields to biomass production using harvest index and shoot to root ratios (Prince et al., 2001; Nalley and Popp, 2010; Popp et al., 2011). A portion of the carbon trapped in biomass remains sequestered in the soil. Above ground biomass can be sequestered in the soil through carbon leaching or incorporation into the soil pending tillage practices. Below ground biomass decomposes via microbial activity, again with some carbon sequestered as a function of soil texture and tillage. Clayey soils have the ability to sequester more carbon than loamy or sandy soils, with tillage directly affecting microbial decomposition and thereby GHG emissions from the soil (Popp et al., 2011; Nalley and Popp, 2010). Sequestration (S_{ijts}) is thus calculated by county (i), crop (j), tillage method (t) and county specific soil type (s). Pine sequestration is distinct from traditional crops as pine sequesters carbon in timber products in addition to the soil. In the case of pine, soil sequestration occurs from carbon stored in the fine, coarse and tap roots, as well as above ground debris (pine needles, branches, etc.) that comes in contact with soil by equipment traffic. Carbon stored in wood products accounts for above ground sequestration. Timber used in pulp wood or wood chips/trash is not counted as sequestering carbon due to the limited amount of time carbon is stored (less than five years typically). Thinning yields are treated as pulp wood. Poles and lumber produced during final harvest on the other hand are expected to trap carbon for an extended period and the carbon contained in these products is counted as part of pine's carbon sequestration potential.

Carbon Emissions

Similar to Nalley et al. (2011), this analysis implements a scan level life cycle assessment (LCA) approach that tracks GHG emissions in their carbon equivalent (CE) form using estimates of 62 of the most common production practices associated with the six largest crops in Arkansas (corn, wheat, cotton, rice, soybeans and sorghum), along with hay, pasture and pine. Included in emissions are the CE emissions for fuel, fertilizer, and chemical used for each crop and production method. Both direct emissions, carbon dioxide (CO_2) from diesel fuel used by farm machinery, for example, and indirect CE emissions from the upstream production of inputs such as fertilizer and chemicals are included in the analysis. Also CE emissions from nitrous oxide (N_2O) produced from nitrogen fertilizer application are included as are methane emissions from rice production at 1,367 lbs of CE per acre (Nalley et al., 2011). For the pasture enterprise, no emissions are recorded from livestock grazing. Noteworthy is that this is a significant source of CE emissions as a result of methane produced from enteric fermentation as well as emissions from urination and defecation. These emissions are not included in this analysis however, as these emissions are functions of livestock profitability, an aspect not modeled within. GHG emissions related to pine production are averaged across the life of the stand and are the smallest relative to all other land use choices. Note that CE emissions as a result of transportation, drying, and processing are not included in this analysis to make comparisons across land use choices clear cut and only up to the farm gate. Where possible, emissions (E_{ijn}) are specific to county (i), crop (j) and production method (n) as dictated by county specific technology adoption. Spatial variation in emissions calculations for hay, pasture and pine production methods was not possible given lack of available data.

Arkansas Crop Model

An existing crop model for Arkansas row crops developed by Popp et al. (2008) is used to track changes in net GHG emissions, sequestration, net returns, and acreage in production. The model assumes producers to be profit maximizers and tracks yield, fertilizer, seed, irrigation, chemical, herbicide, labor and fuel use across production methods and counties to provide a spatial estimate of expected crop patterns. Constraints are included to reflect historical harvested and irrigated acreage minima and maxima by county[1]. The constraints are placed on the model to reflect typical crop rotation, secondary processing and other factors that would limit land use changes. Profit maximization for the model is expressed in two components i) the net returns from production (revenues less production related expenses) for all cropping alternatives and ii) returns from a carbon offset market as follows:

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

where p_j, y_{ij}, c_{ij}, and x_{ijn} are:

p_j is the price of crop *j*. Price for the six largest crops is the five year average commodity price for 2005-2009 from the Great Pacific Trading Company (GPTC). Hay is the 2005-2009 average price for other hay as reported by the USDA/NASS. Pasture cash rental rates are based on 2005-2009 average from the USDA for Arkansas and surrounding states. Pine price is the 2005-2009 average quarterly stumpage prices for North and South

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[1] The 14 land use choices are: pine on pasture, pine on crop, dry grain sorghum, irrigated grain sorghum, dry cotton, irrigated cotton, dry soybeans, irrigated soybeans, double crop soybeans, rice, wheat, corn, hay, and pasture.

Arkansas (UADA - Arkansas Timber Report). For pasture, p_j reflects the pasture cash rental rate.

y_{ij} is the yield of county *i* and crop *j*. Yield for the six largest crops is based on the 2005-2009 average county yields as reported by NASS. Pine yield is a function of annual growth, based on fertilizer application, planting density, and time of thinning and harvest (Peinaar et al,. 1997, Jokela 2002, Adegbidi et al,. 2002, Smith 2010). Hay yields are based on 1992, 1997, 2002 and 2007 census information. Pasture yields are calculated to support a cow/calf pair on 2.5 acres using yield expectations on the basis of Hunneycutt et al. (1998) and do not vary by county. Pasture yields are not used to calculate producer production returns but rather to determine their carbon sequestration potential.

c_{ij} is the county *i* and crop *j* specific total specified costs. Costs of production for the six largest crops are based on county and crop specific average total specified costs from University of Arkansas Cooperative Extension Service (UACES). Pine cost of production as estimated in Smith (2010) are based on literature review and expert opinions (Table 1). Hay and pasture budgets are determined by cost of establishment and maintenance based on input costs (fuel, labor, fertilizer, herbicide and seed) as reported in Table 1. These are generic production costs based on two cuttings for hay and standard cow/calf production methods for pasture. For the latter, cost of production is again only used to determine CE emissions.

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

and

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

where BCF_{ij}, E_{ijn}, S_{ijts}, and p_c are:

BCF_{ij} are the baseline estimates of carbon foot print for county *i* and crop *j* calculated by solving Eq. 1 and noting the estimated carbon footprint for each crop and county without a carbon offset market. Note that, at a carbon price of $0.10/ton, no change in crop pattern occurs from the baseline with the addition of Eq. 2 to the model and hence BCF_{ij} remain unchanged.

E_{ijn} are the per acre carbon equivalent emissions for county *i* and crop *j* by production method *n*.

S_{ijts} is the per acre carbon sequestration for county *i* and crop *j* adjusted for tillage *t* and soil type *s*.

p_c is the price for carbon offset ($/ton).

Solving the following equations allows analysis of crop agriculture's response to a carbon offset market by changing p_c:

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

and is subject to:

$$\begin{array}{lllll} xmin_{ij} & \leq & x_{ij} & \leq & xmax_{ij} \\ \sum x_{ijn} \cdot irr_{ijn} & \leq & irrmax_{j} & & \\ acresmin_{i} & \leq & x_{ij} & \leq & acresmax_{i} \end{array}$$

where:

$xmin_{ij}$ / $xmax_{ij}$	county level historical minimum and maximum crop acres based on the last four census years for hay and pasture and 2000 to 2007 NASS reports for other crops. These are separate for irrigated on non-irrigated production for soybean, grain sorghum and cotton.
$acresmin_i$ / $acresmax_i$	historical county minimum and maximum acres harvested and in pasture. Pine, with no historical tracking of acreage converted from crop/hay or pasture land was limited to an adoption of ten percent of available pasture acres and 1/30th of crop acres. These percentages were chosen so that pine would not encroach on historical pasture acreage required for cow/calf production as in Popp et al. (2010), and as a function of the long term investment horizon of pine production (thirty years).
$irrmax_j$	are the county irrigation amounts applied in the baseline run and constrains potential policy alternatives from using more irrigation water on the basis of crop and production technology specific irrigation amounts per acre of crop production (irr_{ijn}).

Table 2 shows the estimated price (p_j) and per acre state averages of yield (y_{ij}), total specified expenses (c_{ij}), emissions (E_{ij}), sequestration (S_{ijts}), carbon footprint $(E_{ij} - S_{ijts})$, and net returns (nr_{ij}) for each crop. Table 1 provides similar estimates of annualized cost and returns for hay, pasture and pine as specified for the model.

Carbon Market

To model the impact of different carbon prices on land use, a necessary first step is to establish the profit maximizing crop pattern at existing price levels. Thus, the baseline represents the crop mix maximizing state returns under 2005-2009 average commodity and input price conditions using 2007 production technologies and includes pine as a cropping alternative. This baseline also reports on the baseline carbon foot print for the state $(\sum\sum BCF_{ij})$, county $(\sum BCF_j)$ or crop $(\sum BCF_i)$ where carbon footprint is defined as emissions (E_{ijn}) less sequestration (S_{ijts}). A negative carbon footprint thus represents net sequestration whereas a positive number implies the crop or county to be a net emitter of carbon.

Deviations from the baseline as a result of modifying the price of carbon in equation 2 would thus allow determining producer income and crop pattern changes. A range of prices from $0.10 per ton, the most prevalent 2010 trade price for carbon on the Chicago Climate Exchange (CCX), to $5, $15 and $30 per ton as a result of policy interaction exogenous to the model was used. The range of carbon prices are similar to previous analyses (Nalley and Popp, 2010; Popp et al., 2011) and provides estimates of carbon footprint responses to a market based incentive.

Carbon offset cashflows for producers are thus based on deviations from the baseline. Carbon offset revenues for producers are available if, compared to the baseline, carbon footprint declines. The opposite is true if climate change is impacted adversely (i.e. carbon footprint increases). For example, if a producer replaces rice acres, on average the highest emitter (Figure 1), with pine acres, he or she would earn carbon offset revenue in the amount of the change in carbon footprint (1,601 lbs emitted by rice and replaced by net sequestration of 2,802 lbs for pine for a carbon offset payment of 4,403 lbs or 2.20 tons at varying carbon price levels). Production returns per acre change as well, since $181/acre returns from rice production (Table 2) are lost and replaced by minimal production returns from pine at $2/acre (Table 1). In this particular case, a producer would thus not choose to reduce rice acres in favor of pine production until the carbon price is approximately $81/ton at which the loss in production returns is offset by gains 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.

Since carbon offset revenues and production returns are tracked separately as shown in Equations 1 and 2, the impact of policy induced changes to carbon prices can be tracked to offer insights about changes in production returns and carbon market trading as a result of land use changes. It shows to what extent overall agricultural returns shift from returns to production to returns from carbon trading. Also, since the analysis is performed at the county level, spatial changes in pine acres could be tracked.

Results

Baseline model results

The baseline model shows crop mix, net returns, and carbon footprint for Arkansas crop agriculture as defined above. Net state returns are calculated to be $574 million with a carbon foot print of 287 thousand 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 by highlighting acreage allocated to each crop. Baseline results are within +/- 15% of actual acreage allocations as recorded by

NASS in 2007. Comparisons of the baseline with model runs at p_c of \$5, \$15 and \$30 per ton are discussed next.

Relative per Acre Crop Profitability and Carbon footprint

State carbon footprint improves as carbon offset prices increase (Table 4). Carbon sequestration increases from 3.28 to 3.88 million tons whereas emissions are curtailed from 2.99 to 2.95 million tons as p_c increases to \$30 per ton. As such, improvement in carbon footprint is driven by changes in sequestration rather than emission reductions as the price of carbon increases. Further, this is true for all carbon offset price levels. It is primarily a function of acreage being reallocated from net emitting crops (rice, dry cotton and wheat) or from crops with relatively low levels of sequestration (sorghum, soybeans and pasture) to relatively large sequestering crops of pine and corn.

Relative carbon footprint per acre of crop alone, as shown in Figure 1, however, is not the entire story. Relative profitability of the crop is also important as demonstrated by the relatively small reduction of rice acreage (Table 3), the leading emitter, but also the most profitable crop in the state (Table 2). Individual crop's state average net returns per acre to production and carbon markets are shown in Figure 2. They change with the level of p_c, the total acreage of the crop grown, and across counties due to spatial differences in exogenous production method and yield. These relative changes in profitability for individual crops drive acreage reallocation, state carbon footprint and overall agricultural returns to crop production and carbon trading. For example, per acre state average wheat returns increase from \$56/acre under the base scenario to \$58/acre under the \$30/ton carbon offset price. Since total wheat acres declined, this is a result of both carbon offset payments for reducing emissions (wheat is a net emitter) and dropping the least profitable (across the state) wheat acres for crops of higher relative returns. So, while wheat suffers acreage reduction from a carbon offset market as a result of being a net emitter, the per acre returns of remaining acres increased, on average, and it is the relative comparison of per acre returns across crops that drives acreage allocation. Figure 2 shows that as carbon offset prices increase pine's relative state average profitability increases to the point where only rice, corn, and wheat are relatively more profitable. Note that with yield and cost of production differences across counties, Figure 2 does not hold for each individual county. In addition, the acreage reallocation to pine, is also subject to available crop, hay and pasture acreage, which in turn is a function of traditional crop acreage minima as well as the imposed constraint on pine adoption on pasture and on crop land.

Overall, increases in p_c lead to decreased wheat, dry soybean, dry cotton, sorghum, hay, pasture and rice acreage. By the same token, crops with higher sequestration (corn and pine) add acres. Again these changes are driven by the changes in relative profitability discussed earlier. Pine realizes its maximum allowable 10% of pasture acres with a carbon offset price of \$15/ton. Pine acres on crop continue to increase under all three carbon offset price increase scenarios and does not reach its allowable maximum of 3.33% of crop and hay land. The increase in carbon price also adds an additional 10,000 harvested acres 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 carbon offset payments adds an additional revenue source and therefore increases state net returns. Base net returns and percentage increases from the baseline for the different p_c scenarios are shown in Table 5. These changes are from carbon offset revenues and changes in production returns as defined above and are highlighted for the state by crop in Table 6. For example, at p_c of \$15/ton, total carbon revenue for the state is \$7.84 million while overall *NR* for the state increases by \$1.45 million. Hence, production returns declined by \$6.39 million. Since the crop pattern changes to involve more long term crops with pine (a 30 year production horizon), this breakdown of returns between carbon markets and returns from traditional markets for the state 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 trading on an aggregate state level. While the rice sector gains from carbon payments, these payments are insufficient to offset losses in production returns from traditional agriculture. Soybean produced under non-irrigated conditions pays twice -- reducing sequestration due to lost acres and lower returns from traditional sources. Finally pine and corn win in both carbon markets and production returns. To be clear, this does not imply that individual non-irrigated soybean producers lose with a carbon market. They can reallocate their land resources to pine or another more profitable crop that offer added returns because of carbon offset revenue.

Spatial Changes in Pine Acres

Spatially, Figure 3 shows the 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 which is consistent with existing mill locations. As carbon prices increase to \$15/ton acreage increases in the northwest part of the state (replacing pasture acreage). At carbon offset price of \$30/ton, the relative profitability of pine increases such that significant inroads into the Delta counties' traditional row crop agriculture are made.

Conclusions

This study has examined the implications of increasing carbon prices with pine added to a traditional crop model as a designated carbon sequestering crop in Arkansas. The implications of increasing carbon prices from the base ($0.10/ton) to $5, $15, and $30 per ton of carbon were examined to determine the effects on state carbon footprint, acreage reallocation and changes in source of returns to agricultural crop production activities. The analysis has shown that increasing carbon prices lead to improvement in state carbon footprint and net returns. Acreage is reallocated among crops based on their relative profitability; crops with relatively lower returns (primarily pasture, non-irrigated soybean and sorghum) are replaced by crops that provide higher relative returns (pine and corn). This relative profitability is affected by the carbon offset price. However, crops with high production returns (rice) experience only minor changes in acreage and profitability as carbon prices need to be quite high before carbon revenues from acreage reduction would 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 effects of carbon payments on overall profitability changes are different across crops and crop production methods expected increases in carbon price have an overall positive effect. Especially in the case of pine, these added returns result in heightened reliance on carbon markets as the primary source of income.

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

	Hay		Pasture		Pine	
	Total Cost ($)	PV ($)[1]	Total Cost ($)	PV ($)	Total Cost ($)	PV ($)
Establishment						
Field Preparation[2]	90.40	11.30	12.40	1.55	-	-
Pre-plant Weed Control[3]	9.39	1.17	9.39	1.17	35.67	1.19
Planting[4]	68.51	8.56	68.51	8.56	33.67	1.12
Post Plant Weed Control[5]	12.29	1.54	12.29	1.54	35.67	1.19
Operating Interest[6]	12.22	1.53	3.68	0.46	11.60	0.39
Other[7]	-	-	-	-	63.82	2.13
Total Establishment Cost	192.81	24.10	106.26	13.28	180.43	6.02
Annual Maintenance						
Rotary Mower[8]	-	-	9.05	9.05	-	-
Fertilizer[9]	51.25	37.53	51.25	51.25	283.92	3.49
Harvest[10]	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 yrs		8 yrs		30 yrs	
Annual Yield	2.23 tons		1.17 dry tons		8.77 tons	
Total Specified Expenses – PV over stand life	$94.13		80.55		$9.50	
PV of Annual Profit Prorated over Stand Life	$38.04		-		$1.99	
Cash Rental Rate	-		$18.50		-	

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

[2] Field preparation occurs in September and includes one pass with a disk to incorporate 1 ton of lime, 167 lbs of phosphate (0-45-0) and 83 lbs of potash (0-0-60) fertilizers on hay. No fertilizers are applied on pasture at time of field preparation.

[3] This includes one herbicide application of 1 lb a.i. glyphosate (Roundup) in March by air for hay and pasture and 10 pints per acre on pine.

[4] Included are one pass with a cultipacker and 8 lbs of pure live seed applied using a no-till drill for accurate depth control. Operations occur in April for hay and pasture. Pine planting occurs in April using a four man planting crew at a planting density of 700 seedlings per acre at a cost of $0.035 per seedling.

[5] Aerial herbicide applications are gramoxone on hay in the establishment year. Pasture weeds are control with rotary mower and Grazon P+D. Pine herbicide application is again 10 pints per acre of glyphosate.

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

[7] Other costs for pine production are an intial application of fertilizer different from the other two applications 109 lbs of N (46-0-0), 111 lbs of P (0-45-0) and 133 lbs of K (0-0-60).

[8] Rotary mowing of pasture to knock down undesirable grass species and brush is common in Arkansas. Two such operations are modeled.

[9] Pasture fertilizer application as follows:Lime, ammonium nitrate (34-0-0), phosphate (0-45-0) and potash (0-0-60) are applied at rates of .1 t, 125 lb, 100 lb and 75 lb per acre, respectively using a spin spreader. Fertilizer is calculated to reflect standard extension recommendations on lime, phosphate and potash and sufficient nitrogen to support 1 cow/calf pair on 2.5 acres with additional livestock (replacement heifers and herd sires). Hay: The fertilizer program to replace nutrients is 89 lbs of phosphate (0-45-0), 133 lbs of potash (0-0-60) and 220 lbs of ammonium nitrate (34-0-0) for year 2 and onward. Pine: Two additional applications of fertilizer at stand age 6 and 18 of 435 lbs of N (46-0-0), 196 lbs of P (0-45-0) and 192 lbs of K (0-0-60).

[10] Hay harvest is performed using a mower conditioner, hay rake (25% of acreage), large round baler (#1,275 dry matter or #1,500 as is 15% moisture) using bale wrap and an automatic bale mover for staging without tarp or storage pad preparation. For pine no harvest costs are calculated as pine is assumed to be sold at the current stumpage price, as such the costs are incurred by the mill or subcontracted out. The carbon footprint of the harvesting process is recorded to remain consistent across various enterprises. We assume harvest and thinning fuel consumption of 12.64 gal/acre for the feller buncher, cable skidder and loader at a performance rate of approximately 1 acre per hour.

Table 2. Baseline Weighted Average Price, Yield, Total Specified Expenses, Net Returns, Emissions, Sequestration, and Net Carbon by Crop, Arkansas.

Crop	Price[1] (P_j) ($/unit)	Yield (Y_{ij}) (unit/acre)	Total Specified Expenses[3] (C_{ij}) ($/acre)	Net Returns (nr_{ij}) ($/acre)	Emissions ($E_{ij\mathrm{n}}$) (lbs/acre)	Sequestration (S_{ijts}) (lbs/acre)	Net Carbon ($E_{ijn} - S_{ijts}$) (lbs/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)
IRR Soybeans	7.34	40.58	268.80	29.16	225.45	237.23	(11.78)
IRR Sorghum	3.05	103.52	287.48	34.33	516.90	771.60	(254.70)
Dry Sorghum	3.05	70.97	190.25	24.15	387.08	517.63	(130.55)
Dry 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)
Dry Cotton	0.57	896.07	497.06	14.82	462.29	305.14	157.15
IRR 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

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[1] Price is the 5 year GWT average price for rice, corn, cotton, sorghum and soybeans (2005-2009). Pine prices are based on the 5 year quarterly average stumpage price for North and South Arkansas (2005-2009). Pasture price is a 5 year average cash rental rate from the USDA for the delta states. Hay is the 5 year average price reported by the USDA.

[2] Yield for the six largest crops is based on the 2005-2009 average county yields as reported by NASS. Pine yield is a function of annual growth, based on fertilizer application, planting density, and time of thinning and harvest. Hay yield are based on 1992, 1997, 2002 and 2007 census information. Pasture yields are not used to calculate producer returns but rather to determine their carbon sequestration potential.

[3] Total specified expenses for each crop and production method were calculated based on 5 year average input prices including fuel, fertilizer, chemical, and labor (2005-2009).

Table 3. Baseline Acreage (Thousands) and Percentage Change in Acres By Crop from the Baseline for Three Carbon Offset Prices, for Arkansas.

Carbon Price	Total Acres in Production[1]	Corn	Cotton		Soybeans			Rice	Wheat	Sorghum		Hay	Pasture	Pine	
			Dry	IRR	Dry	IRR	DCB			Dry	IRR			Pasture	Crop/Hay
$0.10/Ton	8,005	418	181	544	903	1,659	145	1,521	1,019	64	43	1,434	3,857	0	73
------Percentage Change From Baseline with Carbon Price of $0.10/Ton------															
$5/Ton	0.05	8.20	-	-	(1.31)	-	-	(0.77)	(1.41)	(2.72)	(6.08)	-	-	-	16.66
$15/Ton	0.05	8.67	(5.93)	-	(2.17)	-	-	(0.82)	(2.32)	(15.15)	(5.61)	(0.10)	(10.00)	NA[2]	65.63
$30/Ton	0.15	16.90	(5.93)	-	(4.38)	-	-	(1.55)	(7.66)	(22.59)	(22.32)	(0.58)	(10.00)	NA	172.04

[1] Total of all acres in production for the 14 crops listed above includes pine and pasture.

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

Table 4. State Emissions, Sequestration, and Carbon footprint (in Thousands of Tons) for Three Carbon Offset Prices with Percentage Changes from the Baseline at p_c of \$0.10/ton, Arkansas.

Carbon Price	Emissions[1] ($\sum\sum E_{ijn}$)	Sequestration[1] ($\sum\sum S_{ijts}$)	Carbon Footprint[1]	Emissions % Change from Baseline	Sequestration % Change from Baseline	Net Carbon % Change from Baseline
$0.10/Ton	2,989	(3,276)	(287)	-	-	-
$5/Ton	2,985	(3,308)	(322)	(0.13)	0.96	12.28
$15/Ton	2,960	(3,772)	(811)	(0.96)	15.13	182.66
$30/Ton	2,947	(3,883)	(936)	(1.41)	18.53	226.08

[1] Total state emissions, sequestration and carbon footprint (emissions – sequestration) are calculated from 14 crops, aggregated across 75 counties and production method to obtain state totals.

Table 5. Baseline Net State Returns (Millions $) with Percentage Changes from the Baseline for Three Carbon Offset Prices, Arkansas

Carbon Price	Total Net[1]		Cotton		Soybeans					Sorghum				Pine	
($/Ton)	Returns	Corn	Dry	IRR	Dry	IRR	DCB	Rice	Wheat	Dry	IRR	Hay	Pasture	Pasture	Crop/Hay
$0.10/Ton	574.67	36.80	2.76	4.44	21.99	48.36	(1.67)	275.95	57.48	1.55	1.47	54.06	71.35	-	0.15
	------Percent Change From Baseline with p_c of $0.10/ton------														
$5/Ton	0.02	9.04	-	-	(0.33)	-	-	(0.80)	(1.57)	(0.96)	(7.59)	-	-	-	76.15
$15/Ton	0.25	9.68	(4.94)	-	(0.92)	-	-	(0.81)	(1.79)	(10.31)	(7.13)	(0.05)	(12.10)	NA[2]	762.11
$30/Ton	1.81	16.87	(4.45)	-	(3.15)	-	-	(1.36)	(5.13)	(16.86)	(35.82)	(0.48)	(14.20)	NA	3,809.27

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

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

Table 6. State Total Carbon Payments and Change in Production Returns by Crop and Carbon Offset Price Resulting in Total Changes in Net Returns to Producers in Thousands of $, Arkansas.

	Carbon Trading Returns[1]			Change in Production Returns[2]			Total Change in Net Returns[3]		
Crop/Carbon Price	$5/Ton	$15/Ton	$30/Ton	$5/Ton	$15/Ton	$30/Ton	$5/Ton	$15/Ton	$30/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)
IRR Cotton	-	-	-	-	-	-	0	0	0
Dry Cotton	-	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
IRR Soybeans	-	-	-	-	-	-	0	0	0
Dry Soybeans	(2.9)	(14.3)	(58.1)	(70.2)	(188.5)	(634.6)	(73.1)	(202.8)	(692.7)
DCB Soybeans	-	-	-	-	-	-	0	0	0
IRR Sorghum	(1.7)	(4.8)	(36.5)	(109.8)	(99.9)	(489.7)	(111.5)	(104.8)	(526.2)
Dry Sorghum	(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 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 Pasture	-	8,054.4	16,108.8	-	1,252.1	1,252.1	0	9,306.5	17,360.9
Change in State Net Returns	170.1	7,839.5	19,424.2	(57.1)	(6,391.6)	(9,019.8)	113.0	1,447.9	10,404.5

[1] Payments made to producers for lowering carbon footprint from the baseline. A negative number in the case of dry soybeans indicates a loss of net sequestration as dry soybeans are net sequesters 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 are 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.

[2] Change in production returns are a result of acreage reallocation amongst 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.

[3] Total changes in net returns are net returns predicted by the model estimations under each carbon offset price relative to the baseline. The total net returns represent the sum of carbon trading returns and changes in production returns for each carbon offset price.

Figure 1. Estimated State Carbon Footprint, Sequestration, and Emissons (lbs/acre) by Crop, Arkansas

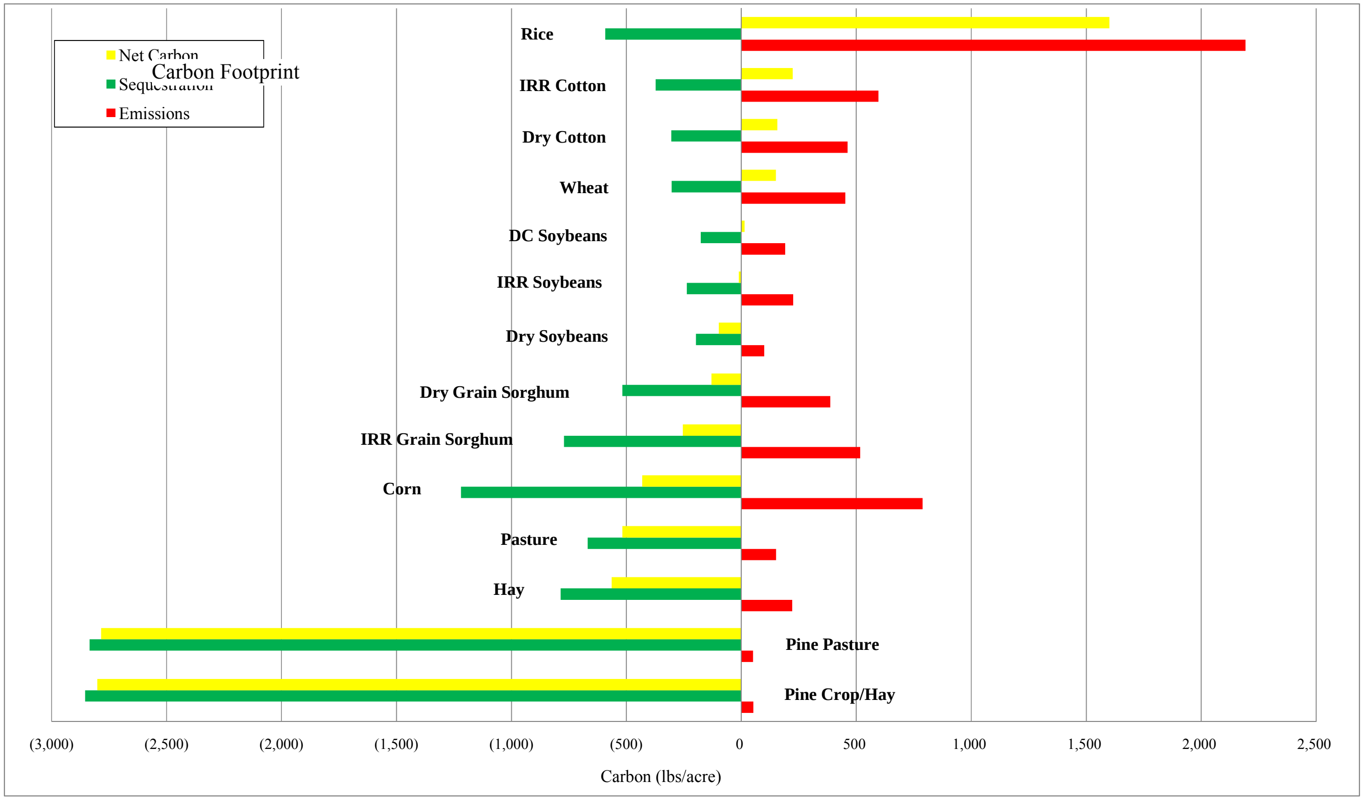

Figure 2. Weighted Average Net Returns to Traditional Crop Production and Carbon Offset Markets per Acre for Crops Under Four Carbon Offset Prices, Arkansas.

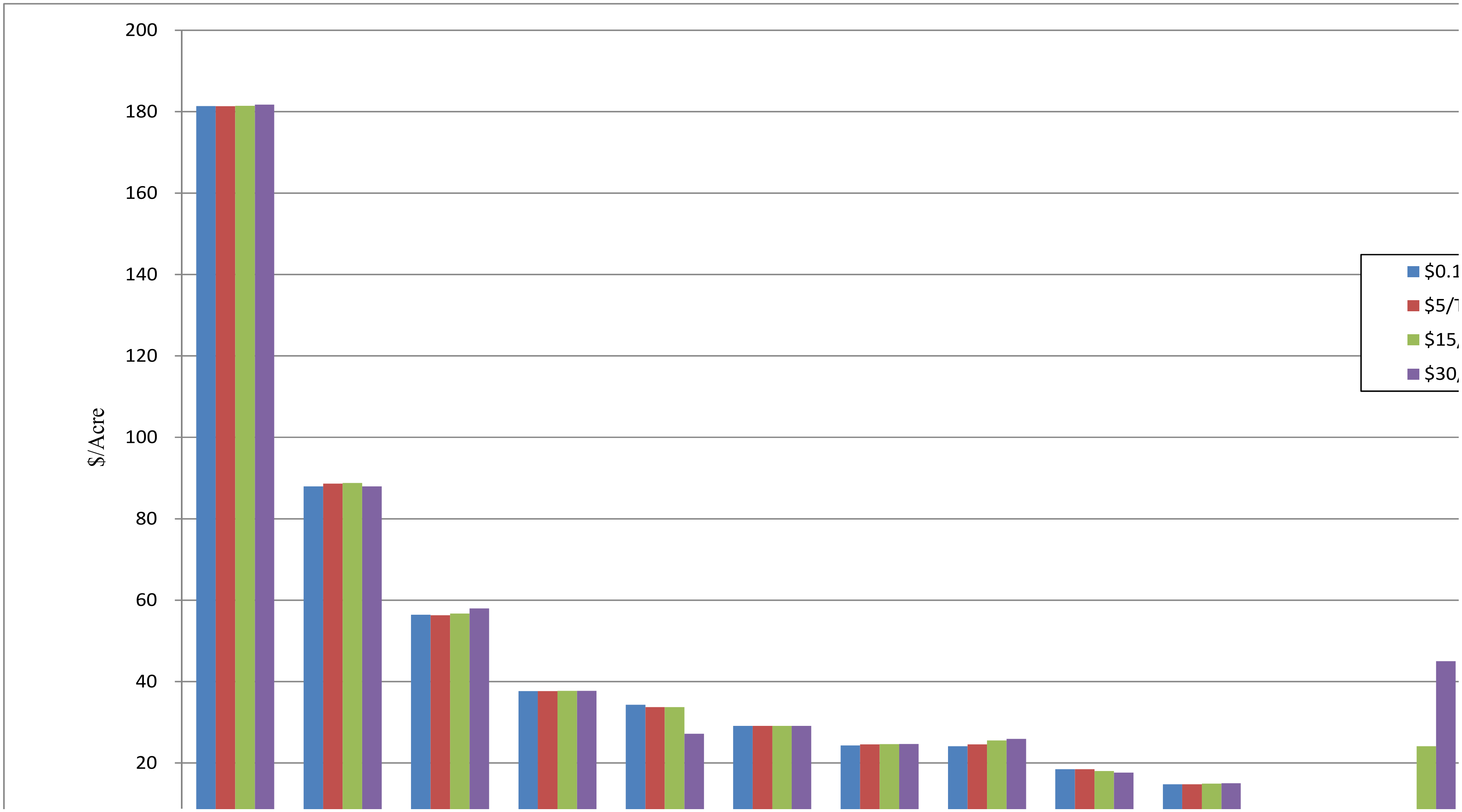

Figure 3. Pine Acres by County under Four Carbon Offset Prices ($/Ton), Arkansas, 2007